The integration of complementary knowledge through collaboration among public R&D organisations:

Lessons from the agri-biotechnology innovation system in Uruguay

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SUMMARY

Research and technological development processes increasingly entail inter-organisational collaboration for the access and integration of external complementary knowledge, especially within emergent technological innovation systems and small developing countries. Collaborative efforts aggregate capabilities of individual actors into system-level innovation capacity, fostering technological and innovation outcomes from both individual organisations and the technological system as a whole.

Significant understanding of these interactive processes has been achieved by previous research on innovation systems, inter-organisational collaboration and networks, and studies of interdisciplinary scientific research. Nevertheless, further knowledge is required on *how and why organisations may differ in their ability to collaboratively exploit potential complementarities*. Consequently, this thesis examines institutional and organisational factors that influence the actual extent of knowledge integration achieved by public research organisations through collaborative research endeavours, within the agri-biotechnology innovation system in Uruguay.

The research followed a mixed empirical method. Exploratory interviews with members of public R&D groups and firms were conducted in order to reach a preliminary understanding of the main forces affecting collaboration and knowledge integration. Quantitative indicators of the degree of knowledge-integration achieved by R&D groups' collaborative links were designed and computed using data gathered through a survey of R&D group members. Indicators were also developed to statistically assess how the extent of collaborative knowledge-integration achieved by an R&D group is influenced by system-level incentive institutions, by the absorptive and relational capacities of the group, and by the compliance of the group with local scientific assessment and reward mechanisms.

This thesis makes various theoretical contributions and draws relevant policy implications. The results show that members of R&D groups may exert differing levels of influence on knowledge-integration. Specifically, postgraduate students were found to play a relevant bridging role, enhancing the ability of the group to access knowledge from complementary disciplines. The study also found consistent evidence of a negative relation between an R&D group's compliance with local scientific incentives, and the group's ability to collaboratively integrate complementary knowledge-assets. Therefore, formal incentive institutions are presumably affecting the exploitation of potential synergies among local knowledge resources and hence the learning and innovation capabilities and the cohesion of the entire agri-biotechnology innovation system. As a methodological contribution, this thesis develops novel indicators to assess the degree of inter-organisational complementarity that go beyond those used in previous research.

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Abbreviations

ANII	National Agency for Research and Innovation
AUDEBIO	Uruguayan Association of Biotechnology Firms
CSIC	Sectoral Commission of Scientific Research of UdelaR
DNA	Deoxyribonucleic acid
DNPI	Uruguayan Office for Industrial Property Rights
DV	Dependent variable
FA	Agronomy School, UdelaR
FC	School of Natural Sciences, UdelaR
FI	Engineering School, UdelaR
FM	Medicine School, UdelaR
FPTA	Fund for the Promotion of Agricultural Technology
FQ	Chemistry School, UdelaR
FV	Veterinary School, UdelaR
GDP	Gross domestic product
GM	Genetically modified
ICE	Institute of Biological Research, Clemente Estable (IIBCE)
IIBCE	Institute of Biological Research, Clemente Estable (ICE)
INASE	National Seeds Institute
INIA	National Agricultural Research Institute
IPM	Pasteur Institute of Montevideo
IPR	Intellectual property rights
LATU	Technological Laboratory of Uruguay
LSE	London School of Economics
MAS	Marker-assisted selection
MERCOSUR	Mercado Común del Sur (Southern Common Market
MGAP	Ministry of Husbandry, Agriculture and Fisheries
OECD	Organisation for Economic Cooperation and Development
PDT	Technological Development Programme
PEDECIBA	Basic Sciences Development Programme
PENCTI	National strategic plan on science, technology and innovation -

PME	Predicted marginal effect
RNA	Ribonucleic acid
SNI	National Researchers Assessment System
STI	Science, Technology and Innovation
TB	Technological Boards
TIS	Technological Innovation System
TRIPS	Agreement on Trade Related Aspects of Intellectual Property Rights
UdelaR	University of the Republic, Uruguay
WTO	World Trade Organisation

Chapter 1 - Introduction

The rapid advances in science and technology have led to more complex forms in the organisation of research, technology development and innovation processes which increasingly go beyond the boundaries of individual organisations (Dosi, 1988; Gibbons et al., 1994; Powell et al; 1996; Coombs et al., 2003). Consequently, the development of inter-organisational arrangements for the access and integration of external complementary resources has become increasingly important for the innovative performance of individual organisations (Rothwell, 1977; Teece, 1986; Hagedoorn, 1993; Rosenkopf & Nerkar, 2001) and the overall development of innovation systems (Carlsson et al., 2002; Lundvall, 2005; Bergek et al., 2008). *Complementarity* of resources and capabilities may be defined as the existence of '*distinctive resources of alliance partners that collectively generate greater…*[innovative outputs]…*than the sum of those obtained from the individual endowments of each partner'* (Dyer & Singh, 1998, pp666-7). The collaborative integration of distributed sources of knowledge is of salient relevance during the emergent stages of a technological innovation system, when research and technological-development capabilities available are scarce and scattered throughout the system, and the potential applications and demand of the new technologies are still uncertain (Colombo et al., 2006; Bergek et al., 2008; Powell et al., 2012).

This need for enhancing the exploitation of potential complementarities is even greater in developing countries where limitations in R&D resources are emphasised, and the knowledge base is distributed among several organisations, mostly from the public research sector (Arocena & Sutz, 2002; Lundvall et al., 2002; Chaminade et al., 2009). Some authors have claimed that in less developed countries, the isolated character of research and innovation efforts hinder interactive processes for the exploitation of complementary skills and technological capabilities available locally (Arocena & Sutz, 2002). Hence, the potential impact of *local*[1] knowledge bases on

[1] Throughout the thesis we use the term *local* (*local* knowledge bases, R&D capabilities or knowledge assets) to refer to knowledge resources existing with the boundaries of a single country.In other words, we use *local* to refer to a national scope. When reporting our empirical results, we use this term so as to

innovation performance, economic growth and development is undermined (Bortagaray, 2007, p341; Lundvall et al., 2009b, p18).

Complementarity between organisations as a rationale for inter-organisational collaboration can be traced back to the work of Teece (1986), whose focus was on how firms that are able to develop novel technologies should rely on complementary specialised capabilities such as marketing or after-sale services, in order to generate market profits from such new technologies (Teece, 1986, p288; Colombo et al., 2006). Collaborative endeavours are assumed to have a positive impact on innovation performance only if they are the result of *potential opportunities for complementarity of resources and capabilities* between the partnering organisations (Teece, 1986; Prahalad & Hamel, 1990; Grant & Baden-Fuller, 2004; Colombo et al., 2006). In the public research domain, inter-organisational complementarity has been examined by a community of scholars studying interdisciplinary scientific research (Rafols, 2007; Rafols & Meyer, 2010; Wagner et al., 2011).

The *primary assumption* underpinning the motivations to pursue the present study is that research oriented to solving local production problems requires the integration of distant complementary knowledge (Van den Besselaar & Heimeriks, 2001) and hence *the larger the extent of collaborative knowledge integration accomplished, the larger the innovation outcomes expected from both individual organisations* (Hage & Hollingsworth, 2000; Rosenkopf & Nerkar, 2001; Nooteboom et al., 2007) *and the technological system as a whole* (Carlsson & Stankiewicz, 1991; Lall, 1992; Cimoli et al., 2009). For the purpose of this research, *collaborative knowledge integration* is defined as a research endeavour '...that integrates concepts or theories, tools or techniques, information or data from different bodies of knowledge' through any form of collaborative research activity between two or more research groups or organisations (Rafols & Meyer, 2010, p265). Based on the assumption presented above, the central concern of this study is pursuing a greater understanding of collaborative knowledge integration processes and assessing the factors that influence the actual extent of

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mean that the scope involves the specific country where the actual empirical study was conducted (Uruguay).

knowledge integration achieved by public R&D groups through their R&D collaborations. The boundaries of each R&D group were empirically defined in our study through our survey to R&D project leaders, namely they were asked to report the whole list of members of the R&D group.

The present research draws on three main fields of scholarly research, namely studies of: innovation systems; inter-organisational collaboration and networks; and studies of interdisciplinary scientific research. The literature on innovation systems claims to provide a relational research approach which emphasises that innovation is a collective and interactive process, highly reliant not only on the internal capabilities of a leading organisation but also on resources external to it (Bergek et al., 2008). It pays singular attention to the linkages, coordination and synergies among components and actors in the system (Johnson & Lundvall, 2000; Carlsson et al., 2002; Malerba, 2005).

While traditional approaches for the study of innovation have been focused mainly on market exchange and competition relations between actors (Porter, 1990), innovation-system perspectives stress the need to access multiple sources of knowledge and thus pay more attention to other formal and informal forms of interaction (Malerba, 2005; Johnson & Lundvall, 2000; Carlsson & Stankiewicz, 1991). Systemic frameworks imply a move in public-policy making from interventions aimed at sorting out market operation problems, towards innovation policies that also look after broader *system-level attributes and processes of interaction among actors* (Lundvall, 2005; Arocena & Sutz, 2002; Hall et al., 2003). This literature has been empirically applied at diverse levels of analysis. In particular, studies of *technological innovation systems* narrow down the complexity of components, actors and types of relations between actors to be analysed by focusing on innovation systems built around specific technologies or products (Carlsson & Stankiewicz, 1991; Carlsson et al., 2002; Hekkert et al., 2007; Suurs & Hekkert, 2009). Specific *emergent technologies* with potential application across many sectors (e.g. biotechnologies in this study) may well face differing enabling conditions for their adaptation and adoption depending on the sector where the technology is introduced (Senker & Van Zwanenberg, 2001; Malerba, 2005). Hence the dynamics of research and technology development in such emergent stages should be investigated at the intersection of technological and sectoral systems of innovation.

With regard to the study of inter-organisational collaboration, there is extensive knowledge accumulated on the determinants and rationales for the formation of partnerships (Gulati, 1998; Gulati & Gargiulo, 1999; Colombo et al., 2006; Luo et al., 2009). The main rationales include accessing complementary resources and capabilities, capability building (learning), costs' reduction, the development of economies of scale and scope, and strategic coordination (Teece, 1992; Gulati & Gargiulo, 1999; Hagedoorn, 2002; Gonçalves do Valle et al., 2002; Salles-Filho, et al., 2006). Other studies have examined how specific organisational attributes affect the ability of an organisation to form and manage collaborative relations with other actors and to obtain benefits from them (Dyer & Singh, 1998; Powell, 1998; Lorenzoni & Lipparini, 1999; Colombo et al., 2006). As a closely related field, studies of inter-organisational networks have made sound contributions in understanding what drives the embeddedness of organisations within networks, and how the *structural properties* of the network affect an organisation's outcomes (Gulati, 1998; Gulati et al., 2011), and the formation of further collaborative relations (Gulati & Gargiulo, 1999; Ahuja, 2000; Hagedoorn et al., 2006). More recently, increased emphasis is being placed in studying the dynamics of network evolution over time (Powell et al., 2005; Zaheer et al., 2010; Ahuja et al., 2012).

Innovation system studies place particular attention to the institutional framework as a relevant component shaping system structure and performance (Carlsson et al., 2002; Lundvall et al., 2002; Woolthuis et al., 2005; Bortagaray, 2007; Padilla-Pérez et al., 2009). In this regard, Woolthuis et al. distinguish two main types of institutions: '…there are 'hard' institutions, being the formal, written, consciously created institutions, and the 'soft' institutions which are informal, have often evolved spontaneously and may be the implicit 'rules of the game' (North, 1991). Both may regulate economic behaviour and interaction, and can thereby stimulate or hinder innovation… As a result, we can distinguish between hard- and soft institutional failures' (Woolthuis et al., 2005, p612). Informal (North, 1994) or *soft institutions* (Woolthuis et al., 2005, p610) originate from values, non-written rules, perceptions, trust in other actors, and routine practices that affect the way individuals and organisations share knowledge and learn, thus exerting an influence on the processes of knowledge integration through inter-organisational R&D collaborations (Laudel & Gläser, 1998; Malerba, 2005; Hall, 2006). The neo-classical argument for policy-making has focused mainly on solving market-failures while usually overlooking the influence on innovation of other soft and hard institutions (Woolthuis et al., 2005, p615).

The collaborative aggregation of actor-level technological capabilities into system-level innovation capability depends, to a large extent, on *institutions and particularly public policies* supporting the realisation of complementarities and interactive learning (Lall, 1992; Cimoli et al., 2009; Padilla-Pérez et al., 2009). In this regard, besides poor patterns of interaction among actors in the system, developing countries usually show weak formal *institutions* supporting those interactions (Padilla-Pérez et al., 2009, pp143-5). Recent studies of the changing institutional environment around public research have noticed the rise of contradictory incentives to scientists. While there is an increasing pressure from academic-research funding to perform application-oriented and socially-relevant research projects, at the same time, a significant rise in research performance assessments results in a pervasive demand on researchers to publish their results in peer-reviewed academic journals (Hessels et al., 2011; Hessels & van Lente, 2011). The authors argue that these two developments may exert conflicting forces over scientists, which affect the final orientation of their research activities (Hessels & van Lente, 2011), and hence their willingness to collaborate with other actors and to integrate complementary sources of knowledge (Laudel & Gläser, 1998; Laudel, 2001; Llerena & Meyer-Krahmer, 2003). Consequently, further scholarly work should examine how *institutions, incentives and policies* may be fostering or hindering collaborative knowledge integration among public research actors, hence likely influencing the impact of the public knowledge base on local innovation performance.

Notwithstanding the intended emphasis of the innovation-systems literature on the interactive character of the innovation process, empirical studies actually looking at interaction processes between components and actors of the system are almost non-existent. Instead, it has been dominated by static structural assessments that are unable to capture the complexity of actors and linkages at low levels of aggregation (Carlsson et al., 2002, p236). Other authors suggested that such a structural approach has shown no clear explanation of systems' economic performance (Spielman & Kelemework, 2009). Some researchers have recognised that despite being key determinants of the system's learning capacity, informal relationships among actors and the quality of such linkages have often been overlooked by innovation-system studies given the difficulties of measuring them (Lundvall et al., 2009b, p10). Similarly, Markard and Truffer (2008) have suggested that most system frameworks fail to consider *complementarities* between actors in the system and what may be affecting their collaborative exploitation.

Moreover, pervasive attention has usually been paid by systemic studies of innovation to R&D activities in private organisations, an approach suitable for developed nations where firms are the main performers of R&D activities. Nevertheless, the figures change when we consider the context of a less developed country and an emerging technological field. In such a context, firms share a minority of total investments in R&D and employment of scientists (Viotti, 2002, p673; Brundenius et al., 2009), while public research encompasses most knowledge assets and R&D activities, becoming a salient determinant of the technological absorption and development abilities of the system as a whole (Viotti, 2002; Edquist, 2005). Hence, under these circumstances, approaches to studying emergent technological systems must pay much greater attention to the dynamics of knowledge generation in the public domain, particularly to inter-organisational interactions and knowledge integration processes among public R&D organisations[2].

The present research intends to contribute to the innovation-systems literature through the definition of a lower level of analysis – the single public research organisation or group – but keeping the scope and boundaries of an entire technological innovation system. In empirical terms, the study required setting its geographical scope within a single developing country, namely Uruguay. While we looked at the structure and working of the whole agri-biotechnology innovation system in Uruguay, we placed particular attention to how institutional attributes of the system influence the lower-level dynamics of inter-organizational collaboration and

[2] E.g. research institutes, universities, public laboratories, etc.

knowledge integration between R&D groups in the public research sub-system. The static structural perspective usually applied by empirical studies in this field is hence avoided. Conversely, an actually-relational approach was empirically applied so as to be able to assess to what extent R&D collaborations among actors integrate complementary sources of knowledge and capabilities distributed throughout the system. By doing so, this approach also allows the exploration of the main forces affecting collaborative knowledge integration.

The investigation also adds to studies of inter-organisational collaboration. Most scholarly work in this field has focused on the study of inter-firm or public-private collaborations. Nevertheless, a smaller body of research has studied collaboration among public research organisations (Katz & Martin, 1997; Laudel, 2001; Rafols, 2007; Heinze & Kuhlmann, 2008). Hence, relatively little attention has been paid to the drivers and barriers of collaboration between research groups, laboratories and research organisations in the public domain. In particular, very few studies have explored the factors influencing the extent to which collaborations between public research organisations actually integrate complementary fields of knowledge and research capabilities (Rafols, 2007; Rafols & Meyer, 2007), which, as argued above, is central for the development and performance of emergent technological innovation systems in developing countries. Scholars studying interdisciplinary scientific research have also identified the need for further understanding of the background conditions that may enhance the extent of knowledge integration in the public research domain (Wagner et al., 2011).

Studies of inter-organisational networks have also received some criticism. Their prevalent attention to the networks' structure and the position of actors within them as drivers of organisational outcomes (Ahuja, 2000; Gulati & Gargiulo, 1999; Powell et al., 1996; Zaheer et al., 2010) has largely overlooked the actual type and value of the resources accessed by an organisation through the network, which are the final determinants of how a network influences the organisation's performance (Gulati et al., 2011, p209). Consequently, some authors have suggested that further research should pay greater attention to the *quality of the links* of an organisation as well as to the precursor factors that drive the actual value of the resources integrated through collaborative links within a network (Gulati et al., 2011, pp208 & 221). The empirical approach of the present study contributes to this body of literature by assessing the extent to which an organisation's collaborative linkages actually exploit potential complementarities (Gulati & Gargiulo, 1999; Grant & Baden-Fuller, 2004; Colombo et al., 2006), namely the extent of collaborative knowledge integration achieved. Exploring this quality-attribute of collaborations and its driving forces should provide a better understanding of the potential contribution of collaborations to the solution of local technological problems (Van den Besselaar & Heimeriks, 2001; Lundvall et al., 2009b, p19) and to the general performance of a technological innovation system (Carlsson & Stankiewicz, 1991; Johnson & Lundvall, 2000; Bergek et al., 2008).

The inter-organisational access to complementary resources and capabilities has been stressed by previous research as a driver of an organisation's economic performance. However, empirical studies of the organisational complementarity approach (i.e. Teece's thesis on 'combination of specialized complementary assets') have predominantly assumed that a single organisation alone develops and produces a novel technology and only then requires accessing external complementary capabilities in order to transform that technology into commercial innovation and profits (Teece, 1986, p286; Colombo et al., 2006, p1167). Therefore, they largely leave unexplored the complex R&D process required to develop the novel technology, which also demands other sorts of complementarities, particularly between diverse – and usually distributed – scientific and technological research capabilities (Luo et al., 2009). In fact, superior technological outcomes are expected when complementary knowledge assets of two R&D organisations are joined and exploited through different sorts of *inter-organisational collaborative arrangements* (Hage & Hollingsworth, 2000; Grant & Baden-Fuller, 2004; Dyer & Singh, 1998). Consequently, further studies should pursue a deeper disaggregation of scientific and technological assets available in different organisations, in order to assess the extent of complementarity among the partners' knowledge assets exploited during inter-organisational collaborative R&D activities (Colombo et al., 2006).

Clear needs for further research were identified in the bodies of literature discussed up to this point. This thesis contributes to address these knowledge gaps. With this aim, the driving question of the research has been:

> *How and why does the extent of scientific and technological complementarity exploited through R&D collaborations differ among collaborating actors of the agri-biotechnology innovation system in the context of developing countries?*

In order to answer this question, the study has explored inter-organisational collaborations between public research organisations, and assessed how and to what extent their joint R&D activities integrate local complementary sources of knowledge and skills distributed throughout the emergent biotechnology innovation system within the national and sectoral boundaries of Uruguayan agriculture[3]. In particular, it performs an analysis of the influence that organisational and system-level attributes exert on the extent of integration of complementary knowledge assets achieved by public R&D groups through their collaborative research efforts in the agri-biotechnology field. A number of relevant factors driving *collaborative knowledge integration* were identified from the bodies of scholarly research reviewed while other forces were found to be relevant for the purpose and scope of this research through an inductive interpretation of a number of exploratory interviews.

Among the factors identified, the research pays particular attention to the role of: (i) system-level institutions and incentives (informal institutions and public policies supporting the scientific community); (ii) structural and relational attributes of the R&D group (absorptive and relational capacities); and (iii) the compliance of the R&D group with scientific assessment and reward institutions. The empirical work followed a mixed methodological approach, involving qualitative exploratory interviews with members of public R&D groups and firms encompassed within the agri-biotechnology system and a subsequent quantitative approach to answer the research questions proposed.

[3] The rationale for choosing these technological, sectoral and national boundaries is presented in Section 3.3.

Quantitative data was generated through a survey addressed to the leaders of agri-biotechnology research projects that were competitively funded in Uruguay between 1999 and 2010. An extensive unique database was developed, collecting and integrating information from the main public agencies or programmes that have funded agri-biotechnology R&D during that time. Project leaders were asked, among other things, to identify the collaborative relations established for the implementation of the project as well as to indicate the disciplinary knowledge fields and R&D capabilities encompassed by their research group. Based on methodological developments from studies of interdisciplinary scientific research intended to measure diversity of knowledge at different levels of analysis, indicators of the extent of knowledge complementarity between collaborating R&D groups were developed. Finally, spatial autocorrelation models[4] were run in order to analyse how actor and system-level attributes may explain differences in the extent of collaborative knowledge integration achieved by these R&D groups.

The thesis results provide theoretical and methodological contributions. It finds clear qualitative and quantitative evidence of how system-level formal institutions, particularly incentive policies targeted to individual researchers, influence the ability of public R&D groups and organisations to integrate complementary knowledge assets through their collaborative research activities. Influences from structural attributes of the R&D group are also observed. In particular, individual members within the R&D group are found to play distinctive roles in fostering the extent of collaborative knowledge integration achieved by the group. Consequently, a better understanding of the drivers and barriers of collaborative knowledge integration is achieved which may well grant a relevant contribution for policy-making aimed at supporting the emergence and development of a technological innovation system and at raising the system-level absorptive capacity, within the context of a developing country.

Methodological contributions are also made by this thesis. Singular quantitative indicators were developed to measure the extent of knowledge-integration accomplished by public R&D groups through their collaborative research. This required

[4] The rationale for the use of this model is explained in Chapter 6.

a substantial effort to adapt indicators developed by previous studies to the empirical context of this research and to build a suitable classification system of knowledge-assets' categories. Moreover, previous empirical studies have assessed knowledge-integration mostly at the level of published research outcomes[5]. The survey-based approach designed for this study contributes to this field with a more suitable method for the context of developing countries[6]; it observed collaboration and knowledge-integration at the level of individual R&D projects, namely the actual locus where research activity and collaborative knowledge-integration takes place. Finally, this thesis' examination of the relation between system-level attributes and the quality of inter-organisational collaborations represents a proper relational empirical perspective that, as was argued above, has been largely missing in previous studies of emergent technological innovation systems.

With regard to the structure of the remaining sections of this thesis, Chapter 2 critically reviews the literature briefly introduced in this chapter, looking for theoretical and methodological insights to address our research question and identifying relevant gaps in need of research contributions. Chapter 3 explains, in detail, the mixed methodology pursued for the implementation of this research. Chapters 4 and 5 provide the results of the qualitative analysis. While the former is a rather descriptive chapter that provides an overall picture of the Uruguayan agri-biotechnology innovation system and its relevant context, Chapter 5 carries out an in-depth analysis of the qualitative interviews. It seeks to identify the main drivers and barriers for collaborative efforts to integrate distant complementary knowledge assets, and generates a number of research propositions on the basis of the qualitative results. Chapter 6 presents a comprehensive description of our quantitative empirical approach and examines the main results from the statistical analysis. Finally, Chapter 7 discusses the overall results, drawing the main conclusions and implications for policy making before closing with an identification of both, the limitations of the present study and the opportunities for further research.

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[5] E.g. scientific papers or patents (Wagner et al., 2011).

[6] Developing-country knowledge production is under-represented in global publication databases so these are not suitable sources to assess knowledge integration in such contexts (Wagner et al., 2011).

Chapter 2 - Literature review and conceptual framework

2.1 Introduction

The present research studies processes of collaborative research between public R&D organisations. It particularly explores the extent to which these organisations *integrate* complementary knowledge assets and R&D capabilities through the collaboration process. The assumption underlying this study is that the *integration* process referred to above is a key determinant of cumulative learning and the exploitation of technological opportunities in developing countries (Viotti, 2002) and is related to the development of major technological discoveries (Hage & Hollingsworth, 2000; Hollingsworth, 2006). On that basis, this study explores *how and to what extent local knowledge assets and R&D capabilities are being integrated and exploited through inter-organisational collaborative arrangements within the emergent agri-biotechnology innovation system in Uruguay.* In other words, the general formulation of the question that this research intends to answer is the following:

> *How and why does the extent of scientific and technological complementarity exploited through R&D collaborations differ among collaborating actors of the agri-biotechnology innovation system in the context of developing countries?*

In order to address this overarching question, we started the literature review process by asking: *which are the main bodies of literature that could allow us to conceptually understand and empirically assess the integration of knowledge that takes place through collaborative research and development processes*. Following this guiding query, the present chapter explores academic literature on inter-organisational collaborations or partnerships, particularly scholarly research regarding non-market collaborative relations established for the purpose of conducting joint R&D activities (Heinze & Kuhlmann, 2008; Lam, 2005; Laudel, 2001). Beforehand, in order to situate the R&D collaboration process within a wider context, studies of innovation systems are reviewed, since they are claimed to follow a relational research approach that pays singular attention to the interactions and coordination between actors and components of the system (Johnson & Lundvall, 2000; Carlsson et al., 2002; Malerba, 2005). Taking the latter into account, the main motivations behind following a systems' perspective in this study and hence in the present review of literature, were setting the wider context or background where R&D collaboration and knowledge integration take place, as well as identifying system-level institutions that may shape the extent of *collaborative knowledge integration* accomplished by the system's actors.

In order to narrow down the scope of this research, and given the interest on R&D collaboration as a means to exploit opportunities to integrate scientific and technological knowledge, the boundaries of this study were set around a single emergent technological field, namely, *biotechnology*. To narrow it even more into a manageable study under the constraints of a PhD, we looked specifically at applications of biotechnology in the agriculture sector (Arundel & Sawaya, 2009). The rationale for choosing these technological and sectoral boundaries is presented in Section 3.3 below. Therefore, we explored those public R&D collaborations encompassed within the *agri-biotechnology innovation system*. These technologically-set boundaries led us to review specific conceptual and empirical studies on *emergent technological innovation systems* within the broader field of innovation systems' studies. In emergent technological fields, the collaborative integration of *complementary resources* is a key driver of the further development of a technological system (Bergek et al., 2008).

In fact, in the context of emergent technological fields, inter-organisational R&D collaboration is mostly driven by the need for accessing complementary knowledge and R&D capabilities[7] (Mowery et al., 1998; Colombo et al., 2006; Heinze & Kuhlmann, 2008). Therefore, studies of complementarity between organisations were also reviewed (Pfeffer, 1972; Pfeffer & Nowak, 1976; Pfeffer & Salancik, 1978), and their empirical and methodological approaches critically analysed. The collaborative access to complementary knowledge is actually a process of *knowledge integration* which has been the subject of research by a community of scholars studying interdisciplinary scientific research (Wagner et al., 2011; Rafols & Meyer, 2010; Rafols, 2007), namely research processes involving multiple disciplines. Therefore, this body of research was

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[7] We refer to these resources generally as *knowledge assets.*

also reviewed with the main aim of gaining insights on empirical approaches and methodologies to assess and measure *knowledge integration* processes.

By identifying and reviewing the main bodies of literature related to the process of *knowledge integration in collaborative R&D activities*, the conceptual and empirical boundaries of this study were narrowed down. The scholarly literature was also reviewed with regard to *which are the forces that may affect the extent of knowledge integration accomplished by collaborating partners*. This exploration pursued the identification of the most relevant forces for the particular context of this study[8] in order to also narrow down the empirical approach developed for addressing the overarching question presented above. Therefore, throughout the whole review of relevant factors shaping R&D collaboration and collaborative knowledge integration, we explored and paid particular attention to structural attributes of R&D organisations, their knowledge assets and research capabilities, the absorptive and relational ability of organisations and finally, system-level institutional incentives and motivations of researchers to integrate knowledge across organisational or disciplinary boundaries. The identification of such main forces from the academic literature was complemented with an inductive exploration conducted during the fieldwork through qualitative interviews[9], resulting in the development of more specific research questions that are presented later in this chapter.

The remainder of this chapter is structured as follows. Section 2.2 defines a number of concepts central for the research questions presented and the argument developed in this chapter. Section 2.3 reviews studies of innovation systems and their variety of approaches for different levels of analysis while Section 2.4 discusses the literature on inter-organisational collaboration and networks. Section 2.5 adds a deeper review of studies on complementarity between organisations' resources as drivers of collaborative relations and knowledge integration in emergent technological fields. Section 2.6 addresses the theoretical basis of the core process analysed in this study, namely the *collaborative integration of complementary knowledge assets*. Additionally,

[8] This refers to the context of the study in terms of technological, sectoral and geographical boundaries.
[9] The qualitative method is described in Chapter 3 and the results of the interviews are presented in Chapter 5.

it critically analyses methodological approaches relevant for the assessment of the extent of knowledge integration in this study as well as the contributions of this research vein that may potentially fill gaps identified in the bodies of literature mentioned before in this paragraph. Then, drawing on the relevant theoretical and empirical perspectives, Section 2.7 provides a broad account of actor- and system-level factors that may influence the process of collaborative knowledge integration and integrates them within a complete conceptual framework. Finally, Section 2.8 closes the chapter with some concluding remarks.

2.2 Relevant definitions

This short section provides, in advance, the definitions of a number of terms and concepts employed throughout this document. It is intended to facilitate the reader's understanding of the conceptual ideas and discussion presented in this chapter. We list these concepts below and enunciate their respective definitions:

- *R&D collaboration*: drawing on Gulati and Gargiulo (1999), and Hagedoorn (2002) we conceptually understand an *R&D collaboration or partnership* as a formal or informal mode of *'...voluntary cooperation in which organizations combine resources to cope with ... environmental forces beyond their direct control...'* (Gulati & Gargiulo, 1999); more specifically, the term refers to those cooperation arrangements *'...where two or more … agents and organizations, share some of their R&D activities'* (Hagedoorn, 2002, pp477-8).

- *Knowledge assets*: knowledge assets are an organisation's internal resources that are essential to conduct its knowledge creation processes (Nonaka et al, 2000). For the purpose of this research, we will focus on two dimensions of knowledge assets relevant in emergent technological fields, namely: (i) the *disciplinary knowledge* embodied in the organisation employees, more specifically its research workers or scientists (acquired though education and work experience; Smith et al., 2005); and (ii) the *R&D capabilities* which are defined for the purpose of this research as the methods, techniques, materials and instrumentation available within the organisation or research group to carry out R&D activities (Rafols & Meyer, 2007, pp637 and 642; Leydesdorff & Rafols, 2011, pp847 and 850).

- *Knowledge integration*: Rafols and Meyer (2010) claim that interdisciplinarity is, in essence, a process of knowledge integration. Therefore, we assimilate their definition of interdisciplinary research *'...as a mode of research that integrates concepts or theories, tools or techniques, information or data from different bodies of knowledge'* (Rafols & Meyer, 2010, p265) to the concept of *knowledge integration* used for this research.

- *Collaborative knowledge integration*: drawing again on Rafols & Meyer (2010, p265) we define the concept of *collaborative knowledge integration* as a *research process '...that integrates concepts or theories, tools or techniques, information or data from different bodies of knowledge' through any form of R&D collaboration between two or more research groups or organisations.*

We have defined above four concepts central to understanding the critical analysis of academic literature presented in the remainder of this chapter. Sections 2.3 to 2.7 below review the main bodies of literature theoretically and/or empirically relevant for our study of collaborative knowledge integration and its driving forces, while Section 2.8 provides a closing summary and integrates the main ideas discussed in this chapter into a comprehensive analytical framework for our study. The next section presents a critical review and analysis of the innovation systems' literature.

2.3 Innovation systems: conceptual and analytical perspectives

2.3.1 <u>General overview on innovation systems' approaches</u>

Innovation systems' approaches have emerged since the 1980s following upon the understanding that knowledge, learning and innovation are key drivers of economic development (Johnson & Lundvall, 2000; Edquist, 2005; Freeman, 1988; Carlsson & Stankiewicz, 1991) Another salient contribution of this approach is that it acknowledges and emphasises *'...that innovation is an interactive process'* (Johnson & Lundvall, 2000, p11) where interactions and collaboration among actors are key determinants of the system's performance. This sort of perspective also came out as an alternative to linear models that assumed that innovation is driven almost entirely by either scientific research (Bush, 1945) or the demand from customers (Schmookler, 1972). Under such premises, an innovation system has been defined as the group of actors, institutions and networks that support the common end of 'developing, diffusing and utilising new products and processes' (Bergek et al., 2008, p408).

It is interesting to note how the concepts of innovation systems and collaboration (interactions, networks) appear closely associated in the innovation systems' literature. In fact, as suggested by Johnson and Lundvall (2000, p21), a distinctive attribute of an innovation systems' perspective is that it proposes combining a rather static exploration of the structural components of a system with a more dynamic exploration of the linkages and synergies among components in the system (Johnson & Lundvall, 2000). The same authors claimed that a *'...strategy based on an innovation system approach would start by analysing all parts of the economy that contribute to competence building and innovation. And especially it would focus on the linkages and synergies between the parts that form the system as a whole'* (Johnson & Lundvall, 2000, p12). Similarly, other advocates of this framework emphasise that innovation is a collective process, highly reliant not only on the internal capabilities of the leading organisation but also on resources external to it (Bergek et al., 2008). Thus, besides the influence of the capabilities existing in incumbent actors, their resource investment and market forces, the emergence and development of a technological innovation system is argued to be affected also by the interactions resulting from *inter-organisational collaborations and networks* (Bergek et al., 2008).

Organisations interact in many different ways. They may be competitors, they may transact goods or services through market mechanisms, or they may exchange and integrate knowledge-based resources and capabilities through *non-market collaborative arrangements* (Edquist, 2005, p196; Grant & Baden-Fuller, 2004). While traditional approaches for the study of innovation focused mainly on market exchange and competition relations between actors (Porter, 1990), the recent conceptual and empirical developments on innovation systems emphasise the need to access multiple sources of knowledge and thus pay more attention to other forms of formal and informal collaboration (Malerba, 2005; Johnson & Lundvall, 2000; Carlsson & Stankiewicz, 1991). In particular, under the uncertainty of an emerging technological field, it has been claimed that such collaborations and networks allow the exploitation of complementarities through the integration of knowledge and capabilities dispersed throughout diverse actors in the system (Malerba, 2005, p393; Grant & Baden-Fuller, 2004; Colombo et al., 2006).

The literature on innovation systems has developed specific approaches for diverse levels of analysis: national (Freeman, 1988; Lundvall, 1988), sectoral (Breschi & Malerba, 1997; Malerba, 2005) and regional (Cooke et al., 1998; Howells, 1999; Asheim & Gertler, 2005) innovation systems. An additional approach focuses the analysis on innovation systems built around specific technologies or products (Carlsson & Stankiewicz, 1991; Carlsson et al., 2002; Suurs & Hekkert, 2009). This technology-specific analytical perspective provides a deeper understanding of dynamic attributes of the system by reducing the degree of complexity of components, actors and types of relations between actors if compared with a national-level system study (Carlsson et al., 2002; Hekkert et al., 2007). This latter analytical perspective has been most recently referred to in the literature as the *technological innovation systems approach* (Markard & Truffer, 2008; Bergek et al., 2008; Suurs & Hekkert, 2009).

Systemic frameworks imply a move in public policy-making from interventions aimed at sorting out market operation problems, towards policies that look not only at the market but also at broader *system-level attributes and processes of interaction among social actors* (Lundvall, 2005; Arocena & Sutz, 2002; Hall et al., 2003). The common rationale for policy intervention suggested by innovation system approaches is identifying and unravelling *'system failures'*, namely attributes of the system that undermine the development and use of innovations (Bergek et al., 2008, p409). A recent typology has identified the following categories of *system failures*: (i) institutional; (ii) infrastructural; (iii) capability; and (iv) *network failures* – also known as interaction failures – (Woolthuis et al., 2005). Network failures have been defined as situations when '...possibilities for interactive learning and innovation are under-utilised and firms may fail to adapt to new technological developments' (Woolthuis et al., 2005, p614). Among the relevant attributes referred to above, particular attention is paid in the present research to those factors that may drive the occurrence of *network or interaction failures*, understanding them specifically as situations where opportunities for interactive learning, collaboration and *complementary knowledge integration* between actors are hindered in some way. As was argued before, the exploration of this later collaborative process is the central concern of the present study.

As suggested by Klerkx & Leeuwis, 'Systems approaches to innovation emphasize that actors in the R&D process are involved in networks that operate within certain institutional contexts...and their *co-operative performance* is a key determinant of the impact of innovations' (Klerkx & Leeuwis, 2008a, p462[10]). Two concepts referred to above are salient for the present research. One is the need to analyse R&D processes within the wider collaboration network of actors involved in such processes. The second interesting reference is to the concept of *'cooperative performance'* which suggests that identifying or prompting links between actors is not enough, but looking at *what happens* within those collaborations and *how they perform* is also relevant. This suggests the need for indicators to assess not only the existence of a collaborative relation between actors but also the *qualities* of such a link since they will have an influence on the impact of the collaboration on innovation (Klerkx & Leeuwis, 2008a). The present research addresses these issues by exploring *the extent to which R&D collaborations are pulling together sources of complementary knowledge and research capabilities distributed throughout the actors involved in the technological system under study*.

Based on such systemic and relational perspectives, some scholars claim that empirical studies of innovation systems have placed a great deal of attention on relational attributes of the system, namely on the linkages between actors in the system, and on how those linkages operate (Fagerberg, 2005; Arocena & Sutz, 2002; Carlsson et al.,

[10] The authors refer to Biggs and Smith, 1998; Leeuwis and Van den Ban, 2004; Smits and Kuhlmann, 2004.

2002). Along these lines, one of the contributions that innovation system frameworks have anticipated doing is changing from analytical approaches that look mainly at structural indicators for different components of the system (such as R&D investments or patenting activity). In particular, advocates of this perspective have claimed a change towards more integral analytical approaches of a relational nature that pay greater attention to other key drivers of innovation such as the patterns of *interaction and collaboration between or within components of the system*, institutional innovations, as well as process and policy innovations (Hall, 2006).

Nevertheless, subsequent empirical research on innovation systems has received some criticism due to its continued attention to structural attributes such as investments and outcomes from incumbents in the innovation process, while it still lacks clear analytical methods to explore the innovation process itself and the relational aspects (or interactive dynamics) at play during the process (Carlsson et al., 2002; Spielman & Kelemework, 2009). Supporting this idea, Lundvall et al. (2009b, p10) claimed that innovation-system studies have paid much attention to the performance of individual actors and the whole R&D infrastructure, recognising that despite being key determinants of the system learning capacity, informal relationships among actors and the quality of such linkages have often been overlooked given the difficulties of measuring them. On that basis, it is argued here that the intended focus on the interactive dynamics and relational attributes of the innovation process has been only slightly explored by innovation systems' research. Instead, despite its valuable potential to explain the innovative ability of a nation, the main strand of research on innovation systems (the national-level approach) has been empirically implemented largely through static comparative analyses of structural components of the system in different countries or regions. Such studies are based mainly on statistics of R&D activities (Viotti, 2002) and quantitative indicators of other components of the system such as bridging institutions (Spielman & Kelemework, 2009), customer demand and finance institutions (Senker & Van Zwanenberg, 2001; Pittaluga & Vigorito, 2005). This sort of research pays almost no attention to relational or collaboration patterns within the system, and hence is unable to capture the complexity of actors and linkages at low levels of aggregation (Carlsson et al., 2002, p236).

Moreover, the focus on R&D investments or other structural indicators is not appropriate for the study of *emergent technologies* for which specific R&D statistics are usually non-existent (Ekboir, 2003, p574), not least for the assessment of emergent innovations in underdeveloped countries (Spielman & Kelemework, 2009). In such contexts, the 'innovation system' as has been defined, may not exist yet, interactive relations between actors are still being developed (Padilla-Pérez et al., 2009, pp145-6), and scattered R&D efforts are made by some related or unrelated actors, mainly from the public sector. Results from studies that applied this sort of structural approach have also shown it to be insufficient to explain innovation outcomes, leading their authors to conclude that more attention should be paid to knowledge-sharing spaces and the attributes of the system that are affecting the coordination, interaction and integration of capabilities between actors in the system (Spielman & Kelemework, 2009, p18; Arocena & Sutz, 2002; Hall, 2006). The present study is expected to contribute to this body of literature by means of adopting a relational perspective in the empirical exploration of R&D collaborations and knowledge integration between actors within the system.

One key attribute affecting the performance of an innovation system is its capacity to change as an adaptive response to changes in the environment (Carlsson et al., 2002). As suggested by Carlsson et al., systems' '[c]hange can be generated endogenously: new components (actors, technological artefacts) are introduced while others exit; the relationships among the components change; and the attributes (capabilities of actors, *nature and intensity of links among actors*) change' (Carlsson et al., 2002, p235). Such suggested attention of systems' approaches to the available capabilities and *complementary collaborative relationships* between actors (given its relevance for systems' adaptation and performance) has been hindered by empirical constraints shared by most innovation systems' approaches. In particular, the definition of the whole system as the unit of analysis of all innovation systems' studies precludes making comparisons at lower levels of aggregation, for example, between organisations and between different linkages among actors of the system (Carlsson et al., 2002). Along these lines, a comparative assessment of different systems' approaches on innovation has suggested that most system frameworks fail to consider *complementarities* between actors in the system (Markard & Truffer, 2008).

As suggested by Carlsson and Stankiewicz, '...by studying the [complementarity]...and the *linkages* between micro units and entire sectors of the economy, economic growth...can be better understood. In this view, the macro economy is not simply the aggregate of various micro units but is regarded also as a complex *network* of micro relationships' (Carlsson & Stankiewicz, 1991, p94). Such lower-level analyses would allow a better understanding of the internal dynamics of the system and its driving forces, and yield policy lessons for improving the functioning of the system – if the scope of the empirical research encompasses the most relevant incumbents in the technology-specific innovation system.

The rather usual meso-level studies of the structure of an innovation system and its past evolution (Carlsson et al., 2002, p236) bring only vague insights about the system's influence on the patterns of *interaction between social actors* (Arocena & Sutz, 2002). This critique suggests that innovation systems' studies need further research on the patterns of interaction among actors at lower levels of aggregation (Carlsson et al., 2002, p236) and on *how these local actors integrate complementary knowledge assets distributed throughout the system*[11]. As an example, despite strongly focusing on the pervasive need of establishing linkages and synergies between actors in the system, Johnson & Lundvall (2000) suggest a rather descriptive approach to such existing or missing links, but no questions are presented on what may be affecting the collaborative exploitation of complementary knowledge and competences. Answering that question may also provide a guide when addressing another relevant question, namely, *Why do relevant interactions not occur?*

Surprisingly, authors of these meso-level studies of innovation-systems claim that this vein of research has been intended to explore, among other aspects, whether or not there may be *potential linkages and synergies* between actors that are being left unexploited within the system (Fagerberg, 2005, p12). It is argued here that the

[11] As is defined and discussed in the next section, this research explores collaborative knowledge integration within the boundaries of a technology-specific innovation system.

structural approach usually applied in empirical studies of innovation systems is not able to address this sort of enquiry. Assessing this issue requires a lower (micro) level of disaggregation in the analysis, the identification of relevant actors, their knowledge assets, and *existing collaborative linkages* between them, in order to empirically estimate the degree of complementarity between collaborating actors as well as the factors affecting the exploitation of complementary knowledge and capabilities.

An interesting element added by the previous paragraph is the conceptual reference to *potential synergies* (Fagerberg, 2005). For the purpose of this research, it is understood that *potential synergies* refer to pairs of actors in the system that, when a coordination or collaborative linkage is effectively formed between them, then enhanced research, development or innovation performance will be observed. But: *where does such an assumed increase in performance – when a potential linkage is realised – come from?* The answer to this question, implicit in the definition of *potential synergies*, is the conceptualisation of *complementarity* (Pfeffer & Salancik, 1978; Teece, 1986; Dyer & Singh, 1998; Gulati & Gargiulo, 1999) between actors in the system in terms of their capabilities and other resources. On this basis[12], better innovation outcomes are expected when the *complementary* knowledge assets of two R&D groups or organisations are joined and exploited through different sorts of *inter-organisational collaborative arrangements* (Hage & Hollingsworth, 2000; Grant & Baden-Fuller, 2004; Dyer & Singh, 1998).

The latter two paragraphs provide a general idea of three key aspects of this research: **(i)** the problem being addressed: collaborative integration of knowledge assets and its determinants; **(ii)** the conceptual framework: assessment of the extent of complementarity between actors' knowledge assets and its driving forces within a wider system framework; and **(iii)** the relational approach introduced in our method in order to address the research questions: a micro-level disaggregation of actors, their knowledge assets and collaborative relations. A deeper analysis of the concept of complementarity and knowledge integration is presented below in Sections 2.5 and 2.6

[12] The conceptual basis of *resource interdependence or complementarity* and its implications for the empirical implementation of this study are discussed in section 2.5.

respectively. This conceptual and empirical orientation of the present study is intended to contribute to some extent to the innovation systems' literature addressing specific issues identified above, that require further development as has been claimed in the scholarly work critically reviewed here. Such spaces for research contributions are reviewed and discussed in the remaining of this section.

Some advocates of the innovation systems framework have recognised the still limited development and consistency of this approach both theoretically and in its empirical results (Edquist, 2005), if sound policy lessons are to be obtained from its application. As an example, the need for further studies of *how collaboration networks develop and evolve* within sectoral systems has been stressed by Malerba (2005). Furthermore, specific empirical studies on agricultural innovation in developing countries support this argument. Spielman & Kelemework[13] conducted a comparative study of agricultural innovation systems in 35 developing countries, based on four domains of structural indicators: (i) knowledge and education; (ii) bridging institutions; (iii) business and enterprise, and (iv) enabling environment (Spielman & Kelemework, 2009). Their results showed that either independently or in an aggregated way these *structural indicators* alone did not provide evidence of a clear relationship with the system's performance (measured as agricultural GDP). Figure 2.1 below illustrates such a poor relationship that the index[14] built by these authors to assess the structural development of the innovation system showed against agricultural GDP (comparison among 35 countries). Given this weakness of the structural approach to account for innovation performance, the same authors suggested that additional information related to 'integrative processes of communication, exchange and learning', and *linkages among actors* (Spielman & Kelemework, 2009, p18) is required to explain the observed performance differences between systems.

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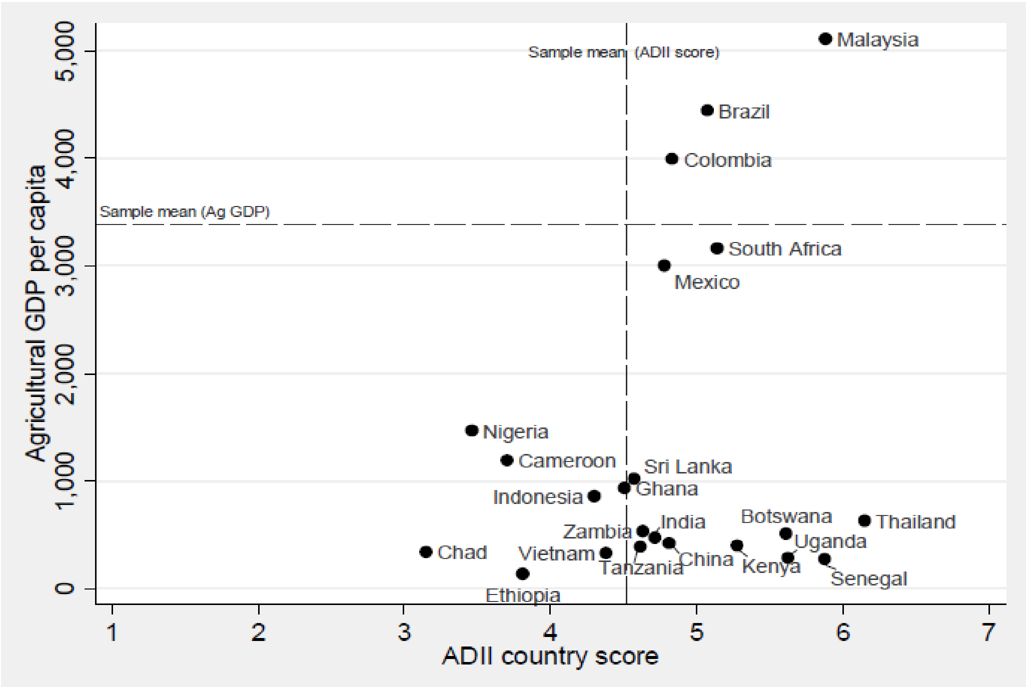
[13] The authors based their study on a systems' framework developed by Arnold & Bell, 2001.
[14] The authors named their index as *ADII* (*Agriculture, Development, and Innovation Index*).

Figure 2.1: Relationship between an aggregate structural indicator of the innovation system against its performance measured by agricultural GDP (Spielman & Kelemework, 2009, p16)



Source: reproduced from Spielman & Kelemework (IFPRI15 discussion paper 00851, 2009, p16).

In other words, when studying agricultural innovation systems, attention should be focused on the attributes of the system that are shaping *knowledge-sharing and collaboration among actors* as well as on their effectiveness in supporting technological change (Arocena & Sutz, 2002; Hall, 2006). Along the same line of argument, a number of authors, trying to identify other relevant factors affecting the performance of an innovation system, have pointed to the access to external sources of knowledge and other resources through inter-organisational networks as a key determinant of the system's performance (Edquist, 2005; Powell et al., 1996; Giuliani & Arza, 2009).

A general account of the innovation systems' literature, its contributions and limitations has been presented in this section. To sum up the discussion developed here, it has been suggested that the sort of static structural assessments employed in

[15] The International Food Policy Research Institute (IFPRI) allows the reproduction of pieces of this work for non-profit purposes, without their written authorisation.

empirical studies of innovation systems still needs to be complemented with sound relational perspectives in order to capture the complexity of actors and linkages at low levels of aggregation (Carlsson et al., 2002, p236). From a narrower perspective, further research is required on how inter-organisational linkages in the system are developed, especially studies paying deeper attention to collaborative processes for the integration of complementary knowledge and R&D capabilities among actors, and to the main forces shaping the extent of collaborative knowledge integration accomplished by partner organisations. This is partly addressed in this research through an exploration of R&D collaborations among public research organisations. It remains to further explore what the systemic studies performed at different levels of analysis or boundaries (technology- and sector-specific system studies) may conceptually and empirically add to the present research. Therefore, the subsequent two sections respectively review approaches to study innovation systems at the level of specific technologies and sectors.

2.3.2 Technological innovation systems

This section briefly reviews studies of *technological innovation systems* (TIS), a vein of thought within the broad field of innovation system studies that was introduced in Section 2.3.1. Such a review is intended to explore whether or not taking a technology-specific perspective on the innovation system may be valuable in addressing the research question presented by this study. Moreover, the implications of the degree of development of the technology being explored on the dynamics of the system in general, and R&D collaboration in particular, are addressed. We start this discussion by reviewing the origins and foundations of the TIS notion.

The concept of a *technological innovation system* draws on the earlier definition by Carlsson and Stankiewicz of *technological systems* as a ‘network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilization of technology. ...They consist of dynamic knowledge and competence networks’ (Carlsson & Stankiewicz, 1991, p111).

More recently, *technological innovation systems*[16] focused the analysis on 'networks of actors and institutions that jointly interact in a specific technological field' (Markard & Truffer, 2008, p611). Similarly, technological innovation systems were defined as 'socio-technical systems focused on the development, diffusion and use of a particular technology' (Bergek et al., 2008, p408). These contributions highlight the relevance of performing technology-specific studies of innovation from a system perspective (Hekkert et al., 2007, p417).

When analysing innovation systems surrounding a specific technology, the stage of development of the technology being studied is a key determinant of the dynamics of the system. On the one hand, we recall here the concept of *technological regimes* proposed by Nelson & Winter (1982) to refer to established technologies. This concept assumes that problems are known and solved through certain organisational and cognitive routines, in this way maintaining stable technological trajectories (Geels, 2002). In contrast, these assumptions cannot be made for a *technological innovation system* in its *emerging* phase.

In such *emergent technological systems,* a number of new related technologies are in their initial stages of use and adaptation, their potential applications are still being explored, and demand is unarticulated (Bergek et al., 2008). Therefore, the system dynamics are characterised by high uncertainty and the central developments take place mainly at the level of scientific knowledge, advanced skills and R&D capabilities. In fact, it has been argued that an emergent *technological innovation system* is still an ideal construct built from disconnected sub-systems (Bergek et al., 2008; Arocena & Sutz, 2002). Therefore, the system as a whole is challenged in terms of being able to effectively exploit its distributed sources of knowledge and competences in order to develop the absorptive and learning capacities necessary to strengthen the system. Another branch of literature that explores emergent technological systems is what has come to be called *strategic niche management* research. We found worthy of note how this research stream stresses the particular importance of *local exploratory*

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[16] Hekkert et al. (2007, p417) refer to these as 'technology specific innovation systems'.

projects[17] as a 'space for interactions between actors and the **building of social networks'** (Geels & Raven, 2006, p377). The 'learning and articulation processes' allowed by these *local experimental networks* support the subsequent development, adjustment and establishment of new technologies (Geels & Raven, 2006, p377).

The present research focuses on ***biotechnology*** as a case of an emergent technological innovation system in the context of a single developing country (Uruguay[18]). The increased complexity of technology development processes referred to above has resulted in a reduction of the gap between science and technology, at least in some technological fields (Pavitt, 1987; Gibbons et al., 1994; Hessels & van Lente, 2008). Biotechnology is a clear example in which science and technology are intricately interrelated (Powell, 1999; Bisang et al., 2009). Such a close relation between science and technology in biotechnological innovation systems results in increased potential opportunities for interaction between agents in any position of the science-technology continuum (Gonçalves do Valle et al., 2002). Exploiting such potential synergies becomes particularly relevant, thus making biotechnology an interesting case for the study of the patterns of integration of complementary scientific knowledge and R&D capabilities through collaborative research activities. This pervasive need to integrate distributed knowledge assets is even more relevant when the boundaries of the analysis are set within a developing country where limitations on R&D resources and capabilities are emphasised, while such resources are located mainly in the public sector but distributed among several public R&D groups and organisations. A deeper discussion on why to focus this research on a developing country – and particularly Uruguay – is developed in Section 3.3, while the next section reviews scholarly work on sectoral innovation systems and explores what a sector-specific perspective could add to this research.

[17] Some empirical and methodological implications of the relevance of these exploratory projects are discussed in section 2.4.
[18] The rationale for conducting this study in Uruguay is presented in section 3.3.

2.3.3 Innovation systems from a sectoral perspective

This section discusses the literature on sectoral systems of innovation as a basis to define the level of analysis for the present research. It is argued here that the study of collaborative knowledge integration requires a sector-specific research approach. A sector has been defined as a 'set of activities unified by linked product groups for a – given or emerging – demand and which share some common knowledge' (Malerba, 2005, p385). Malerba suggested a definition of innovation systems based around specific sectors, establishing the boundaries of the system on the basis of the sector's knowledge and technological domains, actors, networks and institutions (Malerba, 2005). The same author suggests that sectors differ in their knowledge domains, in the accessibility to knowledge and sources of technological opportunities, thus claiming the need for sector-specific studies. For example, the role played by research institutes, universities, government agencies and financial organisations may vary across sectors (Malerba, 2005).

In view of the diverse sectoral contexts referred to above, specific *emergent technologies* that have potential horizontal applications across many sectors (e.g. biotechnologies) may well face differing enabling conditions for their adaptation and adoption depending on the sector where the technology is introduced. It is argued then that, when such *emergent technologies* are the subject of research, as is the case of biotechnology for this study, the dynamics of innovation and knowledge integration should be investigated at the *intersection of technological and sectoral systems of innovation*. This is supported by a comparative study of biotechnology innovation in three sectors (pharmaceutical, agri-food, and equipment and supplies) in European countries, which found 'that the development of biotechnology...takes place mainly at the sectoral level' due to sectoral differences in local and global public perceptions and market demand (Senker & Van Zwanenberg, 2001, p13). This justifies performing *sector-specific studies of collaborative knowledge integration on emerging technological fields* and has implications for the generalisation of the results obtained from such studies to other sectors.

Taking into account the arguments developed above on the need for technology- and sector-specific studies, the present research has explored the integration of complementary knowledge assets through collaborative R&D arrangements within the intersection of the *agriculture sector* and the emergent *biotechnology innovation system*, and within the boundaries of a Latin American developing country, that is to say Uruguay. Having defined the technological, sectoral and national boundaries for our study, we can now turn our attention to the main dynamics where the development of biotechnology innovations applied to developing-country agriculture takes place. This involves focusing our analysis on the key system actors involved in collaborative processes for the integration of knowledge assets.

Looking first at the main actors involved in the development of innovations in the agriculture sector, we argue here that public R&D organisations play a key role in this process. Sources of innovation for agriculture may include: the farmers, producer organisations, universities, other research institutes and centres, industries delivering agricultural supplies – such as seeds, machinery, tools, pesticides, veterinary products and fertilisers – and the food industry (Possas et al., 1996). From Keith Pavitt's taxonomy, agriculture is defined as a 'supplier-dominated' sector (Pavitt, 1984), meaning that primary-producers or farmers are seen more as users than producers of innovations despite some process innovations being developed by farmers through incremental learning-by-doing (Possas et al, 1996; Hall, 2006). What we want to highlight from this perspective is that upstream industries (private input suppliers) and *public R&D organisations* that adapt or develop new product and process technologies are the main sources of innovations for this sector (Possas et al., 1996). Therefore, processes of knowledge integration among these types of actors in the system should be explored in order to address our research questions.

Many of these upstream industries, such as the suppliers of seeds and pesticides, can be characterised in Pavitt's terms, as 'science-based' or knowledge-intensive industries. Technology development performed by *public research organisations* in these fields is also highly based on advanced scientific knowledge and technological capabilities. It is important to recall also that many technological products and processes developed to solve problems of agriculture production have a very low

'...degree of technological appropriability ...implying a considerable lack of attractiveness of R&D and other innovation efforts specifically by agricultural firms,...suggesting also an image of technological backwardness and low productivity gains' (Possas et al., 1996, p936). Therefore, *public research organisations* play a highly relevant role as central sources of science-based and knowledge-intensive technological products and processes for agriculture. The role of public sector research is also emphasised in the context of developing countries. Therefore, in the next section we review specific literature on innovation systems in these types of countries.

2.3.4 Innovation system perspectives and agri-biotechnology in developing countries

This section analyses the implications of adopting an innovation system perspective in the context of developing countries. The argument presented above has emphasised the collective nature of innovation and the increasing relevance of inter-organisational collaborations for system performance. The importance of these interactions is even more significant in developing countries where specialised knowledge bases, critical mass, infrastructure, technological R&D capabilities and funding for research and innovation activities are scarce and distributed among many actors (Lundvall et al., 2002; Viotti, 2002; Bortagaray, 2007). Besides the available resources for researchers being scant in small developing countries, they also face poor employment and future career opportunities, a context that particularly affects young researchers who in many cases end up migrating to countries that offer more compelling career perspectives (Bortagaray, 2007, p106). In order to picture the dimension of this brain-drain problem in Latin America, it has been noted that 50 % of the migrants from this region that go to developed countries have higher education training (Brundenius et al., 2009, p323[19]).

Looking through a systems' perspective in developing countries, Arocena and Sutz have claimed that '...socio-economic behaviour regarding innovation at national level is, in fact, hardly systemic...[and] that the micro-innovative strengths, that really exist,

[19] The authors cite a report from the World Bank (2002).

often remain isolated and encapsulated, thus weakening remarkably their potential contribution to the competitiveness of national economies' (Arocena & Sutz, 2002, p6). A subsequent study observed this 'encapsulated' character of most innovation and learning practices in a small developing country, namely, Uruguay; in particular, it was suggested that innovation in Uruguay takes place as rather isolated efforts made by actors that are usually poorly *connected* to other actors in the system (Bortagaray, 2007, p78). For the specific case of the agri-biotechnology system in Uruguay, it was observed that linkages among local actors are weakly institutionalised, namely there are only a small number of inter-organisational relationships, while these are mostly short-term links driven by informal inter-personal relations and aimed at solving very narrow problems (Bortagaray, 2007, p273).

This isolated character of research and innovation efforts and the poor development of long-term shared visions along the technological system hinder the deployment of cumulative technological-learning processes and hence the innovation performance of the system as a whole (Bortagaray, 2007, p341; Lundvall et al., 2009). On those bases, it has been claimed that in less developed countries innovation processes of a clear interactive nature are poorly or not institutionalised throughout the social and economic structures of the system, suggesting a pervasive need for strengthening the links with, the access to, and the use of different sources of knowledge within the innovation system (Bortagaray, 2007, pp69, 78). Based on these attributes of innovation in small countries, Arocena and Sutz suggest that while the innovation systems' framework might be said to be an 'ex-post' concept for developed nations, it can be seen as an 'ex-ante' concept for developing countries (Arocena & Sutz, 2002, p6; Lundvall et al., 2002).

In line with this argument, it has been argued that agricultural innovation systems in Latin America are more a theoretical idea than a reality, since there is not an effective systemic structure; there is a lack of instruments for institutional governance[20] and a significant presence of 'cannibalism instead of synergy' between organizations (Salles-

[20] In the cited paper, the term *institutional governance mechanisms* refers mainly to support and guidance bodies such as research councils and governing boards (Janssen & Braunschweig, 2003).

Filho et al., 2006, p15[21]). Moreover, despite the creation of organisations to support innovation in the agricultural sector having been a common policy in Latin America, it is argued that they have acted only rather weakly as bridges between actors of the innovation system (Arocena & Sutz, 2002). All this provides a broad picture of the atomisation of actors in agricultural innovation systems in developing countries, showing a truly poor systemic functioning as a result of weak interaction and coordination among actors in the system. Such a picture is far from the sustained interactive learning processes (by means of realising the complementarities and opportunities offered by local sources of skills and knowledge) which are the basis for the building of system-level learning, technological and innovation capacity (Arocena & Sutz , 2002; Viotti, 2002; Bortagaray, 2007; Lundvall et al., 2009). Such an atomistic picture of agricultural innovation systems in Latin America makes even more pertinent the study of factors that may be affecting the collaborative integration of distributed sources of knowledge and R&D capabilities in emergent technological fields. This argument underpinned our selection of agri-biotechnology R&D processes within a developing country as the conceptual and geographical focus for our empirical research.

Under the resource scarcity and weak connections among actors described above, the absorption of external technological opportunities (Viotti, 2002) and system-level innovation are even more dependent on a proper establishment of interactions and the actual exploitation of complementarities among actors and components of the system as well as on access to foreign sources of knowledge (Luo et al., 2009; Bortagaray, 2007, pp86, 106). After studying agri-biotechnology innovation systems in two Latin American countries[22] and New Zealand, Bortagaray (2007) claimed that '[a] single agr[i]-biotechnology firm in a small country, often a small firm, will rarely have enough breadth and depth of resources to deal with different fronts like investment, production, strategic direction, core scientific skills, etc. Then often the case is that firms rely on some external actors/sources to complement for those missing resources'

[21] The authors use the term 'cannibalism' referring to a weak ability to integrate knowledge between actors of the system – mainly from the public sector – due to severe competition for resources, and other sorts of rivalries within the system (Salles-Filho et al., 2006, p15).

[22] Costa Rica and Uruguay.

(Bortagaray, 2007, p86). Such a picture of limited availability of resources – and hence pervasive reliance on relations with complementary actors – saliently characterises the nature of technological innovation in developing countries.

Along these lines, for the case of the agri-biotechnology system in Uruguay, Bortagaray observed that the private sector is very small; there is a small number of firms so the extent of competition is limited (Bortagaray, 2007, p295). In general, firms do not have specialised R&D departments while they only have in-house the most critical research facilities. Therefore, firms rely mainly on the local public research sector or occasionally on foreign partners for the access to advanced or more complex R&D capabilities (Bortagaray, 2007, p313). Such a low technological level of the private sector and its high reliance on external sources of knowledge and technological capabilities are not specific attributes of the Uruguayan case but reflect a frequent character of innovation systems in developing countries (Padilla-Pérez et al., 2009, p145).

The limited research and technological capabilities of private actors in developing countries suggest that public research organisations in this context may play a different role to the one played in developed nations. Studies conducted in developed countries have suggested that the benefits to firms from public research result, to a large extent, from the recruitment of university-trained personnel (Rosenberg & Nelson, 1994, p346) and the access to scientific publications as sources of new ideas and research abilities to address the solution of complex problems (Salter et al., 2000; Salter & Martin, 2001). Some STI scholars have claimed that even for developing countries the most important type of relationship between public sector research and firms is the '...recruitment of well-educated graduates' (Brundenius et al., 2009, p319). We disagree with this claim since, given the limited ability of private actors in developing countries to hire qualified graduates, public research organisations become – besides the roles referred to earlier in this paragraph – key sources of industry specific knowledge and technological capabilities that private actors are not able to develop internally (Mazzoleni & Nelson, 2007; Padilla-Pérez et al., 2009, p173; Bortagaray, 2007). Nevertheless, it has been observed that there is limited trust and a dominance of competition within the public research sub-system of some developing countries; a common picture is that researchers tend to '...work alone and perceive other groups as competitors rather than as collaborators' (Bortagaray, 2007, p274). This is undoubtedly a barrier for the exploitation of local intellectual capital through interactive learning processes, hence undermining the potential impact of local capabilities on innovation, economic growth and development (Lundvall et al., 2009b, p18). Given the patterns of technological innovation described above, pursuing a well-developed network of inter-organisational linkages for the collaborative *integration of different bodies of knowledge* (Rafols, 2007) and complementary capabilities of public research organisations becomes a salient element towards raising the capacity of the system as a whole to absorb external technological opportunities in small developing countries.

In relation to the need for strengthening the relationships among local actors referred to above, it has been claimed that a coherent *institutional framework* becomes a key system component allowing (or hindering) the development of technological capabilities as well as the exploitation of the opportunities for complementarity, innovation and economic development offered by the capabilities functionally in place throughout the whole system (Lall, 1992; Bortagaray, 2007, p354; Padilla-Pérez et al., 2009). The aggregation of actor-level technological capabilities into system-level innovation capability depends, to a large extent, on *institutions and policies* supporting the realisation of complementarities and interactive learning (Lall, 1992; Padilla-Pérez et al., 2009). In this regard, besides poor patterns of interaction among actors in the system, developing countries usually show weak formal *institutions* supporting those interactions (Padilla-Pérez et al., 2009, pp143-5). Therefore, we argue that careful attention, improvement efforts and specific scholarly studies should be targeted at *institutions, incentives and policies* that may be underpinning the excessively competitive environment and scarce trust-based relationships among public research actors referred to above, hence hindering collaborative efforts for the integration of complementary knowledge across organisational boundaries.

Another element that deserves consideration is the pervasive attention that has usually been paid by systemic studies of innovation to R&D activities in private organisations. In developed nations, firms are the main performers of R&D activities but the figures change when we consider the context of a developing country and an emerging technological field. In such a context, firms share a minority of total investments in R&D and employment of scientists (Viotti, 2002, p673; Brundenius et al., 2009), while *public research organisations* encompass most knowledge assets and R&D activities. Hence, under these circumstances public research is at the centre of technological learning processes (Viotti, 2002; Edquist, 2005). Therefore, we suggest that *in this context, the development of proper interactive and collaborative knowledge integration patterns between public R&D actors*[23] *becomes a salient determinant of the technological absorption and development abilities of the system as a whole*. Inter-organisational collaboration networks are seen here as the locus of technological absorption (Viotti, 2002) and locally adapted innovations (Powell et al., 1996).

Previous research illustrates the contrasting situations referred to above. A comparative study performed by Viotti showed that while in Korea 82% of the R&D investment was of private origin (in 1992), in Brazil, private organisations only accounted for 18% of total investments in R&D (in 1994) and employed only 5% of the scientists (Viotti, 2002, p673). These figures for Brazil have changed in the last two decades, but in 2004, public investments still accounted for 60% of total investments in R&D in this country (OECD, 2012) while the private sector employed only 26% of the scientists – in 2003[24] (Brundenius et al., 2009, p324). In the case of Uruguay, private investment accounts for only for 33% of total national investment in R&D (DICYT, 2010) while in Argentina only 23.3% of the R&D investments made in 2010 came from private sources (OECD, 2012)**.** This allows us to conclude that for developing countries with such weak private participation in R&D activities, approaches to studying emergent technological systems must pay much greater attention to the dynamics of *knowledge generation in the public domain* and to *inter-organisational interactions* and *knowledge integration processes* among public R&D organisations. Consequently this was taken into account in the methodological approach developed for this research project, by means of analysing collaborative activities between public

[23] e.g. research institutes, universities, public laboratories, etc.
[24] In comparison, private sector employment of researchers in 2003 was 12.5% in Argentina, 49% in the European Union and 80.5 % in the United States (Brundenius et al., 2009, p 324).

research groups or organisations carried out during the implementation of local R&D projects in Uruguay[25].

Under the sort of structural limitations described above and possessing limited and distributed R&D capabilities, Viotti (2002) argued that the main capability that a developing country should strive to develop is its *technological learning capacity*[26]. Such system-level capacity encompasses the ability to *absorb* and use technological knowledge and artefacts developed elsewhere and to perform *incremental improvements* on them (Viotti, 2002). Therefore, a need is suggested for additional research paying deeper attention to the availability, building and actual *exploitation of scientific and technological capabilities* throughout the whole innovation system, which are the main drivers of the technological learning capacity of the local system (Viotti, 2002; Edquist, 2005).

Proponents of the *technological innovation systems* approach are aligned with the previous argument since they focus on the *absorptive capacity* of the system more than on new technology development (Carlsson et al., 2002). As proposed by the authors, '[g]*lobal technological opportunities are practically unlimited...; the main focus is on how well the system can identify, absorb, and exploit global technological opportunities. This means, e.g. that it may be more important to raise absorptive capacity than to create new technology*' (Carlsson et al., 2002, p237). It has been suggested that the ability to learn from interacting with overseas actors or from foreign direct investments depends on a well-developed system-level absorptive capacity (Lundvall et al., 2009b, p17) while the latter relies mainly on the technological capabilities of the actors in the system and a set of institutions enabling their complementary exploitation (Bortagaray, 2007, p354). Similarly, and agreeing with propositions of Viotti (2002) regarding the relevance of technological learning (absorption and adaptation), instead of innovation *per se* in developing countries, Fuck

[25] As noted earlier, the rationale for conducting this study in Uruguay is presented in Section 3.3.

[26] The opposition between *innovation capacity* and *technological learning capacity* suggested by Viotti (2002) is contested by Lundvall et al. (2009b, p9) arguing that the initial definitions of innovation and innovation systems made by Christopher Freeman and Lundvall encompassed not only the original development of new technology but also – being in fact more important for economic growth – its diffusion, absorption and use, even when the technology was developed elsewhere.

and Bonacelli claim that *'…the large technical and economic scale required to develop new biotechnology puts developing countries in the position of being mere recipients and adapters of this technology'* (Fuck & Bonacelli, 2008, p37[27]). It is argued here that such a large scale demanded even for the adoption, adaptation and application of biotechnological techniques in *local R&D projects* results in a pervasive need in developing countries for the *coordination and integration* of the limited distributed local R&D capabilities. Therefore, the integration of local sources of knowledge through collaborative *inter-organisational R&D projects*, and the factors that may shape this process – what we refer to as *collaborative knowledge integration* – become relevant subjects of study. We argue that addressing them may well grant a better theoretical and empirical understanding of the emergence and development of a technological innovation system, representing also a relevant contribution for policy-making towards raising the system-level absorptive capacity within the context of a developing country.

To sum up, a suitable conceptual and methodological application of the *relational nature* of the innovation systems' framework becomes a valuable research approach for the study of innovation processes in developing countries (Arocena & Sutz, 2002), contributing thus to the extant literature on this field. This can also yield new knowledge and relevant lessons for both policy-making and management of agricultural science, technology and innovation. This subject matter has been recognised as a limitation of innovation system studies given that, despite their systemic or *relational intent*, the structural approach commonly used does not effectively capture the (micro-level) linkages between actors and components in the system (Senker & Van Zwanenberg, 2001; Carlsson et al., 2002; Lundvall et al., 2009b).

Similarly, taking the whole system as the unit of analysis was argued above to be a limitation of all innovation systems' perspectives (Carlsson et al., 2002). The present research contributes to this body of scholarly research through the definition of a lower level of analysis – the single public research organisation or group – but keeping the scope and boundaries of the whole *technological innovation system*. In particular,

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[27] The authors cite Bisang & Varela (2006).

the study performs an analysis of the influence of actor-[28] and system-level attributes on the extent of integration of complementary knowledge assets achieved by public R&D groups through inter-organisational arrangements, but limited to the specific boundaries of the *biotechnological innovation system* (Carlsson et al., 2002; Bergek et al., 2008) and within the national and sectoral delimitations of Uruguayan agriculture. The boundaries of each R&D group were empirically defined in our study through our survey to R&D project leaders, namely they were asked to report the whole list of members of the R&D group.

The selection of this boundary-setting criterion and level of analysis was made on the grounds that it is particularly suitable for the analysis of *emerging technological systems* in developing countries where public sector research plays a key role in the emergence or absorption of new technologies. Finally, by performing an empirical relational assessment of *collaborative knowledge integration* within the studied system, which represents a perspective that has been weakly addressed in the system literature (Carlsson et al., 2002; Lundvall et al., 2009b), this approach bridges scholarly studies in sectoral and technological innovation systems with research on inter-organisational collaboration, R&D partnerships and networks. A critical account of these latter fields of research is presented in the next section.

2.4 Inter-organisational partnerships and networks

Previous research has claimed that the rapid advances in science and technology have led to more complex forms in the organisation of research, technology development and innovation processes (Dosi, 1988; Gibbons et al., 1994; Coombs et al., 2003). The increased systemic complexity referred to above results in a dense picture of complementary capabilities, technologies and resources distributed across the system that need to be smoothly *integrated* in order to undergo a successful innovation process. This moved the locus of innovation from the single organisation to collective organisation forms that allow interactive processes between actors (Powell et al.,

[28] Individual organisation.

1996; Salles-Filho et al., 2006; Powell et al., 2012). As suggested by Powell for the emergent bio-technological innovation system, *'...the knowledge base is both complex and expanding and the sources of expertise are widely dispersed. …organisations interact more, not less, with external parties in order to access both knowledge and resources. Hence, the locus of innovation is found in networks of learning, rather than in individual firms'* (Powell, 1998, p229). Consequently, the development of inter-organisational arrangements – among others – and the access and integration of external complementary resources become increasingly important for the innovative performance of both individual organisations (Rothwell, 1977; Hagedoorn, 1993; Rosenkopf & Nerkar, 2001) and an innovation system as a whole (Carlsson et al., 2002; Lundvall, 2005; Bergek et al., 2008).

Within this context, organisations try to complement their own competences, or learn and develop new in-house capabilities through accessing and *integrating* external sources of knowledge, skills and other resources (Powell et al., 1996; Powell, 1998). The rationale for collaborative arrangements has been explored from diverse theoretical and empirical perspectives. Studies of innovation and organisational behaviour have suggested *resource and capability complementarities*[29], costs' reductions, the development of economies of scale and scope in R&D, understanding users' needs, strategic coordination, and capability building (inter-organisational learning) as the main explanations for the emergence of collaborative initiatives for improved technology development and innovation (Teece, 1992; Hagedoorn, 2002; Gonçalves do Valle et al., 2002; Salles-Filho, et al., 2006). From their perspective, organisational science and inter-organisational network studies suggest that one of the main drivers of collaborative relations is the existence of complementary *resources* between organisations in the system (Dyer & Singh, 1998, pp666-7; Gulati & Gargiulo, 1999; Gulati et al., 2011). In this context, inter-organisational collaborations enhance innovation outcomes of the organisation by allowing *resource-sharing*, the *combination of complementary skills* and access to *knowledge spillovers* (Ahuja, 2000, p427).

[29] Knowledge and capabilities seen as intangible *knowledge assets.*

Organisations that manage to access and integrate such complementary capabilities have been claimed to show better economic performance (Teece, 1986; Colombo et al., 2006). Along these lines, Johnson and Lundvall (2000, p15) suggest that '[a]s the speed of change accelerates, it becomes more important...to get access to new sources of knowledge (through recruitment, internal learning and networking)'. Moreover, analysing the trend towards 'a more distributed structure of innovation', Acha and Cusmano (2005) argued that '[t]he increasing importance of technological partnerships is...related to [an]...increasing competence specialization and increasing systemic complexity, the latter being described as increasing dependence on complementary sources of knowledge and technological advancements' (Acha & Cusmano, 2005, p3). Therefore, the innovation process requires new forms of organisation that frequently involve the development of effective collaborative relations to access external knowledge (Coombs & Metcalfe, 1998; Johnson & Lundvall, 2000, p16; Hall, 2006).

Another (smaller) body of scholarly research has studied *collaboration within public research systems*. These contributions are of particular interest for this research since, as was argued earlier, for emergent technological systems in developing countries, public research organisations play a key role in technological development (Padilla-Pérez et al., 2009, p145). This body of research explores the rationales and motivations followed by public-sector researchers when taking part in collaborative initiatives (Heinze & Kuhlmann, 2008); the institutional barriers to collaboration (Laudel & Gläser, 1998); the relation between collaboration and academic performance (Van Rijnsoever et al., 2008; Van Rijnsoever & Hessels, 2011); the nature, coordination and outcomes of those collaborations (Cummings & Kiesler, 2005); and the patterns of rewards to the collaborators (Katz & Martin, 1997; Laudel, 2001; Laudel 2002). The collaborative rationales of researchers observed by these studies include, amongst others, the realisation of organisational complementarities and the expansion of individual or organisational research capabilities (Heinze & Kuhlmann, 2008). A more detailed description of such rationales is presented in Table 2.1 below. As can be observed from the Table, most drivers of collaboration between public R&D organisations involve some form of integration of knowledge or R&D capabilities as a means to adapt to the increasing complexity of the organisation of research and innovation processes referred to above (Gibbons et al., 1994; Coombs et al., 2003). Nevertheless, very few studies have explored the factors influencing the extent to which collaborations between public research organisations actually integrate complementary fields of knowledge and research capabilities (Rafols, 2007; Rafols & Meyer, 2007).

Table 2.1: Rationales for collaboration between public-sector scientists or research groups

General aim of collaboration	Specific needs pursued
Realisation of organisational complementarities in order to expand research capacity	Need for complementary knowledge within or across scientific fields.
	Access to facilities, equipment, instrumentation and creative methods.
	Access to research topics, questions and creative theoretical ideas for basic or applied science.
	Complementarity between basic and applied research.
Improve current research capacity	Keep focus on specific research fields (specialisation).
	Access to new research questions.
	Acquire new skills, methodological know-how and instrumental techniques.
Obtain resources to conduct research activities	Build consortia to compete for external funds.
	Access to students and junior researchers.
	Capture research funding from firms.

Source: elaborated by the author based on Heinze and Kuhlmann (2008, pp893-4), Laudel (2001 and 2002), and Katz and Martin (1997).

In order to narrow down the scope of the research problem addressed by this research, it draws on previous studies which suggest that the need for knowledge integration among actors described above is even more prevalent when we deal with emerging knowledge-intensive technological fields (Colombo et al., 2006; Heinze & Kuhlmann, 2008; Powell et al., 2012) or when looking at developing countries (Arocena & Sutz, 2002; Lundvall et al., 2002; Chaminade et al., 2009). Analysing *knowledge integration* processes in emergent technological fields, researchers have observed that the development and application of new technologies goes beyond traditional *discipline or sectoral boundaries* (Rafols & Meyer, 2010). Large companies and organisations may be able to develop internally a complex set of knowledge assets allowing them to apply emergent technologies across diverse complementary industrial sectors (Janssen & Braunchsweig, 2003, p38[30]). Nevertheless, when we consider how smaller organisations deal with this context of intricate complementarities, they tend mostly to form inter-organisational collaborative arrangements of different sorts, which have been shown to be closely associated with the innovation performance of this sort of organisations (Niosi, 2003; Colombo et al., 2006).

With regard to small developing countries, the scarcity of resources and skills makes such countries particularly reliant on well-established complementarities between actors and components of the system and, in a similar way, on a coherent set of institutions and incentives to organisations and individuals, in order to enable the realisation and exploitation of such complementarities (Lall, 1992; Bortagaray, 2007, pp350 & 354; Padilla-Pérez et al., 2009). Nevertheless, the weak systemic character of innovation processes referred to in the previous section (Arocena & Sutz, 2002) may suggest that for developing countries, instead of considering collaboration *networks* as a given structural component of the innovation system – as is the case in most studies in developed countries – the actual establishment of effective collaborative relations should be seen as an intermediate output of the system that should be pursued. This does not pretend to neglect the value of networks in this context but casts doubt on what should be the focus of empirical studies. In fact, the present study maintains that instead of studying the structure of networks and its relation with actors' performance, which has been broadly studied by scholars of this field (Ahuja, 2000; Gulati & Gargiulo, 1999; Powell et al., 1996; Zaheer et al., 2010), for developing countries the focus should be on the main forces promoting or hindering: (i) the development of collaboration networks, and (ii) the extent to which these collaborative linkages and networks are able to integrate complementary sources of knowledge and capabilities (as an indicator of the quality of the collaborations and their potential contribution to local innovation). This implies that looking at the establishment of relationships is not enough to explain innovation outcomes; further understanding is also required on the antecedents of the *quality* of those relationships

[30] The authors refer to large life science companies deploying interdependent capabilities on 'pharmacology, agriculture, nutrition, medicine, etc.' (Janssen & Braunchsweig, 2003, p38).

in terms of the extent to which they actually exploit potential complementarities (Gulati & Gargiulo, 1999; Grant & Baden-Fuller, 2004; Colombo et al., 2006) and hence their potential contribution to the solution of local technological problems (Lundvall et al., 2009b, p19).

This is supported by Arocena and Sutz (2002) who recognise that one of the problems faced by Latin American countries is their inability to use the local knowledge base as a source of economic growth. To address this inability, the authors emphasise the need to promote the development of *'interactive learning spaces'* defined as '...more or less stable situations in which some actors have opportunities to strengthen their capacities to learn, while interacting in the search for solutions to given problems' (Arocena & Sutz, 2002, p11). This argument supports the claim of a need for differential research approaches to the singular context of less developed countries. Besides avoiding the static structural perspective usually applied by innovation-system studies, an actually relational empirical approach should explore particularly how *relationships* among actors are developed and to what extent these collaborations *integrate complementary sources of knowledge and capabilities* distributed throughout the system. Effective collaborations are understood as those integrating highly complementary knowledge and capabilities (Teece, 1986; Grant & Baden-Fuller, 2004; Colombo et al., 2006), which are assumed here to allow a proper development of the absorptive and technological learning capacity of the entire system (Viotti, 2002), and to foster the solution of societal problems (Van den Besselaar & Heimeriks, 2001), hence enhancing the innovation potential of the system as a whole (Carlsson & Stankiewicz, 1991; Lall, 1992; Cimoli et al., 2009).

The first part of this section has discussed the increasing relevance of collaborative forms for the organisation of the innovation process, and how this is particularly emphasised in the context of emerging technological fields and developing countries. There is a large body of research that studies inter-organisational collaborations from a resource-complementarity perspective (Teece, 1986; Grant & Baden-Fuller, 2004; Colombo et al., 2006; Zhang et al, 2007). Moreover, a related field of scholarly research has studied inter-organisational collaborations from a broader network perspective (Ahuja, 2000; Powell et al., 1996; Zaheer et al., 2010).

Scholarly studies of inter-organisational collaboration and networks have addressed, to some extent, the sort of *relational perspectives* that, as was claimed in Section 2.3.1, has been scarcely explored in the innovation systems literature. Research on inter-organisational partnerships or alliances has largely explored the antecedents, working and outcomes of collaborations between firms (Gulati, 1998; Gulati & Gargiulo, 1999; Colombo et al., 2006; Luo et al., 2009). Lawton Smith and Dickson have examined critical factors shaping the success of inter-firm collaborations, with a particular focus on how the geographical context and common cultural content of the inter-organisational interaction influence the collaborations' outcomes (Lawton Smith & Dickson, 2003). The authors identified a number of critical factors such as: compatibility and common aims among partners; control over the joint efforts; commitment and clear expectations; contractual arrangements; communication; trust development; power asymmetries; contingencies; potential risks; and differences in partners' organisational and institutional context (Lawton Smith & Dickson, 2003). With regards to the geographical and cultural context, the same scholars suggested the relevance of cultural and geographical proximity as well as national and local regulatory frameworks, conventions and other institutions (Lawton Smith & Dickson, 2003). Such formal and informal institutions underlie organisational rules, routines, practices, attitudes, incentives to cooperate, business cultures, relational capability, communication, flexibility, expectations, agreements and mutual engagement[31]; consequently they affect the extent of technological learning from cooperation (Lawton Smith & Dickson, 2003). The authors also argued that a common cultural content facilitate working and learning among partners; this encompasses common language, common technical knowledge, common organisational knowledge, common market knowledge, and understanding of partners' regulatory environment (Lawton Smith & Dickson, 2003).

Other authors have examined how specific organisational attributes affect the ability of an organisation to form collaborative relations with other actors and to obtain

[31] Among all these critical factors, the author found communication to be the most important one explaining the success of collaboration despite it is not a sufficient condition to achieve the desired outcomes (Lawton Smith & Dickson, 2003).

benefits from them (Dyer & Singh, 1998; Powell, 1998; Lorenzoni & Lipparini, 1999; Colombo et al., 2006). Nevertheless, the usual empirical approach to study collaborations does not provide an overall view of the innovation dynamics in the whole system (Dyer & Singh, 1998; Corley et al., 2006). Moreover, researchers have claimed that the determinants of inter-firm alliances aimed at the commercial exploitation of an innovation (i.e. Teece's thesis on 'combination of specialized complementary assets') are clearly different from the factors shaping partnerships aimed at integrating capabilities to perform explorative R&D projects (Colombo et al., 2006). This justifies the value of performing a specific study on the determinants of knowledge integration through the latter type of collaborative relations, namely R&D partnerships, in the context of emergent technological innovation systems.

From their related strand, studies of inter-organisational networks may, in some cases, encompass most actors in a sectoral or technological innovation system (Giuliani & Arza, 2009; Powell et al., 1996). This vein of research has made sound contributions to understand what drives the embeddedness of organisations within networks, and how the *structural properties* of the network affect an organisation's outcomes and performance (Gulati, 1998; Gulati et al., 2011), and the formation of further collaborative relations (Gulati & Gargiulo, 1999; Ahuja, 2000; Hagedoorn et al., 2006). More recently, increased emphasis is being placed in studying the dynamics of network evolution over time (Powell et al., 2005; Zaheer et al., 2010; Ahuja et al., 2012).

Nevertheless, the narrow focus of network studies on how direct linkages or the structure of networks influence an organisation's performance has largely overlooked the actual type and value of the resources accessed by an organisation through inter-organisational networks, which are the final determinants of how a network influences the organisation's performance (Gulati et al., 2011, p209). Consequently, some authors have suggested that further research should move from the predominant focus on *structural network properties* towards greater attention to the *quality of the links* of an organisation in terms of the extent to which they '...enable the organisation to connect with distant and diverse partners... [and what is] the potential value of the network resources available to the organisation'; they also claimed for additional investigation on the precursor factors that drive the actual exploitation of valuable complementary resources through collaborative links within a network (Gulati et al., 2011, pp208 & 221). Similarly, studies of knowledge integration among scientific disciplines have argued that such a focus of the network literature on *social-interaction* and the network structure has mostly overlooked the *cognitive dimension of actors' interactions*, namely the actual flows and integration of different bodies of knowledge, R&D capabilities and technologies among actors as a result of their interaction efforts (Wagner et al., 2011). In other words, besides the structure of social interaction, further understanding is required on the patterns of *cognitive relatedness* among elements within a network (Leydesdorff & Rafols, 2011; Wagner et al., 2011). The present research intends to contribute to this literature empirically, combining both the *cognitive* and *social integration dimensions* described above, by means of exploring the extent of knowledge-asset integration (the cognitive side) accomplished through the implementation of *collaborative R&D projects* jointly conducted by public research organisations (the social integration side). We discuss next why this form of collaboration is relevant for the purposes of this study.

It is worth recalling at this point some definitions of the forms of collaboration addressed in this research. An *alliance* has been defined generically as a mode of *'...voluntary cooperation in which organizations combine resources to cope with the uncertainty created by environmental forces beyond their direct control'* (Gulati & Gargiulo, 1999). Given we are exploring an emergent technological innovation system, among the diverse forms and objectives that these inter-organisational arrangements may pursue, the present study pays particular attention to *R&D partnerships*, namely those collaborations aimed at *generating new knowledge* for the development of new or improved products and processes. Formal or informal *R&D partnerships* have been defined as those arrangements *'where two or more … independent economic agents and organizations, share some of their R&D activities'* (Hagedoorn, 2002, pp477-8). One drawback of extant empirical studies on collaborative R&D arrangements is that a rather large proportion of them have focused on a single form of governance of the collaboration, namely on research joint ventures between firms, that usually lasts a long period of time (Colombo et al., 2006). But since in developing countries, as well as in emergent technological systems most collaborations have lower degrees of formalisation and laxer structures (Bortagaray, 2007, p276; Lundvall et al., 2009b, p10), additional research is required on the determinants of *complementary knowledge integration* in *short-term collaborative R&D projects* that play a relevant role in the consolidation of these nascent technological systems (Geels & Raven, 2006).

A similar sort of bias on the types of collaborations studied is also reflected in studies in developing-country agriculture. With a rather narrow focus, many studies on agricultural R&D collaborations have paid attention mainly to partnerships developed by multinational *life-science companies*, where the global company usually makes a significant contribution in terms of advanced scientific capabilities (Hall, 2006). Nevertheless, national collaborative interactions (their rationales and determinants) that play a key role in developing local absorption, learning and technology development capacity (Viotti, 2002; Lundvall et al., 2009b) have received relatively little attention in these studies. Such local collaborations may be aimed at overcoming local problems such as developing locally adapted crops, farm management systems, quality improvement, storage, processing, transportation or attainment of international standards in order to gain access to new markets (Hall, 2006).

In addition, research on emergent technologies in developed countries has paid much attention to the role played by *inter-firm* collaborative arrangements (Pisano, 1991; Hagedoorn et al., 2006; Nooteboom et al., 2007) or *university-industry linkages* on the innovation process (Arundel & Geuna, 2004; Lam, 2005; Senker & Van Zwanenberg, 2001). But for emerging technologies in developing countries, given the weak R&D capabilities of the private sector, most knowledge development and adaptation activities are performed by public R&D organisations (Viotti, 2002; Padilla-Pérez et al., 2009; Brundenius et al., 2009). This is also the case for the agri-biotechnology innovation system in Uruguay, where '[p]rivate sources for funding innovation projects in general and biotechnological developments in particular are totally missing both in the private and public sectors' (Bortagaray, 2007, p264). In these developing-country contexts, it is argued here that the dynamics of collaboration and complementarity of capabilities between public research actors (public-public collaboration) becomes a key process enabling the exploitation of the scarce and dispersed *public-sector knowledge capabilities,* and the development of system-level absorptive capacity (Viotti, 2002).

We now move the discussion to the empirical arena, particularly to the level at which *collaborative knowledge integration* should be assessed for the purpose of this research. It is worth recalling at this point the definition for the concept of *collaborative knowledge integration* that we presented in section 2.2 (drawing on Rafols & Meyer, 2010, p265) as a research process '...that integrates concepts or theories, tools or techniques, information or data from different bodies of knowledge' through any form of collaborative research activity between two or more research groups or organisations. With regards to the *form of collaborative research activity*, the literature on strategic niche management places particular emphasis on local '...*experimental projects* [that] provide space for interactions between actors and the *building of social networks*[,]...[and] provide space for *learning and...articulation of expectations and visions*' (Geels & Raven, 2006, p377). The same authors conceptually distinguish a '...*local network* [that] *consists of actors who work on the* [experimental] *project, and develop and align heterogeneous bits and pieces on location'* within the context and support conditions provided by a *'global network'* of actors involved in the emergent technological field (Geels & Raven, 2006, pp377-8). The development and alignment of 'heterogeneous bits' referred to by the authors is understood here as the *combination of complementary capabilities and resources* between local actors in the emergent system.

It is interesting to note the relevance placed by the research cited in the previous paragraph (Geels & Raven, 2006) on local actors and their collaborative experimental projects as key spaces for the further development of the emergent system, provided they effectively 'align heterogeneous bits and pieces' of the system (Geels & Raven, 2006, pp377-8). Drawing on this contribution, from a methodological point of view, it can be claimed that in-depth studies of collaborative inter-organisational arrangements and knowledge integration taking place during the implementation of *'local experimental projects'* represent a valuable research approach for understanding the drivers of the emergence of technological systems in specific geographically-bounded contexts. Following an empirical approach of this sort represents – as was noted above – a contribution to studies of inter-organisational collaboration that have focused mainly on formal collaborations between firms or between firms and universities, while paying limited attention to informal R&D collaborations between public organisations. Studying knowledge integration in local collaborative R&D projects also contributes empirically to studies of interdisciplinary knowledge integration[32], which have been mainly based on bibliographic data within specific knowledge or technological boundaries but paying less attention to geographically localised studies (Wagner et al., 2011).

Up to now, our review and discussion in this section has addressed changes in the organisation of research and innovation, particularly how these processes are becoming increasingly complex, making them more reliant on the establishment of inter-organisational collaborations and access to complementary knowledge and capabilities (Carlsson et al., 2002; Coombs et al., 2003; Acha & Cusmano, 2005). We argued also that this reliance on the *collaborative integration of complementary capabilities* is more emphasised in the context of emergent technological fields and developing countries (Powell et al., 2012; Powell et al., 2012). While studies of inter-organisational partnerships have mainly explored the determinants, workings and outcomes of these collaboration forms (Hagedoorn et al., 2006), network studies have focused primarily on the relations among network structure, organisational performance and network evolution (Ahuja, 2000), but both strands of research have paid limited attention to how and to what extent the collaborating actors *integrate complementary knowledge and technological capabilities* (Wagner et al., 2011). Moreover, we have seen that little consideration has been given to collaboration and knowledge integration between public research groups and organisations that are the main sources of technological knowledge in developing countries (Padilla-Pérez et al., 2009). Finally, we supported the empirical relevance of studying collaborative knowledge integration at the level of local – explorative – R&D projects (Geels & Raven, 2006). Based on these arguments, we would argue that the need to study local R&D collaborations between public research organisations, as well as the degree to which these inter-organisational relations integrate *complementary knowledge and capabilities,'* is particularly salient in the context of emergent technologies in

[32] This suggested contribution is addressed in more detail in Section 2.6.

developing countries. Given the particular attention we are placing on the *integration of complementary knowledge assets*, we review in the next section, academic research addressing the theoretical basis of *complementarity* between organisations' knowledge and technological resources (Pfeffer, 1972; Pfeffer & Nowak, 1976; Pfeffer & Salancik, 1978).

2.5 Complementarity between organisations

The importance of adopting an overtly relational approach to systems' thinking and empirical assessment has been emphasised in previous sections. This need for further research arises from the fact that, despite the described trend towards increased collaboration, it cannot be assumed that there is a straightforward relation between inter-organisational collaboration and improved innovation performance in the system. In other words, from a policy-making perspective this is not simply a matter of promoting any sort of collaboration but instead, quality attributes of the collaborative relation play a crucial role in how the joint effort influences the outcomes of R&D and innovation processes. In fact, *collaborative endeavours are assumed to have a positive impact on innovation performance only if they are the result of potential opportunities for complementarity of resources and capabilities* between the partnering organisations (Grant & Baden-Fuller, 2004; Carvalho et al., 2005, p36[33]; Hall, 2006; Colombo et al., 2006). That is to say, for the purpose of this study we assume this positive relation between collaborative knowledge integration and innovation outcomes, while focusing our questions and analysis on the factors shaping the extent that an organisation's collaborations integrate complementary knowledge assets. Therefore, a relational approach to studying emergent technological systems should empirically explore the extent or *degree of complementarity* among R&D knowledge assets and capabilities of the collaborating actors, as well as the factors that may be shaping the development of collaborative linkages that actually exploit high degrees of complementarity between the partners' knowledge assets.

[33] The authors refer to Prahalad and Hamel, 1998; Williamson, 1985; Teece, 1986.

Therefore, the definition and assessment method of *complementarity* between actors becomes a central issue for the proposed conceptual and empirical approach. *Complementarity* of resources and capabilities may be defined as the existence of '*distinctive resources of alliance partners that collectively generate greater…*[innovative outputs]…*than the sum of those obtained from the individual endowments of each partner'* (Dyer & Singh, 1998, pp666-7). It is worth emphasising here the *distinctive* character that the resources contributed by each partner to the partnership should have. More precisely, Gulati and Gargiulo argue that *'*[c]*omplementarity between two organizations can arise when (a) there is a gap between the specific capabilities controlled by each organization and those they need to pursue their strategy and (b) this gap can be filled at least partially by accessing the capabilities controlled by the other organization'* (Gulati & Gargiulo, 1999, p1460-1).

Milgrom and Roberts draw on the theories and mathematics of *complementarity* and *supermodularity* in order to reach a better theoretical understanding of the relationship – and the notions of *fit* and *synergies* – among an organisation's strategy, structure and managerial processes (Milgrom & Roberts, 1995, p180). These authors define that activities are *complementary* '...if doing (more of) any one of them increases the returns to doing (more of) the others' (Milgrom & Roberts, 1995, p181). This definition encompasses the notion of syenrgies, namely that 'the whole is more than the sum of its parts' (Milgrom & Roberts, 1995, p184).

Relaying on Milgrom and Roberts (1995), a simple mathematical definition of complementarity between a firm's activities was provided by Cassiman and Veugelers (2006):

> 'Suppose that there are two activities, A_1 and A_2. Each activity can be performed by the firm ($A_i = 1$) or not ($A_i = 0$) and $i \in \{1,2\}$. The function $\Pi(A_1, A_2)$ is *supermodular*, and A_1 and A_2 are *complements* only if
>
> $$\Pi(1, 1) - \Pi(0, 1) \geq \Pi(1, 0) - \Pi(0, 0)$$

> i.e., adding an activity while the other activity is already being performed has a higher incremental effect on performance (Π) than adding the activity in isolation' (Cassiman & Veugelers, 2006, p70).

The notion of *complementarity* between organisations as a rationale for inter-organisational collaboration can be traced back to the work of Teece (1986), whose focus was on how firms that are able to develop a novel technology should rely on complementary specialised capabilities such as marketing or after-sale services in order to derive market profits from such new technologies (Teece, 1986, p288; Colombo et al., 2006). Nevertheless, advocates of this approach, to some extent, assume that a single organisation alone ('the innovator') is able to develop and produce such novel technology (Teece, 1986, p286; Colombo et al., 2006, p1167). Therefore, they leave rather unexplored the complex process required to develop the *novel technology* that also relies on other sorts of complementarities, particularly between diverse – and usually distributed – scientific and technological research capabilities (Luo et al., 2009), increasingly demanding also, as was argued before, collaborative organisation forms of the technological R&D processes.

Exemplifying this relatively narrow perspective on how *complementarity* has been conceptualised, empirical research that follows Teece's approach usually uses rough classifications of capabilities aggregated into rather broad categories (e.g. discriminating only between those of a *technological* and *commercial* nature), while the *complementarity* between those general categories is somehow approximately measured (Fagerberg, 2005). Nevertheless, deeper disaggregation within those general categories is overlooked. Additionally, the availability of complementary – commercial – capabilities is not directly assessed by these studies; instead firm size is measured as a proxy, and it is simply assumed that larger firms will have such complementary commercial capabilities (Colombo et al., 2006, p1192). As a significant limitation, the authors of this study recognised that: *'...a more direct assessment of the explanatory power of the "combination of specialized complementary assets" model of alliance formation would require the development of more accurate indicators of the assets possessed by firms'* (Colombo et al., 2006, p1193). This conclusion points to a clear need for further research that reaches lower levels of disaggregation among types of capabilities compared to those used in the studies mentioned above, in order to allow a deeper exploration of complementarities, particularly those among sub-categories of technological and research capabilities.

Colombo et al. (2006) studied the drivers and barriers of the formation of two types of inter-organisational collaborative relations, namely, commercial alliances and 'explorative technological alliances' (Colombo et al., 2006, p1166). For the formation of commercial alliances, the authors found an 'inverted-U-shaped' relationship with organisational size (as proxy of specialised commercial assets). In other words, smaller organisations are less able to deal with the transaction costs of searching for commercial alliance opportunities and operating a collaborative endeavour, while bigger firms tend to form more commercial alliances up to a certain threshold. After such a threshold, even larger organisations tend to form fewer commercial alliances, given that they opt for using internal – commercial – capabilities for their innovation processes (Colombo et al., 2006). So, the existence of complementarity is narrowly observed here when an organisation has a 'complementary' capability to commercialise a given new technology.

But what about the R&D process pursued to develop such a technology and the access to external complementary resources or capabilities that was required during that process? Due to the simplistic and narrow way that the study referred to above measured *complementarity* (based on aggregated categories of capabilities related to value chain stages such as technological R&D, testing, manufacturing, and commercial capabilities), the authors did not find significant effects of *complementarity* of capabilities in the development of alliances aimed at performing *joint exploratory research activities* (Colombo et al., 2006, p1192). When trying to explain collaborations aimed at undertaking *collaborative research and technology development* (R&D), instead of a U-shape, the authors found a linear relationship between firm size and the formation of R&D alliances (Colombo et al., 2006). The study concluded that in-house availability of *complementary commercial capabilities* does not explain the formation of *exploratory R&D partnerships*. It can be claimed from the previous argument that the widely used broad-level conceptualisation of *commercial complementary assets* proposed by Teece (1986) has no explanatory power with regard to the formation of *exploratory R&D partnerships* and hence that a deeper disaggregation of scientific and technological assets is required in order to better explore factors shaping the integration of complementary knowledge assets during exploratory collaborative R&D activities (Colombo et al., 2006).

In the authors' words, their *'...findings seem to indicate that the lack of specialized commercial assets from which smaller* [firms]...*often suffer generates no inducement towards the establishment of explorative technological alliances. So they cast doubts on whether the "combination of specialized complementary assets" model has any explanatory power of the formation of this type of alliance'* (Colombo et al., 2006, p1192). In other words, Teece's approach focused on the combination of 'specialised complementary assets' (Teece, 1986, p295) overlooks the inherent complexities of technological R&D capabilities that have a technology-specific character, and (as argued here) also determine R&D complementarities between organisations in the system. The assertions presented above point to the need for methodological approaches that enable a clearer identification of the knowledge assets and research capabilities available in different organisations of the technological system. On the basis of such improved capability identification, better *measures of complementarity* (beyond the simplistic division into technological and commercial capabilities) should be possible. We address, subsequently, some methodological implications from the discussion presented in the two preceding paragraphs.

The relational methodological approach developed for this research intends to address the suggested need for lower levels of disaggregation of complementary knowledge assets for the empirical assessment of collaborative arrangements aimed at performing exploratory research in emergent fields. In particular, we developed a specific method for this study, meant to assess the knowledge assets controlled or available in each organisation and to produce quantitative relational indictors of the degree of knowledge integration accomplished through local collaborative R&D projects. We subsequently explored how organisational- and system-level attributes shape the extent of scientific and technological complementarity among actors' knowledge assets that is actually exploited through collaborative R&D arrangements. The underlying assumption that we make here, drawing on the relation between complementarity (measured as cognitive distance) and partners' innovation performance found by Nooteboom et al. (2007)[34] is that organisations that tend to collaborate with partners that have (on average) rather similar knowledge bases and R&D capabilities (thus achieving low levels of *collaborative-knowledge integration*) are assumed to attain lower levels of technological learning and innovation outcomes (Nooteboom et al., 2007). In other words, it is assumed for the purpose of this research that these organisations are not exploiting opportunities to collaborate with other more distant (complementary) actors of the system, hence lessening the extent of knowledge integration, the performance of the individual organisation (Nooteboom et al., 2007) and of the system as a whole (Carlsson & Stankiewicz, 1991, p94). Seen from the other side, these organisations can be interpreted as being rather closed or having redundant collaborative relations (Burt, 1992), not allowing complementary organisations to access their knowledge base and capabilities, thereby hindering the exploitation of opportunities for more innovative combinations of distant complementary knowledge assets (Rosenkopf & Nerkar, 2001).

Nooteboom et al. (2007, p1017, 1019) assessed the heterogeneity of resources of collaborating actors through their concept and empirical measure of *'cognitive distance'* between an organisation and all its partners in terms of their *technological knowledge*. As represented in Figure 2.2, the authors found an inverted-U shaped relationship between cognitive distance and innovation performance. In their own words:

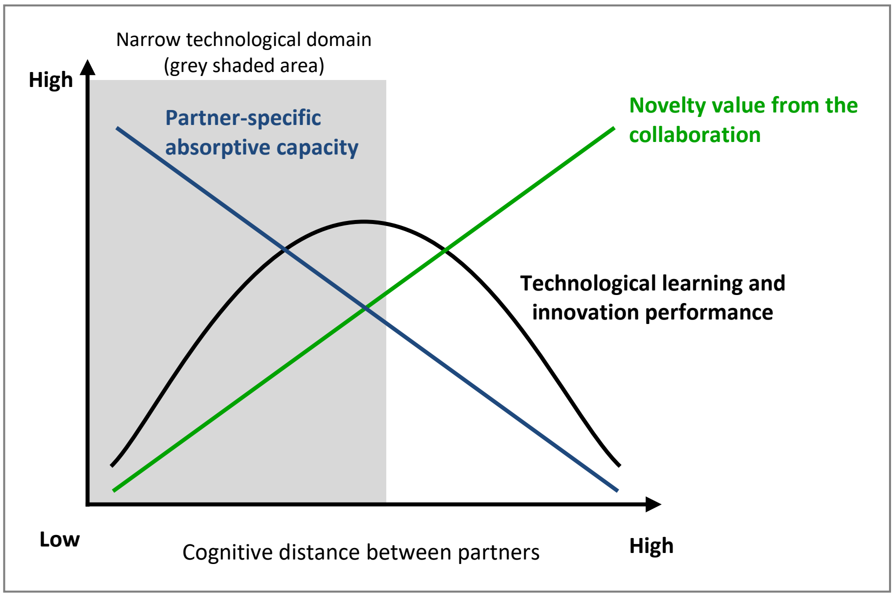
> 'In [the] first instance, as cognitive distance increases, it has a positive effect on learning by interaction. ... [C]ognitive distance yields opportunities for novel combinations of complementary resources. However, at a certain point, cognitive distance becomes so large as to preclude sufficient mutual understanding needed to utilize those opportunities. Of course, a certain mutual understanding is needed for collaboration ... However, too much familiarity may take out the innovative steam from collaboration. The challenge then is to find partners at sufficient cognitive distance to tell something new,

[34] Hage and Hollingsworth (2000) also observed this association pattern.

> but not so distant as to preclude mutual understanding' (Nooteboom et al., 2007, p1017).

As claimed by Nooteboom et al. and represented in Figure 2.2, greater cognitive distance between an organisation and its partners (that is, distance in terms of technological knowledge) results in 'an opportunity as well as a potential problem'; namely it increases the 'novelty value' of collaborations but decreases the 'partner-specific absorptive capacity' (Dyer & Singh, 1998, p665) of the organisation (Nooteboom et al., 2007, p1019). By focusing on the notion of *distance*, the authors intend to note the contrast between their approach compared to studies that have stressed only the negative effects of *cognitive distance* on absorptive capacity (Nooteboom et al., 2007); such studies (Mowery et al., 1996; Mowery et al., 1998) over-emphasise the value of homogeneity or *knowledge similarity* between partners, but neglect the negative effect of homogeneity on the novelty value of the collaboration (Nooteboom et al., 2007).

Figure 2.2: Cognitive-distance between partners and innovation performance



Source: adapted by the author drawing on Nooteboom et al. (2007, Fig. 1, p1018)

Based on the argument above, we suggest that we should expect an inverted-U shaped relation between cognitive distance and innovation as represented in the figure above, when we study collaborations encompassing technological fields with broad and diverse knowledge bases. Nevertheless, since our study focuses on a very specific technological system (agri-biotechnology), we can assume that extremely large knowledge distances between organisations that could hinder innovation should not be expected in our case. Therefore, we are in the position to assume that the cognitive distance between collaborating organisations and its likely impact on innovation will be mostly placed in the grey-shaded left half of the graph (Fig. 2.2 above), namely that the extent of common knowledge between actors is sufficient to allow mutual learning and effective collaborative efforts for research and technology development. We do not assess innovation performance in this study but for the purpose of interpreting our results we assume that the cognitive distances between collaborating organisations and their expected relation to innovation vary within the left half of the figure above. That is to say that for our technologically bounded set of actors of the agri-biotechnology system in Uruguay, we assume that the greater the technological cognitive distance between partner organisations or groups, the higher the expected innovation outcomes from their collaborative R&D effort.

Having discussed the relation of inter-partner cognitive distance and innovation performance, we should emphasise now that the existence of highly complementary resources in two organisations – and hence a *potential synergy* between them – is not a sufficient driving force for their actual exploitation through a collaborative endeavour (Gulati & Gargiulo, 1999, p1444). Despite the existence of such a *potential synergy* between two organisations, diverse organisational factors and attributes of the technological system may hinder the collaborative integration of those complementary knowledge assets. Therefore, the most relevant factors that may be shaping the extent of knowledge-asset integration through R&D collaboration are reviewed and discussed in section 2.7 below. Using a combined qualitative and quantitative methodological approach (described in Chapter 3), the behaviour of these forces has been explored in relation to the degree of knowledge integration accomplished through collaborative projects undertaken by public research organisations within the boundaries of the agri-biotechnology innovation system in Uruguay.

We should now turn our attention to the empirical measurement of complementarity. A first concern here is the need to define how the *extent of integration of complementary knowledge* between collaborating organisations is to be assessed. The need for lower levels of disaggregation of the knowledge assets and R&D capabilities controlled by the actors of the system to be assessed was set out above. This represents a challenge for our empirical methodology, requiring the development of fine-grained classifications of the types of R&D capabilities or knowledge assets available in each organisation. In relation to this, it has been claimed that '[o]*rganizational...capabilities...are multifaceted and ambiguous; assessing them across a large number of organizations poses a formidable measurement problem. In addition, an index of complementarity for all possible pairs of organizations requires measuring the extent to which the capabilities of one organization can "complement" the capabilities of every other organization in the industry…'* (Gulati & Gargiulo, 1999, p1460-1). The multidimensional character of capabilities referred to above suggests the need to identify the relevant dimensions to be considered for the assessment of capabilities in public research organisations within the context of an emergent technological system.

In this regard, studies of interdisciplinary research '...propose that the need for a broad set of instrumentalities is one of the main drivers of... links [and integration] between research subfields' (Rafols & Meyer, 2007, p646). Following Derek de Solla Price (Price, 1984, p13), the concept of *'instrumentality'* or *'research technologies'* is used by these authors to refer to the methods, materials and instruments required for research activities (Rafols & Meyer, 2007, p646). Similarly, Leydesdorff and Rafols found that collaboration networks play a relevant role in the diffusion of these 'research technologies' or 'instrumentalities' (Leydesdorff & Rafols, 2011, pp847, 850). Taking into account this suggested relevance that *research-technologies* have in explaining collaboration and knowledge integration, we took the concept as one of the dimensions to assess knowledge assets for the present research, but we refer to it hereinafter with the term *'R&D capabilities'*[35]. The second dimension chosen, on the basis of the vast body of research on knowledge integration across disciplines, were precisely the *disciplines* encompassed by the researchers in each organisation or research group. These methodological implications deserve deeper exploration. Therefore, in the next section we review scholarly literature on interdisciplinary research in order to gain empirical and methodological insights into the assessment of knowledge integration across disciplinary, technological and organisational boundaries.

2.6 The process of knowledge integration and R&D collaboration in emergent systems

2.6.1 Assessing collaborative knowledge integration

It has been argued in this chapter that the intended special attention on the *interactive dynamics* and *relational attributes* of the innovation process has not been the focus of most previous studies of innovation systems. Instead, they have been dominated by static structural assessments that are less able to capture the complexity of relations between actors at lower levels of aggregation (Carlsson et al., 2002, p236). Additionally, it was argued that for the study of emergent technologies in developing countries, particular attention should be paid to the collaborative interactions between public research organisations and to the integration of complementary knowledge assets realised through such collaborations. These arguments led us to review the work of scholars who have been studying *interdisciplinary research* processes and outcomes, since this scholarly community has developed sound empirical and methodological approaches for the assessment of knowledge integration. In particular, they have constructed robust relational indicators of the linkages or commonalities between knowledge fields (Rafols & Meyer, 2007; Porter & Rafols, 2009), organisations (Boyack, 2009), authors (Rafols & Meyer, 2010) or other

[35] The classification system developed for this study to assess knowledge assets is presented in Chapter 5.

relevant units of analysis (Wagner et al., 2011). Hence, our aim has been to gain insights from this field in order to assemble a relational enquiry approach for our research – something that, as noted, has been somewhat missing in previous studies on innovation systems.

Scholars involved in the study of interdisciplinary research processes have come to the rather general understanding that interdisciplinarity involves essentially a process of *knowledge integration* (Rafols & Meyer, 2010; Leydesdorff & Rafols, 2011; Wagner et al., 2011[36]). They define interdisciplinarity and consequently *knowledge integration '...as a mode of research that integrates concepts or theories, tools or techniques, information or data from different bodies of knowledge'* (Rafols & Meyer, 2010, p265). Knowledge integration may be accomplished through different types of processes that go from a basically individual cognitive process where different bodies of knowledge are integrated within a researcher's mind (not involving any sort of collaboration - e.g. Wagner et al., 2011, p16) to a highly collaborative integration process that involves deep interaction among researchers from two or more groups or laboratories (Rafols, 2007, p403). Since in this research we are interested in the study of the latter mode of knowledge integration, namely the one that takes place through R&D collaboration, we adapt the definition of Rafols & Meyer (2010, p265) and define the concept of *collaborative knowledge integration*[37] as:

> a *process '...of research that integrates concepts or theories, tools or techniques, information or data from different bodies of knowledge' through any form of collaborative research activity between two or more research groups or laboratories*[38].

This literature places particular emphasis on the character of knowledge integration as a *process* and on its cognitive nature, independently of whether it is individual or collective. Therefore, in an effort to capture knowledge integration at the actual

[36] Other relevant references in this strand of research include Rafols, 2007; Rafols & Meyer, 2007; Leydesdorff & Schank, 2008; Boyack, 2009; Porter & Rafols, 2009; Rafols et al., 2010.

[37] This definition was provided in advance, in Section 2.2.

[38] The segment within quotation marks in this definitions is a textual citation of Rafols & Meyer (2010, p265),

process-level, it has been claimed that in empirical work, *'...a valid assessment of the interdisciplinarity of research must involve some indication of the degree or extent of knowledge integration that took place as the research was being conducted...'* (Wagner et al., 2011, p16). Nevertheless, since *'*[t]*he process of integration – whether cognitive or social – is more difficult to observe (and measure) than are the results of the process, which are largely found in published literature* [,]*...more literature has focused on the outputs of research rather than the processes'* (Wagner et al., 2011, p16). In other words, this community of scholars has mainly assessed the *cognitive dimension* of knowledge integration reflected at the level of published research outcomes, while relatively little attention has been paid to the actual level or unit of analysis where the process of knowledge integration takes place (e.g. the R&D project) as well as to the social interactions required by the process (Wagner et al., 2011). Exceptions to this include Rafols (2007) and Rafols and Meyer (2007). Conversely, other scholars focus only on the social integration process in collective R&D efforts, but do not pay attention to the types of knowledge that are being integrated (Wagner et al., 2011).

As was noted above, most studies of knowledge integration have used the outputs of research as the unit of analysis to assess integration, since outcomes such as published articles can be easily observed (Hinze, 1999; Wagner et al., 2011, p16). Nevertheless, it has been argued that the use of bibliometric indicators can only provide a somewhat distorted assessment of knowledge integration since they are based on publications indexed in bibliographic databases; these databases are not able to homogeneously account for contributions from the diverse range of relevant fields of knowledge. For example, databases such as Scopus or ISI have poor indexing of relevant contributions from the social sciences such as books, book chapters and non-English journals (Wagner et al., 2011, p24), the latter being particularly relevant in the context of developing countries. Therefore, since measuring knowledge integration by analysing publications in bibliographic databases would be clearly misleading for developing-country studies as well as being unable to reflect the extent of knowledge integration achieved during the actual R&D processes, alternative measures are required to address the research questions proposed here.

Drawing on the previous arguments, and considering that publications from Uruguay are poorly indexed in international databases (Bortagaray, 2007), it was concluded that the methodological approach for the present research can better capture collaboration and knowledge integration at the *R&D process-level*, particularly by looking at individual *R&D projects* as the actual locus where research activity and *collaborative knowledge integration* take place (see Chapter 3 for details). The R&D project provides information on the two main dimensions of knowledge integration**,** namely the actual knowledge assets being integrated (disciplinary knowledge categories and R&D capabilities) and the social interactions[39] among organisations (R&D partnerships) required for the integration to take place (Rafols, 2007). This can be seen as a singular methodological contribution of this research to the literature on knowledge integration and interdisciplinarity (see Chapters 3 and 5).

Therefore, the present research attempts to address the gap referred to above by assessing jointly the social and cognitive dimensions of the process of knowledge integration that takes place during an inter-organisational collaborative R&D project. This was implemented through a combined exploration of: (i) R&D collaborative relations between pairs of actors linked during the execution of R&D projects (the social integration dimension); and (ii) the extent of *collaborative knowledge integration* accomplished during those collaborations (i.e. the cognitive integration). The next section critically explores empirical methods intended to assess this latter dimension.

2.6.2 Methodological approaches to measuring complementary knowledge integration

From the methodological point of view, answering our research questions required developing some sorts of measures or quantitative indicators of the degree of

[39] I use the term 'social interactions' for the purpose of this research specifically for information regarding 'who collaborates with whom?' A question on this was put to the coordinator or research leader of each R&D project analysed in this research. They were asked to provide a list of external research groups that participated in the project (see Chapter 3 and the survey questionnaire in Appendix 8.5).

complementarity between R&D groups collaborating in a research project, namely indicators of the extent of *collaborative knowledge integration* as defined here. Studies on knowledge integration across scientific disciplines have developed sound empirical methodologies. The present research has drawn on such methods in order to develop the sort of indicators of the degree of complementarity among collaborating R&D groups, laboratories or organisations we mentioned above. These indicators should somehow capture the degree of complementarity among the knowledge assets (disciplinary knowledge and R&D capabilities) pulled together – or integrated in our conceptual terminology – by every pair of R&D groups collaborating during the implementation of each R&D project[40] assessed in this study. As is described in detail in Chapter 3 on methodology and Chapter 6, indicators of *similarity* and *difference* among the knowledge bases[41] of pairs of collaborating actors were developed in order to identify and discriminate between actors showing contrasting levels of knowledge integration accomplished through their collaborative R&D projects. Such discrimination among actors with differing *abilities to integrate distant complementary knowledge* allows further exploration of the factors that may be shaping those differences.

Including a measure of *similarity between categories of technological knowledge* as a dimension of the indicator for *collaborative knowledge integration*[42] is a salient attribute of our proposed operationalisation for this indicator. This has required first building a robust classification system of knowledge-asset categories suitable for our study – as argued before, and for our case, we developed two category systems for R&D capabilities and disciplines respectively. Subsequently we had to develop a measure of how different two given R&D capabilities or disciplines were. As argued by the proponents of this indicator, '...for emerging fields, the inclusion of distance [or similarity] among categories lessens the effect of inappropriate categorisation...: if a ... category i is very similar to an existing category j, their distance d_{ij} will be close to zero,

[40] The selection of the R&D project as the level of analysis is discussed in detail in Chapter 3.
[41] R&D capabilities and disciplinary knowledge
[42] Rafols and Meyer (2010) use this dimension for the indicator of *diversity* they developed to assess knowledge integration in published scientific papers by specific authors.

and its inclusion in [the] categories list will result in only slightly increased...' measures of knowledge integration (Rafols & Meyer, 2010, p267).

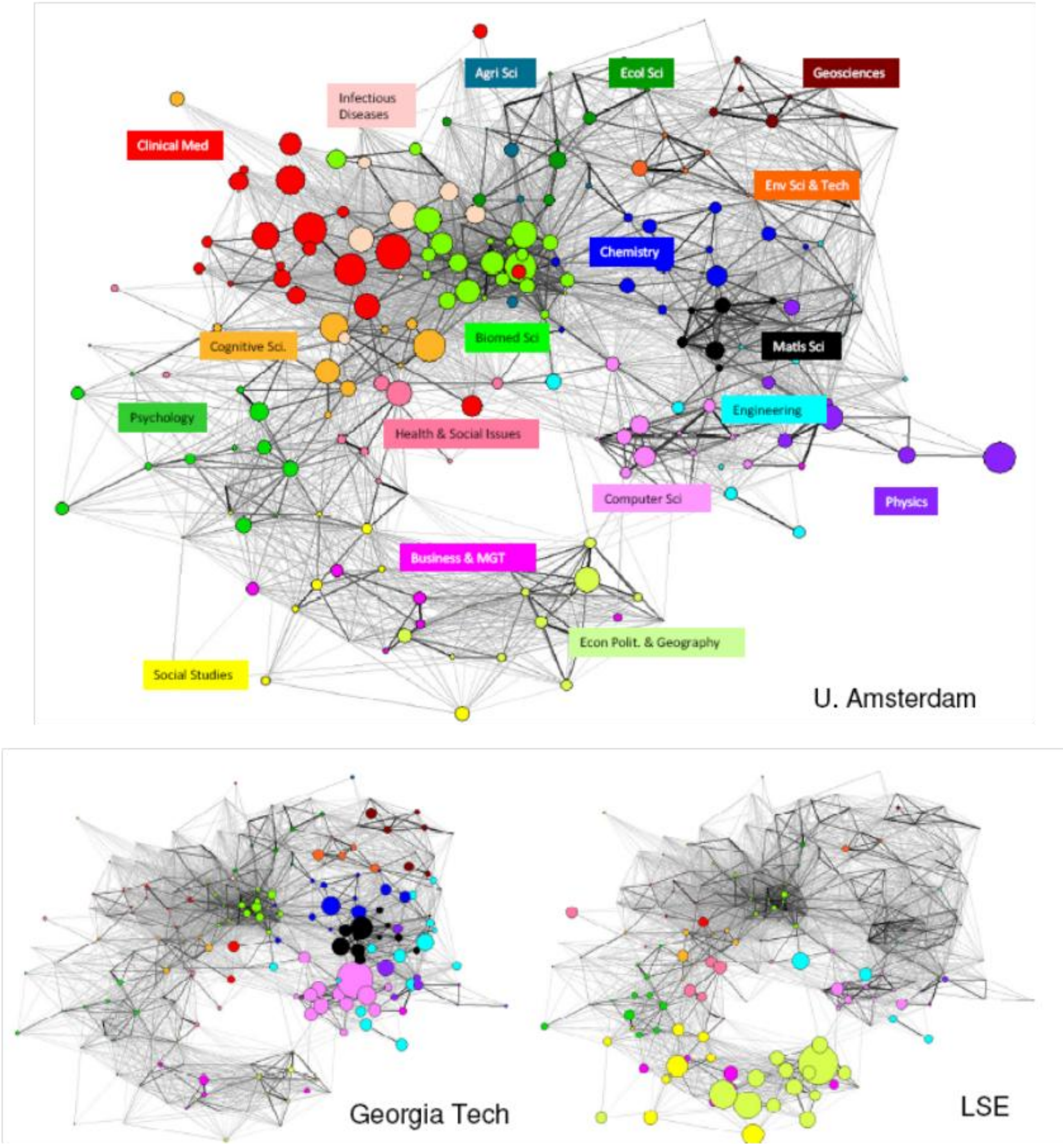
On the basis of this sort of measure of the relative degree of similarity (or proximity) and difference (or distance) between categories of scientific knowledge, scholars studying the structure of science and interdisciplinary research have used *spatial techniques* such as network analysis in order to develop graphical network representations of entire knowledge systems (Leydesdorff & Rafols, 2009). As described by Wagner et al. (2011, p20), a spatial *'...approach to using bibliometrics is a methodology that describes a landscape, or space within which science operates, typically from the point of view of a single object (journal, paper, or author)'*. These representations provide a tool for an intuitive visualisation and easy assessment of the degree of difference between different categories of knowledge assets represented by their distance or proximity in the whole knowledge network map, building what has been called a 'metaphorical knowledge space' (Wagner et al., 2011, p20). In addition, some studies have used these knowledge network maps or knowledge spaces to represent the knowledge assets of a specific organisation (or R&D group) overlaid on the complete knowledge-space in order to compare them with the knowledge assets controlled by its actual or potential partners (Boyack, 2009; Rafols et al., 2010). Such an overlay map provides a visual representation of the extent of collaborative knowledge integration achieved by those collaborating actors.

In order to provide an example, Figure 2.3 presents a 'global map of science' developed by Rafols et al. (2010, p1876) based on the patterns of similarities[43] among Subject Categories of the Web of Science using data from the Journal Citation Reports. This base map, or 'metaphorical knowledge space' in the words of Wagner et al. (2011, p20), is subsequently used by the authors to overlay the publication profiles (2000 to 2009) of three organisations: the University of Amsterdam, Georgia Institute of Technology (Georgia Tech), and the London School of Economics (LSE) (Rafols et al.., 2010). The relative size of the dots in Figure 2.3 is proportional to the number of

[43] The authors compute relative measures of similarity among 221 Subject Categories (SCs) based on the records of citing SC to cited SC (Rafols et al., 2010, p1876).

publications of each organisation in each Subject Category, allowing the reader to perform a quick intuitive comparison of the knowledge resources (publications in this case) of each organisation. As will be discussed later, we adopt this tool for our research to represent, in a network graph, the patterns of similarity relationships among all knowledge-asset categories encompassed by the *local technological system* we propose to study here (agri-biotechnology).

Figure 2.3: Global map of science overlaid with universities' publication profiles



Source: Reproduced from Rafols et al. (2010, Fig. 3, p1878).

To sum up, on the one hand, we saw in the previous section that some scholars study knowledge integration from a *social-integration perspective*. That is to say, they focus mostly on the determinants and outcomes of collaboration processes between actors or individuals in knowledge-intensive environments, but pay little attention to the actual sorts of knowledge being integrated during such collaborations (Wagner et al., 2011, p16). On the other hand, we reviewed in this section the work of another research vein that uses the spatial – or network – analytical and graphical techniques described above to measure patterns of integration of knowledge for different units of analysis (usually articles) within the background of a whole knowledge system (Wagner et al., 2011, p18). Most of the studies applying this approach rely on citation analysis, namely on the pattern of knowledge fields cited by articles or journals, as aggregated indicators of the degree of *proximity* or *similarity* among knowledge fields. The main shortcomings of this approach are that the degree of knowledge integration is measured at the level of research-outcomes while the single type of research-outcome assessed is the scientific peer-reviewed publication indexed in bibliographic databases (Wagner et al., 2011, p19). Hence, knowledge integration occurring when the actual integration process takes place (e.g. the R&D project for our case) is overlooked. Another shortcoming of this approach is that it pays almost no attention to the social interactions involved in collaborative knowledge integration which are the focus of the first approach described in this paragraph.

The combined empirical exploration of collaborative R&D projects (social interactions among research groups) and the degree of integration of specific disciplinary knowledge and research-capabilities accomplished by the collaborating R&D groups (the cognitive dimension of knowledge integration) proposed here is presented as a distinctive element of this research. This brings together in a single study the two perspectives discussed above that have previously been applied rather separately to studies of knowledge integration; namely the social-integration perspective and the cognitive approach based on knowledge proximity measures (Wagner et al., 2011). Hence, by combining data on R&D collaboration with those on research-capabilities and disciplines existing for each individual research group or organisation[44], the conceptual and methodological approach developed here to assess collaborative knowledge integration (see Chapters 3 and 6) is roughly midway between studies of inter-organisational collaboration and studies of knowledge integration at the level of local knowledge systems. The need for further research on *'...the contexts and processes that foster knowledge integration in research'* was identified by recent studies as an important gap in the latter research field (Wagner et al., 2011, p24). The next section reviews scholarly research on such processes or driving conditions that may influence the extent of knowledge integration achieved though collaborative R&D activities. Besides reviewing previous research, we identified potentially relevant forces shaping knowledge integration through the initial exploratory interviews performed for this research[45].

2.7 Exploring factors that shape collaborative knowledge integration

On the basis of the literature that was critically analysed and accounted for to this point in this chapter, this section pursues an overall exploration of key forces that may be shaping the process of *collaborative knowledge integration* and hence that may provide potential answers to the research question presented in the introduction of this chapter (Section 2.1). It is worth recalling at this point our main research question:

> *How and why does the extent of scientific and technological complementarity exploited through R&D collaborations differ among collaborating actors of the agri-biotechnology innovation system in the context of developing countries?*

In order to identify the relevant forces driving *collaborative knowledge integration* that we discuss below, we followed two complementary approaches: (i) we identified a number of relevant factors from the bodies of scholarly research reviewed in this

[44] I use the term 'organisations' to refer to the actual organisational (sub) structure where research activities take place, thus encompassing public research organisations, as well as lower-level research groups, laboratories and R&D departments.
[45] We qualitatively explored motivations and (dis)incentives to researchers, structures or mechanisms supporting collaboration, system-level institutions, and organisational capabilities shaping the extent of collaborative integration of research-capabilities and disciplinary knowledge.

chapter; and (ii) we complemented this by pursuing an *inductive field work* phase, namely through a reflection on partial facts or data – observed in our case though exploratory interviews[46] – that allowed us to articulate 'suggested comprehensive...meaning[s]' (Dewey, 1910, p79); in other words, based on an inductive interpretation of interview data, we formulated likely explanations to our research question as a guide for our subsequent quantitative assessment of knowledge integration. Next, we introduce two more specific research questions intended to narrow down our empirical approach to address the overarching question we set out above, and to guide the identification of forces shaping collaborative knowledge integration that we develop in this section.

Our first specific (sub-)question looks at the system under study from an institutional perspective. Institutional economics (North, 1990; North, 1994), evolutionary economics (Nelson & Winter, 1982), and more recently innovation systems' studies (Carlsson et al., 2002; Lundvall et al., 2002) have emphasised the salient role of *institutions* in supporting interactive learning, innovation and economic growth (Arocena & Sutz , 2002; Bergek et al., 2008; Cimoli et al., 2009). In particular, the innovation systems' literature suggests that interactive learning processes – which are affected by institutions – are the means to realise complementarities and opportunities offered by local sources of skills and knowledge, supporting in this way the building of stronger system-wide technological and innovation capacities (Arocena & Sutz , 2002; Bortagaray, 2007; Lundvall et al., 2009). Therefore, institutions and more narrowly public policies, have become key drivers (or barriers) of the exploitation of opportunities for the complementary aggregation of actor-level technological capabilities into system-level innovation capability (Lall, 1992; Cimoli et al., 2009, pp337-43; Bortagaray, 2007, p354). This is particularly relevant in developing countries since they are more reliant on well-established complementarities among actors and components of the system, but usually show weak formal *institutions* supporting interactions among actors (Padilla-Pérez et al., 2009, pp143-5; Bortagaray, 2007). Based on our argument above, we will particularly address the following question:

[46] Semi-structured exploratory interviews were conducted with key actors in the technological system, focusing particularly on public research organisations.

How do system-level institutions and incentives for public sector researchers shape the extent of integration of complementary knowledge assets achieved by R&D groups through collaborative research activities within a developing-country agri-biotechnology innovation system?

The second (sub-)question we present draws on the resource-based view of organisations which sees the integration of complementary resources and R&D capabilities as the main driver of inter-organisational collaborations (Teece, 1986; Mowery et al., 1998; Colombo et al., 2006). Some studies within this vein consider knowledge as the main organisational resource, hence paying particular attention to attributes of organisations that shape their ability to access and use[47] external sources of knowledge (Cohen & Levinthal, 1990; Colombo et al., 2006; Zhang et al., 2007). This encompasses the ability to establish interactive relationships (Dyer & Singh, 1998) as well as to effectively integrate multiple sources of specialised knowledge, skills and capabilities in the context of such partnerships (Lane & Lubatkin, 1998; Simonin, 1999; Dyer & Nobeoka, 2000; Grant & Baden-Fuller, 2004). On this basis, we articulate our second specific question as follows:

How do organisational-level attributes shape the extent of integration of complementary knowledge assets achieved by R&D groups through collaborative research activities within the agri-biotechnology innovation system?

In order to address these specific research questions, the subsequent conceptual and empirical work focuses on a number of actor-, relational-, and system-level attributes that may shape the extent of knowledge integration achieved by R&D groups through collaborative research activities. We organise our following discussion into three groups of attributes that, for the purpose and boundaries of this research, were

[47] Link, access and use of external knowledge assets are encompassed by our conceptual definition of *collaborative knowledge integration*.

understood as those exerting the most relevant influences on the extent of *collaborative knowledge integration* achieved by an organisation or R&D group:

i) Structural and relational attributes of the R&D group. [48]

ii) System-level institutions and incentives.

iii) Compliance of the R&D group with scientific reward institutions.

The latter group of attributes is somehow in-between the first two groups, since it has to do with how the compliance of individual R&D groups with formal system-level institutions (particularly scientific incentives and rewards) influences the group's ability to integrate knowledge through its R&D partnerships. This issue came up as a relevant factor from our inductive analysis of exploratory interviews. Before addressing these groups of attributes we review some contextual factors suggested by the relevant academic literature that, despite not being deliberately assessed in our empirical research, we should acknowledge that they might have an influence[49] on the processes of *collaborative knowledge integration* we are studying here.

2.7.1 Background or contextual factors

There is a series of aspects that exert an influence on the general development of the whole technological innovation system as well as on specific collaboration processes. While some of these attributes might not directly influence the extent of collaborative knowledge integration, they may be more central to address other sorts of research questions than the ones we are trying to answer here; hence they were considered part of the relevant background of our study's analytical framework (Section 2.8). Given their importance for the functioning of the system, these background factors were taken into account in the exploratory stages of the empirical work. These attributes include, amongst others, the availability and demand of trained human

[48] We refer to the *R&D group* since, as is described in Chapter 3, it is defined as the appropriate unit of analysis for our study.

[49] We assumed such an influence to be less relevant than the one played by the three groups of attributes we focused our attention on. Therefore, in order to limit the scope of this research within the constraints of a feasible PhD thesis, we relegated these factors to the background of our study.

resources (Edquist, 2005; Viotti, 2002; Senker & Van Zwanenberg, 2001), competitive funding for R&D and innovation activities (Bergek et al., 2008; Colombo et al., 2006; Heinze & Kuhlmann, 2008), sources of inter-organisational conflicts (Heinze & Kuhlmann, 2008; Arocena & Sutz, 2002), consumer perceptions, mechanisms or platforms supporting non-market interactions and coordination among actors (Senker & Van Zwanenberg, 2001; Acha & Cusmano, 2005; Rafols, 2007) and the applicable regulatory institutions (Senker & Van Zwanenberg, 2001).

Some studies have suggested that inadequate availability and balance of core and third-party competitive funding coupled with increasing pressures for more efficient production of scientific and technological outputs have resulted in increased levels of competition for research funds within the public sector (Heinze & Kuhlmann, 2008). This may be one among several sources of conflict between actors which is naturally present within any innovation system (Arocena & Sutz, 2002). Other sources of conflict may include inter-organisational disagreements or overlaps in the responsibilities of different – public – organisations (Arocena & Sutz, 2002), differences in status hierarchies, stereotypes, prejudices and compatibility of working routines (Heinze & Kuhlmann, 2008). When these sources of conflict are present, opportunities for collaboration and complementarity between actors may be undermined. Looking at the whole system, when the competition for R&D funds referred to above is excessive, the potential for exploiting economies of scale and scope of the available knowledge assets and other science and technology resources is undermined (Salles-Filho et al., 2006).

With regard to graduate and postgraduate education and training programmes, the availability of graduates and the demand for trained personnel are relevant contextual issues that deserve exploration, in particular how these have some bearing on the interactive dynamics among the knowledge assets distributed throughout the system (Viotti, 2002). As suggested by Viotti, *'...''human capital'' would not become an effective technological absorber or improver ...without its effective engagement in productive or in science and technological activities. Though education is a necessary condition for the effective acquisition and improvement of technologies, it is not a sufficient one'* (Viotti, 2002, p667). In other words, if public-sector research and private innovation efforts are not strong enough, they may not demand the available trained specialists in a given technological field. This is a relevant factor affecting knowledge integration when looking at the whole innovation system. Nevertheless, this is beyond the scope of this study since we are exploring knowledge integration only within the public research (sub-)system.

Beyond the structural attributes of the system reviewed above (higher education and R&D funding) that have been broadly explored in innovation system studies (Lundvall et al., 2009b; Spielman & Kelemework, 2009), there are system-level *social – or soft – institutions* (Woolthuis et al., 2005, p610) such as values, trust in other actors, habits, and practices that affect the way individuals and organisations share knowledge and learn, thus exerting an influence on the processes of knowledge integration through inter-organisational R&D collaborations (Laudel & Gläser, 1998; Malerba, 2005; Hall, 2006). As an example, a study of the development of a new tillage technology in Brazil showed how the values and routines of public-sector researchers[50] discouraged them from collaborating in exploratory activities promoted by farmers and input-supplier firms, thus reducing significantly the pace of knowledge generation for the adaptation of the technology to local conditions (Ekboir, 2003). All these issues are part of the institutional set-up that is taken into account as background forces in this study of knowledge integration achieved by means of inter-organisational collaborative arrangements.

Studies of innovation systems have also emphasised the role played by 'bridging institutions' in supporting interaction and coordination among actors and flows of information and knowledge throughout the system (Spielman & Kelemework, 2009; Arnold & Bell, 2001). A specific path of research enquiry within innovation studies has paid particular attention to this *bridging* process, by studying what have come to be termed as *innovation intermediaries* (Howells, 2006; Klerkx & Leeuwis, 2008b) or *intermediary bodies* that are midway between actors at the policy-level and research performers (Van der Meulen & Rip, 1998, p758). Howells (2006, p720) defines an

[50] Researchers were rather closed to external demands and had negative prejudices towards working with multinational companies (Ekboir, 2003).

innovation intermediary as '[a]n *organization* or *body* that acts [as] an agent or broker in any aspect of the innovation process between two or more parties'. Some of the roles filled by these intermediaries are: providing information about potential partners and sources of external knowledge; brokering or mediating interactions and/or coordination among two or more actors of the system; facilitating the formation of networks; helping in the articulation of demand for R&D efforts; supporting the search and access to external funding; and fostering the integration of knowledge domains, capabilities and technologies (Callon, 1994; Howells, 2006; Klerkx & Leeuwis, 2008b; Lynn et al., 1996).

Diverse types of *intermediary bodies* have been described in the literature, ranging from organisations deliberately created to fulfil an intermediary role (e.g. science councils or innovation agencies), through instruments, programmes or platforms that support specific functions or stages of the innovations process (committees, system-level planning exercises) to the boundary-spanning or brokering role of individuals such as independent consultants (Bessant & Rush, 1995; Klerkx & Leeuwis, 2008b; Lam, 2005). Bridging mechanisms or platforms act as 'interfaces' between organisations with differing motivations, supporting non-market interactions and coordination among actors (Edquist, 2005). These sorts of bridging mechanisms as well as specific actors acting as 'integrators' of knowledge play a relevant role in supporting innovation (Acha & Cusmano, 2005), particularly during the emergence of new technological systems (Senker & Van Zwanenberg, 2001) or knowledge fields (Rafols, 2007). Social interaction and coordination fostered by bridging platforms or instruments have been claimed to facilitate the identification, negotiation and alignment of expectations and motivations among incumbent actors, towards a potential inter-organisational arrangement (Ring & Van de Ven, 1994).

Such positive expectations along with the legitimacy of new technologies play a role in building collaborative relations in emergent technological systems (Bergek et al., 2008; Geels & Raven, 2006; Senker et al., 1999). The interrelation between expectations on new technologies and network development is stressed by the strategic niche management literature. As suggested by a study of the emergence of biogas technologies; *'[w]hen learning processes produce outcomes that do not meet the* *expectations, this leads to a backlash in expectations that turn from positive to negative. When actors' beliefs turn sour, networks fall apart and resources are reduced, leading to a decline in development'* (Geels & Raven, 2006, p389).

A number of studies have found evidence that the existence of specific non-market mechanisms supporting inter-organisational interaction such as collaborative research centres (Laudel & Gläser, 1998; Llerena & Meyer-Krahmer, 2003), ad-hoc technical committees (Rosenkopf et al., 2001) or – in the case of agriculture – governing boards formed around commodity value chains (Janssen & Braunschweig, 2003; Klerkx & Leewis, 2008b) contribute to the collaborative integration of knowledge and capabilities across organisational boundaries. Llerena & Meyer-Krahmer refer to a case of an innovation 'federation' that represented an effective means for achieving inter-organisational coordination, interdisciplinarity, economies of scale and vertical integration in the French pharmaceutical industry (Llerena & Meyer-Krahmer, 2003, pp83-4). Moreover, specific funding for collaborative R&D (Acha & Cusmano, 2005) or 'industrial platforms' - such as those funded by the European Commission through its Framework Programmes – support the transfer and integration of technological knowledge among actors in the system (Senker & Van Zwanenberg, 2001). Conversely, it was observed that non-existent or weak structures supporting inter-organisational interactions are a common attribute of South American agricultural innovation systems, resulting in substantial barriers to the exploitation of potential synergies among actors (Salles-Filho et al., 2006).

Among the types of intermediary bodies described above, we turn now to the role of individuals. Klerks and Leeuwis (2008b) pointed to the role of independent innovation consultants in network brokerage. Closely related to this role, organisations that rely heavily on external sources of knowledge and capabilities require well developed internal capabilities to perform such a network brokering or boundary-spanning function (Lam, 2005). These are knowledge intensive organisations that instead of resorting to external intermediary bodies, base their strategy towards searching for and accessing external knowledge on internal capabilities, specifically *individual 'linked scientists'* with well-developed links with the external knowledge base offered by the scientific community relevant to the organisation's R&D activities (Lam, 2005, p267).

This internal bridging function is usually performed by *postdocs or doctoral students* that act as boundary-spanners moving and internalising external knowledge and capabilities into the organisation's internal R&D efforts (Lam, 2005). Similar bridging roles of highly trained individuals were observed in collaborative networks in the automotive (Harryson et al., 2008, p766) and semiconductor industries (Almeida & Kogut, 1999). This suggests that, for our study, we should pay attention to how the R&D groups being assessed are composed, and the role of their members – either researchers or postgraduate students – in boundary-spanning and external knowledge integration processes.

Public technology and innovation policies can play a key role in supporting the development of the inter-organisational interfaces mentioned above through the development of specific institutional mechanisms that promote inter-organisational collaborative links (Edquist, 2005, p194) or collaborative training programmes (Lam, 2005). These mechanisms commonly play a role in reducing transactions costs incurred by small organisations, increasing their chances of taking part in alliances (Colombo et al., 2006). On the other hand, the inverse relation has also been observed when sponsored organisations need to spend significant amounts of time on management and accountability of the supported collaboration, thus hindering their involvement in further collaborative initiatives (Colombo et al., 2006, p1173). It is worth noting that it is beyond the objectives of our research to perform an intensive exploration of the role of intermediaries in collaborative knowledge integration. Nevertheless, taking into account their relevance in the general coordination and integration of the innovation system, we explored through qualitative interviews[51] the existence of the sort of bridging and boundary-spanning mechanisms described above within the emergent agri-biotechnology innovation system in Uruguay, as well as the involvement or links of public research actors with these bodies. Moreover, on the basis of Lam's argument (2005) discussed above, we also explored qualitatively and quantitatively the presence of specialised roles of individual members in each R&D group or organisation (effective

[51] See questionnaire protocol for exploratory interviews in Appendix 8.1.

researchers and postgraduate students) in fostering *collaborative knowledge integration*.

2.7.2 Organisation-level attributes shaping collaboration and knowledge integration

The complex *interactive* forms in which R&D and innovation are organised and the rather pervasive need to share knowledge and competences (Acha & Cusmano, 2005; Coombs et al., 2003; Powell et al., 1996), result in organisations being required to be effective in identifying and accessing complementary capabilities, resources and skills from diverse research fields available through other actors in the system (Lane & Lubatkin, 1998; Dyer & Singh, 1998; de Carvalho et al., 2005; Hall, 2006). Notwithstanding this pressure, one relevant difficulty that research organisations face when collaborating is dealing with the coordination or transaction costs resulting from the collaborative activity (Rafols, 2007; Cummings & Kiesler, 2005). This issue results in a trade-off between the potential benefits from collaborative knowledge integration and the coordination costs incurred in developing the interactive research activity (Colombo et al., 2006; Rafols, 2007). The *absorptive capacity* of an organisation has been defined as its ability (based on prior knowledge, skills and organisational routines) to identify, assimilate and exploit external sources of knowledge (Cohen & Levinthal, 1990, p128; Cockburn & Henderson, 1998, p158; Szulanski, 1996, p31). This capability, which is cumulatively built from previous R&D efforts (Cohen & Levinthal, 1990), also supports the ability of the organisation to deal with the coordination and transaction costs incurred in forming and implementing collaborative arrangements (Colombo et al., 2006) and specifically in transferring and integrating knowledge across organisational boundaries (Cummings & Kiesler, 2005).

In the empirical terrain, most scholarly works including the seminal contribution of Cohen and Levinthal (1990) have assessed *absorptive capacity* by measuring the intensity of R&D efforts of the organisation (Gambardella, 1992; Tsai, 2001; Zahra & George, 2002; Fontana et al., 2006). Other studies have developed indicators of the extent and quality of the organisation's knowledge base to measure absorptive capacity, particularly by looking at the organisation's skilled personnel such as scientists and engineers and their degree of training (Rothwell & Dodgson, 1991; Giuliani & Arza, 2009). Therefore, the collaboration and knowledge integration patterns of organisations are expected to depend upon the *size* of the scientific and engineering staff in the organisation and their *skills*. Scientists' influence on the development of collaborative relations is two-fold: (i) they constitute the knowledge and skills base that an organisation may contribute to a collaborative R&D process and determine the actor's ability to access and use external knowledge (Cohen & Levinthal, 1990); and (ii) besides the absorptive role of scientific and technological capabilities of an organisation, in uncertain knowledge fields they also *signal* and provide *visibility* to the competences, legitimacy and reputation of the organisation for potential partners in search of complementary capabilities (Giuliani & Arza, 2009; Luo et al., 2009). By assessing absorptive capacity through indicators of organisation *size*, studies of inter-firm research collaborations suggest that small organisations feel a stronger influence from the potential risks[52] and transaction costs referred to above, so they are more likely to be held back from establishing collaborative relations (Colombo et al., 2006, p1169). These authors reached this conclusion after finding a positive linear relationship between firm size and the formation of exploratory R&D partnerships, namely the larger the *size* of the organisation, the more able it is to deal with transaction costs involved in managing R&D partnerships and thus the more exploratory R&D collaborations it developed (Colombo et al., 2006). Such studies have assessed the relation between *absorptive capacity* and the establishment of collaborative R&D partnerships but have left rather unexplored the type of knowledge or capabilities being accessed - that is to say, how this capacity influences the extent of collaborative knowledge integration accomplished by the organisation. We address this latter influence in our empirical study.

Subsequent development of the concept of *absorptive capacity* has taken place as a result of the increasing preponderance of interactive-partnership forms in innovation and the transaction processes involved in the exchanges of knowledge and capabilities

[52] Transaction cost theory suggests that, during inter-firm collaborative initiatives, opportunistic behaviour by one of the partners may happen, resulting in a risk to the final appropriation of knowledge and technologies previously held by the partners or jointly developed (Colombo et al., 2006).

between actors. Specifically, *'relational capability'* has been defined as the distinctive ability of an organisation to: establish interactive relationships; access other actors' knowledge resources and capabilities (Dyer & Singh, 1998, p672; Lorenzoni & Lipparini, 1999, p317); and to internalise them into the organisation (Grant, 1996). This involves the development of partnering capabilities (Hall, 2006) or 'collaborative know-how' (Simonin, 1997, p1150) that involves a process of *'learning how to collaborate'* (Powell, 1998, p238) by the organisation. Therefore, some scholars have used measures of alliance experience as an indicator of *relational capability* (Gulati, 1995; Ahuja, 2000). As suggested by Lorenzoni and Lipparini, '[o]nce a firm begins collaborating, it develops experience at interacting, and this provides fertile ground for further innovative interactions' (Lorenzoni & Lipparini, 1999, p335). These studies, in fact, test whether the accumulation of *relational capability* allows organisations to form new collaborations but leave unexplored the extent to which that relational capability also results in an increased ability to access distant complementary knowledge assets (Gulati, 1995; Gulati & Gargiulo, 1999; Lorenzoni & Lipparini, 1999). So, it is not only a matter of the amount of collaborations but also their quality, namely *whether higher levels of relational capability (measured as a high number of collaboration linkages) also result in a larger exploitation of potential inter-organisational synergies or, what is effectively the same, in increased degrees of collaborative knowledge integration*. Our quantitative empirical methodology addresses this question.

Turning now to studies of knowledge integration specifically in the academic domain, Rafols (2007) suggested that the high *coordination costs*[53] involved in collaborative R&D projects on emergent technologies (such as bionanotechnology) result in diminished degrees of *collaborative knowledge integration* from different research fields (captured by the author's conceptual definition of *cognitive diversity*; Rafols, 2007, p409). Nevertheless, the author's attribution of the low levels of collaborative knowledge integration to one single attribute of R&D collaborations (their coordination costs) is questioned here. We argue that besides coordination-costs' issues, other organisational or system-level attributes might play a relevant role,

[53] The authors refer to coordination costs as the costs of relationship development and coordination of activities required by collaboration efforts (Cummings & Kiesler, 2005, p704).

discouraging researchers from integrating and getting involved in other knowledge fields, a behaviour intended to avoid weakening specialisation and academic performance in their respective disciplines (Llerena & Meyer-Krahmer, 2003, p79; Hessels et al., 2011, p564).

The conceptual approach developed for the present research proposes to assess how attributes – other than coordination costs – concerning the collaborative relation, the involved actors and the technological system may possibly affect the degree of *collaborative knowledge integration*. The attributes assessed through a mixed qualitative and quantitative approach include: (*i*) system-level formal institutions – particularly research evaluation and reward rules; (*ii*) informal institutions such as scientists' views and routine practices enabling the integration of external knowledge through collaboration (which are, in fact, affected to some extent by formal institutions); (*iii*) attributes of the organisations or research groups involved in the collaborations[54]; and (*iv*) other system-level background factors that may support or hinder the collaborative integration of knowledge (see a simplified representation of the conceptual framework in Section 2.8). In the next section, we review extant research on system-level institutional forces particularly relevant for public-sector research organisations which represent the locus where knowledge integration is assessed in our study.

2.7.3 System-level institutional factors shaping knowledge integration

We have discussed in previous sections how *institutions* play a key role enabling the aggregation of complementary actor-level technological capabilities into system-level innovation capability (Lall, 1992; Cimoli et al., 2009, pp337-43; Bortagaray, 2007, p354). Before expanding this argument, we should provide a definition for the concept of *institutions. 'Institutions are the humanly devised constraints that structure human interaction. They are made up of formal constraints (e.g., rules, laws, constitutions),*

[54] As discussed above we particularly refer to absorptive capacity (assessed through indicators of size and education level of the R&D group's members) as well as to partnering experience (Ahuja, 2000) as indicators of the relational capacity of each research group.

informal constraints (e.g., norms of behavior, conventions, self-imposed codes of conduct), and their enforcement characteristics. Together they define the incentive structure of societies and specifically economies' (North, 1994, p360). Given our focus on emergent technologies and public sector research, for the purposes of our study, we focus on the role of formal non-market institutions which '...offer the main governance structure in many activities where market exchanges are socially inappropriate or simply ineffective' (Cimoli et al., 2009, p340).

Formal institutions and, more narrowly, public policies may play a major role supporting technological learning, the development of indigenous technological capabilities, complementary interactions among actors and the exploitation of innovation opportunities, hence fostering economic development (Cimoli et al., 2009, pp337-43). The incentive structure set by the *institutional framework* becomes a fundamental force that may allow or hinder the exploitation of opportunities for complementarity, innovation and economic development offered by the capabilities functionally in place throughout the whole system (Lall, 1992; Padilla-Pérez et al., 2009; Bortagaray, 2007, p354). This is particularly relevant in developing countries, since they commonly have poor patterns of interaction among actors in the system and weak formal and informal *institutions* supporting those interactions (Padilla-Pérez et al., 2009, pp143-5), hence requiring distinctive approaches for the development of policies supporting innovation compared to developed economies (Chaminade et al., 2009, p365). The scarcity of resources in developing countries make them particularly reliant on well-established complementarities among actors of the system and hence on a coherent set of institutions and incentives to organisations and individuals underpinning the realisation of such potential complementarities (Bortagaray, 2007, pp350, 354).

Therefore, we argue that further scholarly studies should pay careful attention to how system-level *institutions, incentives and public research policies* may be supporting processes for collaborative knowledge integration among public research actors and hence fostering or hindering the synergistic exploitation of local knowledge assets and skills built throughout the public research system. An influential study on the benefits of public research has suggested that there is a '...growing technological complexity and the need to 'fuse' previously separate streams of science or technology...[hence] nations need a portfolio-based approach to the public funding of basic research – a portfolio both in terms of research fields and technologies but also in terms of a full range of mechanisms and institutions for ensuring that the potential benefits of publicly funded research are transferred and exploited successfully' (Salter & Martin, 2001, pp528-9). This makes clear the key role of public science policies in underpinning a country's ability to effectively exploit the potential benefits offered by the knowledge-bases existing in the public research sub-system. Previous studies of the influence of the institutional framework on emergent technological systems have suggested the need to further explore '...how and why are interactions blocked or feared...[and] what mechanisms are preventing researchers from articulating knowledge areas and cognitive approaches' (Bortagaray, 2007, pp357). Our research partially addresses this need, particularly by exploring how researchers' formal assessment institutions may be shaping the extent of collaborative knowledge integration realised by public research groups.

We turn our discussion next to the institutional rules, academic incentives and related science and technology policies that may shape the general orientation of the scientific research system, and briefly review the general changes that have been taking place in such institutions during the last two decades. We refer, on the one hand, to trends in scientific systems' practices and incentives towards an increasing attention to the practical application and social relevance of research results and, on the other hand, to the interplay between this changing emphasis with the influence exerted by researchers' assessment institutions – be they formal or informal rules (Gibbons et al., 1994; Hessels & van Lente, 2008; Hessels & van Lente, 2011). The institutional change in the practices and orientation of scientific research towards an increased applicability of results in the solution of socially-relevant problems has been termed 'Mode 2' research after the seminal contribution of Gibbons et al. (1994). Other (previous and subsequent) contributions regarding this change have developed related descriptive and/or prescriptive approaches such as the triple helix (Etzkowitz & Leydesdorff, 2000;

Sutz, 2000), finalisation science (Böhme & Krohn, 1976; Forman, 2007) and post-academic science (Ziman, 2003; Hessels & van Lente, 2008[55]).

More recent studies of this changing institutional environment have focused on two main developments influencing the actual magnitude of such a change towards greater social relevance, namely: (i) the increasing pressure from academic research funding to perform application-oriented and socially-relevant research projects; and at the same time, (ii) a significant rise of performance assessments policies and instruments that result in a pervasive pressure on researchers to publish their results in peer-reviewed academic journals (Hessels et al., 2011). It has been claimed that these two developments may exert conflicting forces, resulting in a tension on the final orientation of research, depending on the research field (Hessels & van Lente, 2011). As the cited publication clearly states:

> *'...researchers experience a tension between satisfying the needs of application-oriented funding sources and reaching high scores on evaluations dominated by bibliometric indicators ... The dominant funding shifts may imply a pressure for more practical relevance, while the rise of performance evaluations has increased the pressure to publish, which may devalue practical concerns and stakeholder interactions'* (Hessels et al., 2011, p555).

The authors argue that the 'interplay' between these conflicting forces has received limited attention in science and technology studies, suggesting also that field-specific studies are required since the influence of institutional changes may differ among scientific fields as a result of their different knowledge bases and their positions within the structure of the innovation system (Hessels & van Lente, 2011, p216). With the aim of addressing this gap, the authors raise a number of questions for further research that are also helpful in guiding our exploration of how academic institutions may influence collaborative knowledge integration; we next cite two of these suggested questions: (i) *'Do new criteria, relating to the societal relevance of research results, currently count significantly in...retrospective evaluations of individuals, projects or*

[55] These authors develop a comprehensive review of the main analyses and contributions on the changes in the scientific research system referred to in this section.

organisations?' (Hessels & van Lente, 2008, p758); and (ii) *'have the changes in the science-society relationship made practical applications into a source of credibility for academic scientists...?'*[56] (Hessels & van Lente, 2011, p216).

The authors found contrasting results, depending on the research field. For example, for catalytic chemistry the authors found that application-oriented research has a positive impact on academic recognition as well as on scientists' performance in research evaluations (Hessels & van Lente, 2011). Nevertheless, opposite influences were observed for research on animal sciences. The authors observed that recognition and the orientation of research in this latter field are mostly dominated by scientific criteria; in the authors' words, performance assessment of individual researchers *'...tend to be dominated by bibliometric criteria that stimulate an inward looking perspective in which the role of societal stakeholders is marginal'* (Hessels et al., 2011, p565). In particular, the authors argue that:

> *'In* [animal production systems]...*there appears to be a mismatch between the societal knowledge demands and the existing disciplinary institutions to support the fulfilment of these demands. The new leading question...requires a combination of knowledge dealing with animal feeding, animal housing, and animal behaviour, which have traditionally been separate. ... The trans-disciplinary approach currently being developed...is not yet supported by a clearly visible international research community, scholarly organizations and established scientific journals. Journals with a respectable tradition (and a high impact factor) stem from the era of the old research system, which was oriented towards productivity enhancement'* (Hessels et al., 2011, p564).

The previous paragraphs point to a need for further research that our study has addressed to some extent. First, it was argued that little attention has been given to the 'interplay' between the influences exerted by the increasing need for application-oriented research and the upsurge of research assessment rules dominated by bibliometric indicators (Hessels & van Lente, 2011, p216). In addition, from the

[56] The second question was addressed comparatively for three sub-fields of chemistry research in the Netherlands.

literature on innovation systems, the need for research on *institutional rules* that affect how organisations perform particular internal and external activities (such as networking) in an innovation system was suggested by Edquist[57] (2005). The present research addresses these issues by exploring how academic views, local researchers' assessment institutions and 'global rules' on scientific peer-reviewed publishing shape the extent of knowledge integration accomplished by R&D groups through their collaborative research activities. It is worth noting that previous studies already mentioned have analysed either specific collaborative initiatives (Llerena & Meyer-Krahmer, 2003) or specific research fields within a nation (Hessels & van Lente, 2011; Hessels et al., 2011), but employing case studies and survey methodologies with neither an assessment of the knowledge assets being integrated nor an indicator of the extent of collaborative knowledge integration. This gap in the literature was already identified by Colombo et al. in 2006 and still requires further research contributions (Colombo et al., 2006, p1193).

The assumption underlying this study is that *collaborative knowledge integration* fosters the development of absorptive and learning capacity, and the exploitation of technological opportunities in developing countries (Viotti, 2002) hence enhancing the innovation performance of individual organisations (Nooteboom et al., 2007) and of the entire system (Carlsson & Stankiewicz, 1991, p94). At a lower level, after Van den Besselaar and Heimeriks (2001), knowledge integration across scientific and technological fields is assumed to be a process that pursues the solution of societal problems. Therefore, by characterising the relation between *academic institutions* (views, motivations, incentives and researchers' assessment rules) and *collaborative knowledge integration*, this research contributes to exploring the interplay between the conflicting forces referred to in the previous paragraph, in the particular context of agri-biotechnology R&D in Uruguay. Additionally, our exploration was conducted through a truly relational approach (rarely employed in previous system studies) by

[57] The authors refer to institutions that may encompass a single organisation, a group of organisations, communities of scientists, engineers or entrepreneurs, or the whole system. In our research, attention was given to institutional rules affecting the local community of researchers in the public sector, which encompasses the local researchers' assessment system and 'global rules' on scientific publishing and recognition (Hessels & van Lente, 2011, p233).

developing measures of complementarity between collaborating R&D groups that take into account the backdrop of the whole *knowledge-space* of the public-research (sub) system under study (see Section 2.6.2 on measurement). We subsequently test the relation between an R&D group's compliance with academic institutions (performance assessment) with such measures of complementary knowledge integration achieved by the R&D group through its collaborative relations (see the description of the methodological approach in Chapter 3).

With regard to researchers' views towards collaboration across knowledge-fields, Llerena & Meyer-Krahmer (2003) observed that researchers may be discouraged from getting involved in collaborations with partners from other knowledge fields, in order to avoid weakening specialisation, *academic performance* and thus *reputation* within their respective disciplines. The authors argued that common *incentives* in public-sector research mainly reward discipline-oriented outcomes (Llerena & Meyer-Krahmer, 2003, p79). These barriers were even reinforced by rigid disciplinary structures of some university schools and faculties (Llerena & Meyer-Krahmer, 2003). Therefore, these disciplinary structures (informal institutions at the school level in this case) accompanied by unclear or non-existent incentives at individual, organisational and research-system levels, may well have acted as an obstacle for *collaborative knowledge integration* (Llerena & Meyer-Krahmer, 2003, p85). As was suggested above, these sorts of institutional barriers are to some extent related to the influence of researchers' evaluation institutions that are reflected in disciplinary views and motivations of individual scientists or research communities that may deter researchers from engaging in more integrative collaborations between research groups or laboratories. Based on the argument above, our study pays particular attention to whether or not there is an influence of *traditional scientific assessment norms and incentives well established in the global scientific community – mostly based on peer-reviewed publication records – in supporting or hindering collaborative efforts that attempt to integrate distant complementary knowledge*. This influence is explored in the context of R&D collaborations among public research organisations (R&D groups) within the boundaries of the Uruguayan agri-biotechnology innovation system.

Such an influence is exerted before a decision to collaborate with a potential partner (that has distant complementary knowledge assets) is taken. From an empirical point of view, this can be explored in qualitative interviews but presents difficulties in terms of being assessed through a quantitative approach. Therefore, we took an ex-post assessment perspective by exploring the influence of these institutional incentives after the collaborative effort has taken place. With this aim, we developed a comparative approach that allowed us to quantitatively distinguish between: (i) R&D groups that collaboratively integrate *highly complementary knowledge* (relatively high cognitive distance from its R&D partners); and (ii) R&D groups that collaboratively integrate *less complementary knowledge assets* (comparatively lower cognitive distance from its R&D partners), namely those that achieve lower degrees of knowledge integration in their collaborative R&D activities. Once we had characterised and segregated R&D groups achieving distinctive degrees of collaborative knowledge integration, we were subsequently able to explore how the *influence of traditional academic assessment norms* may explain such differences between R&D groups. We assessed the *influence of traditional academic assessment norms* on R&D groups' behaviour by measuring the relative extent of *compliance* that individual R&D groups show with regard to such rules and incentive mechanisms (performance in scientific assessment exercises).

The present research explores the relevance of the rules and incentive mechanisms referred to above with the aim of drawing lessons for policy makers regarding the required interventions to address potentially relevant institutional drivers or barriers to inter-organisational interaction and collaborative knowledge integration. To sum up, the role and relevance of the institutional factors discussed in this section on the extent of collaborative knowledge integration (understood here as the exploitation of potentially complementary knowledge assets) are explored in this research through both qualitative and quantitative approaches. As stated earlier, the core assumption is that greater technological advancement can be achieved if system-level institutions support the development of collaborative R&D activities among public R&D groups in the agri-biotechnology system that achieve high degrees of *collaborative knowledge integration*. In the next section, we summarise the discussion we deployed throughout this chapter and synthesise it in a comprehensive conceptual framework developed for this study.

2.8 Closing remarks

Throughout this chapter we have substantiated our claim for the need of scholarly research addressing the integration of knowledge and capabilities that takes place through collaborative R&D partnerships between public research organisations within the context of emerging technological innovation systems in developing countries. Therefore we focused our attention on the process that we defined as *collaborative knowledge integration*. Our research intends to address this gap by exploring how and to what extent local knowledge assets and R&D capabilities are being integrated and exploited through inter-organisational collaborative arrangements within the emergent agri-biotechnology innovation system in Uruguay. In order to better understand these dynamics, we also explored the most relevant forces that may shape the extent of knowledge integration accomplished by the collaborating organisations.

The assumption underpinning this study is that *collaborative knowledge integration* fosters the development of absorptive and learning capacity (Viotti, 2002), and the exploitation of opportunities for the complementary aggregation of actor-level technological capabilities into system-level innovation capability in developing countries (Lall, 1992; Cimoli et al., 2009, pp337-43; Bortagaray, 2007, p354). Additionally, we assume that *collaborative knowledge integration* contributes to the solution of socially-relevant problems (Van den Besselaar & Heimeriks, 2001) and enhances the innovation performance of both individual organisations (Nooteboom et al., 2007) and the entire system (Carlsson & Stankiewicz, 1991, p94). On that basis, we formulated our main research question as follows: *How and why does the extent of scientific and technological complementarity exploited through R&D collaborations differ among collaborating actors of the agri-biotechnology innovation system in the context of developing countries?*

Our argument for the significance of collaborative processes for knowledge integration has drawn on the collective nature of innovation activities emphasised by the reviewed literature, and the increasing relevance of inter-organisational collaborations for the overall system's innovation performance – especially in emerging technological systems. The importance of studying knowledge integration through such interactions is even more salient in developing countries where specialised knowledge bases, technological R&D capabilities and funding for research and innovation activities are scarce and distributed among many actors (Viotti, 2002; Bortagaray, 2007) while interaction and coordination among actors in the system and institutions supporting them are poorly developed (Arocena & Sutz , 2002; Padilla-Pérez et al., 2009). This poor systemic functioning undermines the potential impact of local capabilities on innovation and socioeconomic development in developing countries (Arocena & Sutz, 2002; Lundvall et al., 2009b, p18). Moreover, we argued for a special focus on public research organisations (and their interactions), since they are at the centre of technological learning processes and encompass most knowledge assets and R&D activities in developing countries (Viotti, 2002; Edquist, 2005), while the private sector has a generally low technological level and a high reliance on external sources of knowledge and technological capabilities (Padilla-Pérez et al., 2009, p145).

In order to set the theoretical underpinnings of our research question, we reviewed academic literature on inter-organisational collaborations and networks, focusing particularly on non-market collaborative relations established for the purpose of conducting joint R&D activities (Heinze & Kuhlmann, 2008; Lam, 2005; Laudel, 2001). Studies of innovation systems were also reviewed in order to situate R&D collaboration and knowledge integration processes within a wider context, and taking into account that this body of research claims to follow a relational research approach that pays singular attention to the interactions and coordination between actors and components of the system (Johnson & Lundvall, 2000; Carlsson et al., 2002; Malerba, 2005). After exploring specific system perspectives for national, technological and sectoral-level studies, we provided certain conceptual foundations to set the boundaries of our study around the intersection between a sectoral and an emerging technological innovation system, and within the situational and institutional scope of a single developing country. More central for the phenomenon we want to study, we critically analysed studies of complementarity between organisations (Pfeffer, 1972; Pfeffer & Nowak, 1976; Pfeffer & Salancik, 1978; Teece, 1986; Colombo et al., 2006) and scientific knowledge fields (Rafols & Meyer, 2010; Wagner et al., 2011), paying particular attention to their empirical and methodological approaches. Within this academic literature, we reviewed studies of interdisciplinary research processes and outcomes (Wagner et al., 2011; Rafols & Meyer, 2010; Rafols, 2007) since this scholarly community has analysed the integration of complementary knowledge fields (in its various forms, be it through collaboration or other means) and developed sound empirical and methodological approaches to assess and measure *knowledge integration* processes. Finally, we also discussed extant research on the role of institutions and, particularly, public policies enabling or hindering inter-organisational interactions and knowledge integration in emergent technological systems (Lall, 1992; Padilla-Pérez et al., 2009).

Throughout our discussion in this chapter we have pointed to a number of gaps in the bodies of literature critically analysed that suggest the need for further scholarly study. We summarise in Table 2.2 below, how our research expects to contribute by addressing, to some extent, such identified gaps. Among these addressed gaps, we argue that our central contribution lies in studying the extent of collaborative knowledge integration accomplished by public research organisations and the most relevant forces shaping this process. The need for further research on *'...the contexts and processes that foster knowledge integration in research'* was highlighted by recent studies as a salient gap in extant research (Wagner et al., 2011, p24).

Table 2.2: Summary of suggested contributions to extant research

Body of literature	Proposed contributions	Supporting references
Innovation systems' studies	Development of a truly relational approach that, while encompassing the whole technological system, explores interactions and integration of capabilities among actors at lower levels of aggregation than the structural approaches predominantly used by scholars of this field.	Carlsson & Stankiewicz, 1991, p94 Carlsson et al., 2002, p236 Markard & Truffer, 2008 Arocena & Sutz, 2002
	Particular attention paid to knowledge generation dynamics and inter-organisational interactions within the public research sector, since this is the main performer of R&D activities in the context of emergent technological systems in developing countries (in contrast to developed nations)	Viotti, 2002, p673; Brundenius et al., 2009 Pittaluga & Vigorito, 2005, p174
	Exploration of how system-level institutions (particularly researchers' assessment rules and incentives) shape the extent of knowledge integration achieved by R&D groups through their collaborative research activities. It has been claimed that scientists face conflicting forces from formal institutional incentives that might affect inter-organisational interactions and the integration of complementary knowledge fields. Nevertheless, the influence of such conflicting forces in specific knowledge-fields has received little attention in science and technology studies. Previous studies have analysed either specific collaborative initiatives or specific research fields within a nation, employing case studies and survey methodologies but developing neither an assessment of the knowledge assets being integrated nor indicators of the extent of collaborative knowledge integration accomplished.	Hessels et al., 2011, p555 Hessels & van Lente, 2011, p216 Llerena & Meyer-Krahmer, 2003
Inter-organisational collaboration	Study of mostly informal R&D collaboration and knowledge integration among public research organisations within an emergent technological system in a developing country; this complements the most common approach to study inter-organisational collaborations that focuses mainly on formal relations between firms (e.g. joint ventures) or between university and industry organisations but paying little attention to collaborations at the national level.	Colombo et al., 2006 Hall, 2006
	On the access to complementary assets: Study of R&D collaborative arrangements and the factors shaping the extent to which the collaborating actors access and integrate *complementary knowledge assets* and R&D capabilities distributed throughout the system (degree of complementarity among partners' knowledge assets); this goes beyond the well-established concept of *complementary assets* proposed by Teece (1986) based on highly aggregated categories of organisational assets (e.g. R&D vs. commercial assets) that have shown no explanatory power for *exploratory R&D partnerships*, the subject of our research.	Colombo et al., 2006, p1167 Luo et al., 2009 Teece, 1986, p286
	From an empirical perspective, a survey-based method was developed for a fine-grained identification of the knowledge assets possessed by public research organisations in the technological system studied, allowing the generation of a reliable indicator for the degree of complementarity between actors. Previous studies have suggested that this deeper disaggregation of research capabilities was required for further assessment of the drivers of R&D collaborations.	Colombo et al., 2006
	We explore how organisational-level attributes such as absorptive- and relational-capability may shape the extent of knowledge integration accomplished by an actor through its collaborative R&D efforts. Previous research on inter-organisational collaboration has focused mainly on whether these capabilities allow an organisation to form new collaborations but leave unexplored if they also foster an increased quality of those collaborations in terms of the extent to which the partners provide access to distant complementary knowledge assets.	Gulati, 1995 Ahuja, 2000 Dyer & Singh, 1998

Body of literature	Proposed contributions	Supporting references
Knowledge integration	**Level of analysis - peer reviewed publication vs. the R&D project:** Assessment of knowledge integration at the level of local collaborative R&D projects between public research organisations. This approach captures the extent of knowledge integration at the *research process-level*, namely at the actual locus where the research activity and the process of knowledge integration took place. Contrastingly, the most common approach – identified as a shortcoming in this research field – has been to measure the degree of knowledge integration at the *research-outcomes-level*, looking specifically at a single type of easily observable outcome (the scientific peer-reviewed publication indexed in bibliographic databases), while overlooking the actual processes where the integration takes place (Wagner et al., 2011, p19). This literature has also paid little attention to the study of knowledge integration in geographically localised research activities, and suggested the need for further research on *'...the contexts and processes that foster knowledge integration in research'* (Wagner et al., 2011, p24) as a salient gap in this research field, to which we contribute with our assessment of the forces shaping collaborative knowledge integration.	Wagner et al., 2011, p16,19
	Cognitive and social integration assessed together: By looking at *collaborative R&D projects*, our approach provides combined information on the two main dimensions of knowledge integration**,** namely the actual knowledge assets and research-capabilities being integrated (the *cognitive dimension*) and the social interactions among organisations or R&D groups (R&D partnerships) required for the integration to take place (the *social dimension*). This is claimed to be a singular conceptual and methodological contribution of this research to the literature on knowledge integration and interdisciplinarity, since studies of knowledge integration have adopted mostly separate approaches to assess the *cognitive* and *social* dimensions of integration. On one side, scholars studying integration among scientific research fields based on bibliometric data and knowledge proximity indicators have focused mostly on the *cognitive dimension* of knowledge integration, while paying relatively little attention to the social interactions among actors involved in the integration process. On the other hand, studies of inter-organisational collaborations and networks have focused on the *social dimension* of integration, exploring patterns of relatedness or social proximity among actors within a system or network, while they mostly overlook *how* and *to what extent* these relationships among actors integrate complementary sources of knowledge and capabilities distributed throughout the system. These two perspectives are brought together in a single study here.	Wagner et al., 2011 Leydesdorff & Rafols, 2011 Rafols, 2007

Source: elaborated by the author based on the cited references and the argument set out in Chapter 2.

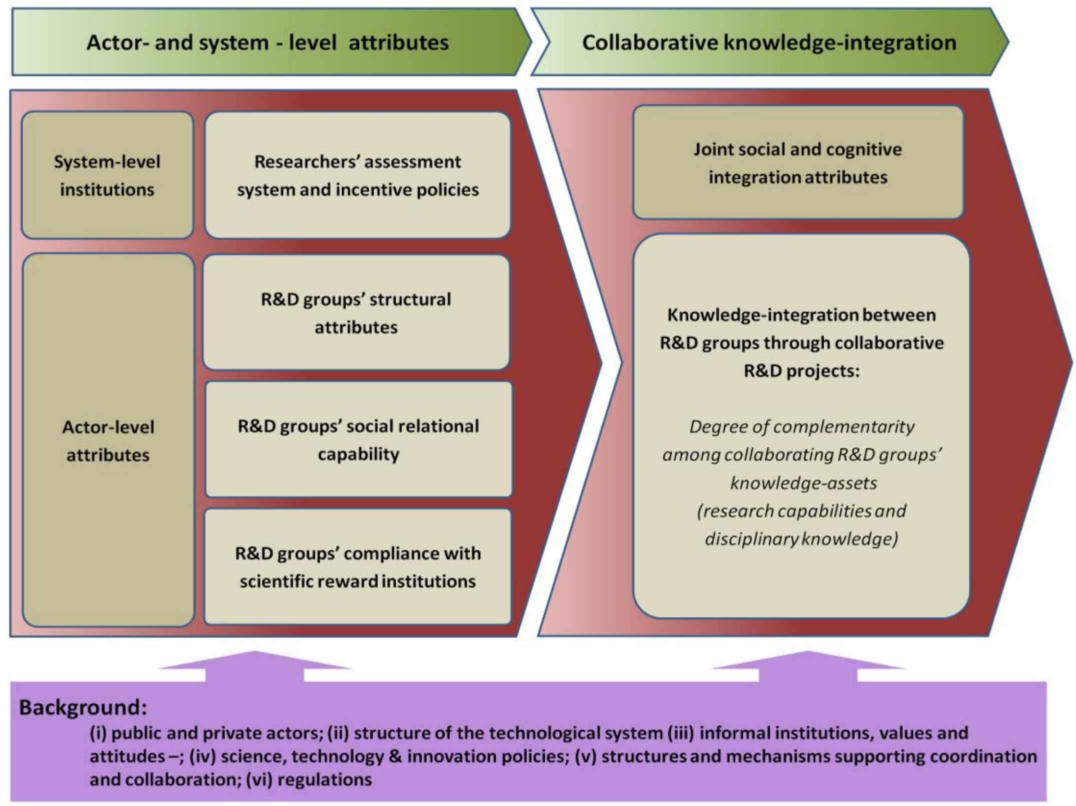
We identified a number of relevant factors driving *collaborative knowledge integration* from the bodies of scholarly research reviewed in this chapter while other forces were found to be relevant for the purpose and boundaries of this research through an inductive interpretation of a number of exploratory interviews. Moreover, we narrowed down our conceptual and empirical focus to address the overarching question by introducing and discussing the relevance of the following two more specific research questions that also guided the identification of forces shaping collaborative knowledge integration: (i) *How do system-level institutions and incentives for public sector researchers shape the extent of integration of complementary* *knowledge assets achieved by R&D groups through collaborative research activities within a developing-country agri-biotechnology innovation system?*; and (ii) *How do organisational-level attributes shape the extent of integration of complementary knowledge assets achieved by R&D groups through collaborative research activities within a developing-country agri-biotechnology innovation system?*

Guided by these two narrower questions, we subsequently interrogated the literature and our exploratory qualitative observations about how the extent of knowledge integration achieved by an organisation or R&D group through collaborative research activities might be shaped specifically by: (i) structural and relational attributes of the R&D group (absorptive and relational capacities); (ii) system-level institutions and incentives (particularly public policies supporting interaction and knowledge integration among organisations and knowledge fields); (iii) compliance of the R&D group with scientific reward institutions; and (iv) other applicable contextual conditions[58]. In Figure 2.4 we bring together the theoretical foundations of our study and the suggested causal relations[59] between the extent of collaborative knowledge integration and relevant forces that we conceptually outlined in Section 2.7. The diagram intends to concisely illustrate the overall conceptual framework on which we base the empirical work, analysis and discussion we set out in this thesis.

[58] We included here a number of factors argued to be part of the relevant background for the purpose of this research. These include: the overall structure of the technological innovation system under study; the availability and demand of trained human resources (Edquist, 2005; Viotti, 2002; Senker & Van Zwanenberg, 2001); sources of competitive funding for R&D and innovation activities (Bergek et al., 2008; Colombo et al., 2006; Heinze & Kuhlmann, 2008); sources of inter-organisational conflicts (Heinze & Kuhlmann, 2008; Arocena & Sutz, 2002); consumer perceptions; existence of intermediary mechanisms or platforms supporting non-market interactions and coordination among actors (Senker & Van Zwanenberg, 2001; Acha & Cusmano, 2005; Rafols, 2007); informal institutions; and, applicable STI policies and other regulatory norms (Senker & Van Zwanenberg, 2001). The role of these factors was explored during the desk work and interview stages of our fieldwork.

[59] We say 'suggested causal relations' since our methodological approach does not allow us to test causality.

Figure 2.4: Conceptual framework



Source: elaborated by the author

Finally, we have argued that, besides the conceptual contributions we propose to make (see Table 2.2 above), our study offers a relevant methodological contribution for the assessment of knowledge integration through inter-organisational collaboration. In particular, we developed singular quantitative indicators of the degree of complementarity between R&D groups collaborating in a research project, in order to build a measure of the extent of *collaborative knowledge integration* achieved by every single organisation or research group encompassed by our study. This required a substantial effort to adapt indicators developed in previous studies to the context of our empirical research and to build a suitable classification system of knowledge assets' categories. The proposed combined exploration of the degree of complementarity between R&D groups in terms of their knowledge assets (cognitive dimension of knowledge integration), and collaborative R&D relations among research groups developed during the implementation of R&D projects (the social dimension of knowledge integration) is presented as a distinctive element of our research. This allows us to capture knowledge integration at the *R&D process-level* (individual *R&D projects*), namely at the actual locus where research activity and *collaborative knowledge integration* take place, an approach that has been mostly absent in previous studies of knowledge integration. The next chapter describes the overall empirical methodology adopted by this study while we also discuss in more detail the methodological contribution suggested in this paragraph.

Chapter 3 - Methodology

3.1 Introduction

The present research studies how knowledge and research capabilities are integrated across organisational boundaries through collaborative R&D arrangements, a process that we define as *collaborative knowledge integration*. In particular, we have argued for the need to study how the extent of collaborative knowledge integration achieved by an organisation or R&D group through its interactive research activities might be shaped by a number of forces stemming either from the broad technological innovation system or from specific attributes of the individual organisation being assessed. In the previous chapter, we discussed the theoretical foundations underpinning our research questions and suggested contributions, which encompass academic literature on: innovation systems (with a focus on emergent technologies and sectoral systems); inter-organisational networks and R&D partnerships; complementarity among organisations' resources; and studies of interdisciplinary research – the latter understood as a research process that integrates knowledge from different scientific fields.

This research contributes to the bodies of scholarly research referred to above by means of both the singular methodological approach to measure the extent of collaborative knowledge integration accomplished by public research organisations within the context of the agri-biotechnology innovation system, and the assessment of the most relevant factors shaping collaborative knowledge integration through the conceptual framework presented in Chapter 2. The conceptual and methodological contributions rely mainly on a combined exploration of two dimensions of the knowledge integration process that takes place during the implementation of R&D projects; namely we refer to a *social dimension* given by the formal and informal linkages established between public R&D groups to conduct the collaborative research activity, and a *cognitive dimension* resulting from the relatedness between the knowledge assets controlled by the collaborating R&D groups (with similarity or distance as measures of the degree of complementarity between groups). As was argued earlier, previous studies have mostly explored these two dimensions separately. Moreover, proper relational perspectives (like the one proposed here) have been missing in previous studies of emergent technological innovation systems in developing (and even in developed) countries, since these have followed predominately structural approaches (Carlsson et al., 2002). This research expects to draw relevant lessons for policy-making in support of emergent technologies in the context of middle-income developing countries.

Based on the critical review of extant literature, in the previous chapter we discussed and substantiated a number of key arguments that should be taken into account in order to understand our research questions, empirical approach and subsequent interpretation of the results. The main argument is that *collaborative knowledge integration* fosters the development of absorptive and learning capacity at the level of the whole system in developing countries (Viotti, 2002), through the complementary aggregation of actor-level technological capabilities into system-level innovation capacity (Lall, 1992; Cimoli et al., 2009, pp337-43; Bortagaray, 2007, p354). This argument is supported by Nooteboom et al. (2007), who suggest that organisations that tend to collaborate with partners that have (on average) rather similar knowledge bases and R&D capabilities (thus reaching low levels of *collaborative-knowledge integration*) achieve comparatively lower levels of technological learning and innovation outcomes (Nooteboom et al., 2007). For the purpose of this research, it is assumed that these organisations are not exploiting opportunities to collaborate with other more distant (complementary) actors of the system, hence lessening the extent of knowledge integration, the performance of the individual organisation (Nooteboom et al., 2007) and of the system as a whole (Carlsson & Stankiewicz, 1991, p94). Similarly, we assume that *collaborative knowledge integration* contributes to the solution of socially-relevant problems (Van den Besselaar & Heimeriks, 2001) and that collaborative R&D arrangements are key determinants of the exploitation of innovation opportunities offered by emergent technologies (Geels & Raven, 2006), particularly in developing countries (Arocena & Sutz , 2002; Lundvall et al., 2009). To sum up, we assume this positive relation between collaborative knowledge integration and innovation outcomes, while focusing our questions and analysis on the factors shaping the extent to which an organisations' R&D collaborations succeed in integrating complementary knowledge assets.

We now turn to how our proposed study of collaborative knowledge integration and its most relevant driving forces was empirically carried out. Our empirical research followed a 'mixed methods' approach, combining inductive analysis of qualitative data (Dewey, 1910, p79) gathered through exploratory interviews and deductive analysis of quantitative data encompassing purposely developed indicators for collaborative knowledge integration and its main driving factors. As a brief summary of the process, we started by reviewing the bodies of scholarly literature relevant for the study of collaborative knowledge integration from a system perspective, and identifying key forces that may shape this collaborative process. We presented the outcomes of this critical review in the previous chapter together with the complete conceptual framework we developed to address our research questions.

We then embarked on our empirical work, reviewing a number of technical and policy reports in order to gain a general understanding of the structure and main dynamic attributes of the agri-biotechnology innovation system in Uruguay, and to identify key individual actors involved in this system. Subsequently, we performed exploratory interviews in order to preliminarily assess the influence being played on research collaboration and knowledge integration by the key forces identified from the literature, and to identify other relevant factors driving collaborative knowledge integration that might not have emerged from the literature review. After adjusting our conceptual framework in light of the evidence gathered through the interviews, we moved to develop a quantitative approach to empirically apply such a framework to a study of collaborative knowledge integration by public research organisations in the agri-biotechnology innovation system of Uruguay. This involved substantial efforts in developing novel indicators of cognitive distance and similarity between collaborating R&D groups, and designing and implementing a survey to R&D groups in order to collect the data required to operationalise these indicators. Finally, we statistically analysed the quantitative results and applied a spatial autocorrelation model (see Section 6.2 of Chapter 6 for details) in order to assess how differences in the extent of collaborative knowledge integration may be explained by the influence of the main driving system- and organisational-level forces identified earlier. The Table below provides an ordered list of the stages we went through in our empirical research and a description of the specific activities carried out in each stage.

Table 3.1: Empirical research process

Stage		Description and goals
1	Review of theoretical basis of the research	Preliminary literature review and identification of needs for further research. Definition of research questions. Identification of the main factors driving or hindering organisations or R&D groups to integrate external research capabilities and knowledge, and to establish collaborative relations for this purpose.
2	Conceptual framework	Development of the conceptual framework intended to analyse and explain why public R&D groups differ in the extent of collaborative knowledge integration they achieve. It was built drawing on the bodies of literature critically reviewed and preliminary findings from a deductive analysis of exploratory interviews (Stage 4 in this Table). Definition of the scope and boundaries for the empirical assessment of our research questions.
3	Desk work	Review of local technical and policy reports in order to characterise the agri-biotechnology innovation system in Uruguay. Actors' mapping: identification of incumbent organisations and R&D groups of the agri-biotechnology innovation system. Identification and selection of individual members of the R&D groups identified to be subsequently interviewed.
4	Exploratory semi-structured interviews	First stage: five pilot interviews with qualified informants in order to explore in a preliminary manner the most relevant actor- and system-level attributes at play in the processes of inter-organisational collaboration and knowledge integration within the empirical boundaries set for our study. Second stage: further exploratory interviews with R&D leaders or researchers. Exploration of the role played by specific actor- and system-level attributes identified in the literature review as the main factors shaping the collaborative integration of complementary capabilities and knowledge, and inductive identification of additional relevant factors.
5	Qualitative analysis of interviews	Analysis of preliminary results obtained from the exploratory interviews. Adjustment of the conceptual framework on the basis of these preliminary results.

Stage		Description and goals
6	Design of quantitative methods	Further review of literature on quantitative approaches to assess collaborative knowledge integration. Definition of the unit of analysis. Design of quantitative indicators to measure the extent of collaborative knowledge integration accomplished by R&D groups and the factors shaping this process. Design of classification systems to assess the knowledge assets controlled by each R&D group (R&D capabilities and disciplinary knowledge). Design of a survey questionnaire and on-line delivery platform intended to collect the data required to compute the quantitative indicators designed.
7	Implementation of survey of R&D project coordinators	Identification of agri-biotechnology R&D projects[60]: access, integration and building of a comprehensive database of agri-biotechnology R&D projects carried out in Uruguay between 1999 and 2010. On-line and phone administration of the survey questionnaire to coordinators of the agri-biotechnology R&D projects identified. Survey intended to build relational data on two dimensions: (i) social interaction among organisations or research groups during the implementation of R&D projects; and (ii) cognitive distance or relatedness among actors' knowledge assets (disciplines and research capabilities). Factors shaping knowledge integration were also assessed through this survey.
8	Analysis of quantitative results	Variables for the assessment of collaborative knowledge integration and its driving forces were computed from data collected through the survey, operationalising the indicators previously designed (stage 6). The extent of knowledge integration was conceptualised and operationalised through measures of *similarity* and *difference* among the knowledge assets controlled by pairs of collaborating R&D groups. Adaptation of a spatial auto-correlation model to analyse our quantitative data and interpretation of statistical results: examination of how differences between R&D groups in the extent of knowledge integration achieved through collaborative research, are associated with the driving forces identified previously (stages 1 and 4).

Source: elaborated by the author

The following sections describe in more detail the research work carried out during each of the stages referred to in the Table above. In particular, our work in reviewing the relevant academic literature and defining the research questions is explained in Section 3.2, while Section 3.3 illustrates the design of the conceptual framework and sets the national, sectoral and technological boundaries within which we empirically apply this framework to address our research questions. Section 3.4 portrays the desk activities we carried out, the subsequent interviewing stage and the empirical

[60] R&D projects are seen in this study as the locus of research activity where the integration of distributed disciplinary knowledge and R&D capabilities is assessed.

approach to analyse the qualitative data gathered though the interviews. Finally, Section 3.5 closes the chapter by introducing our quantitative approach designed to assess collaborative knowledge integration and its driving forces.

3.2 Review of theoretical foundations and definition of research questions

Although the critical review of extant academic literature was something of an iterative process throughout the entire study, the main work on building the theoretical basis for our study was undertaken between the formulation of our initial research proposal and the start of the fieldwork. The aim was to reach a broad understanding of the theoretical developments concerning innovation systems, R&D collaboration and knowledge integration among organisations. More specifically, it encompassed scholarly studies of emergent technological innovation systems and sectoral systems, inter-organisational R&D partnerships and networks, complementarity among organisations' resources, and studies of interdisciplinary research – that is, studies of research processes that integrate different fields of scientific or technological knowledge.

This critical review provided theoretical and empirical insights required to define the conceptual scope for our concerns on how local sources of knowledge and R&D capabilities are collaboratively integrated and exploited through inter-organisational arrangements within an emergent technological innovation system. On that basis, we then identified certain issues needing further scholarly research and formulated research questions pertinent to the various bodies of academic enquiry referred to in the previous paragraph. To be more precise, looking at the extent of *collaborative knowledge integration* as an attribute of every individual organisation involved in research collaborations, we defined our main research question as follows: *How and why does the extent of scientific and technological complementarity exploited through R&D collaborations differ among collaborating actors of the agri-biotechnology innovation system in the context of developing countries?*

Drawing also on the literature review, we discussed a number of system- and actor-level attributes that may shape the extent to which R&D capabilities and disciplinary knowledge are integrated by R&D groups though their collaborative research projects. Based on this discussion and on the outcomes of inductive exploratory interviews, we subsequently decided to focus our study on a narrow selection of specific attributes argued to be particularly relevant for the context of our research. Correspondingly, we also narrowed down our conceptual and empirical approach by defining the following two specific sub-questions for our research:

(i) *How do system-level institutions and incentives for public sector researchers shape the extent of integration of complementary knowledge assets achieved by R&D groups through collaborative research activities within a developing-country agri-biotechnology innovation system?*; and

(ii) *How do organisational-level attributes shape the extent of integration of complementary knowledge assets achieved by R&D groups through collaborative research activities within a developing-country agri-biotechnology innovation system?*

The next section illustrates how we approached these questions by first defining clear conceptual and empirical boundaries for the subsequent stages of our research.

3.3 Conceptual framework and empirical boundaries for the study

As was argued above, we focused our study on a narrow selection of attributes that are likely to shape the extent of collaborative knowledge integration achieved by R&D groups in the context of our research. The boundaries of each R&D group were empirically defined in our study through our survey to R&D project leaders, namely they were asked to report the whole list of members of the R&D group. We classified these selected attributes into three categories, namely: (i) structural and relational attributes of the R&D group; (ii) system-level institutions and incentives; and (iii) compliance of the R&D group with scientific reward institutions. After discussing the role of these attributes, we developed a comprehensive conceptual framework on which to base our empirical study of knowledge integration through collaborative research activities. An illustrative representation of such a framework has already been presented at the end of Section 2.8 above (Figure 2.4).

The actual empirical application of this conceptual framework required a clear and well-grounded definition of the boundaries for our research, even more so considering the time and resources' restrictions of a doctoral research project. We defined the boundaries for this study in terms of four dimensions, namely: (i) knowledge and technological field (Carlsson et al., 2002); (ii) production sector (Malerba, 2005; Spielman & Birner, 2008); (iii) country (Freeman, 1988); and (iv) component – or type of actor – within the innovation system (Senker & van Zwanenberg, 2001). With regards to knowledge and technological field, we first focused on emergent technologies since for this sort of field, the scientific knowledge base is complex and distributed among diverse actors. As a consequence, innovation processes related to emergent technologies are characterised as being mostly of a collective rather than an individual nature (Luo et al., 2009). As a result of this complexity in emergent technological fields, different types of collaborations – the subject of this research – represent an increasingly prevalent organisational form intended to access specialised and / or complementary knowledge (Pfeffer & Nowak, 1976; Powell et al., 1996; Luo et al., 2009).

Similarly, Malerba (2005) argues that formal or informal linkages between organisations occur more frequently when there is uncertainty with regard to (novel) technological development pathways and a need to access or learn new competences. In other words, there is an *'...increasing dependence on complementary sources of knowledge and technological advancements'* that results in a pervasive need for developing technological R&D collaborations between actors in the system (Acha & Cusmano, 2005, p3). Taking all of this into account, we set the technological boundaries for our study within the biotechnological field, a case that can still be considered as an emergent technological system in the context of developing countries[61], hence demanding sound interactions among actors in the system and the collaborative integration of local knowledge assets (Arocena & Sutz, 2002; Pittaluga & Vigorito, 2005; Fuck & Bonacelli, 2008).

In order to define the boundaries of a technological system, the technology itself ought to be clearly defined first. For the purpose of this research, we drew on an OECD (2005) report that provides two definitions of *biotechnology*, one general and one a list-based definition of *biotechnology techniques*. The general definition states that biotechnology is:

> *'The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services'* (OECD, 2005, p9).

The list-based definition is provided in the Table below. On the basis of the list-based definition of biotechnology and other sources we detail later, we developed two classifications for biotechnology R&D capabilities and disciplines respectively, which were subsequently used in the survey questionnaire to characterise the knowledge base of each R&D group (see Section 3.5). We then considered as a biotechnology R&D group or laboratory, every research unit where at least one of the biotechnology R&D capabilities and disciplines included in the classification is available in the group and applied to their research activities.

[61] We discuss why the study was conducted within the boundaries of a developing country later in this section.

Table 3.2: List-based definition of biotechnology techniques

Techniques and examples
DNA/RNA: Genomics, pharmacogenomics, gene probes, genetic engineering, DNA/RNA sequencing/synthesis/amplification, gene expression profiling, and use of antisense technology.
Proteins and other molecules: Sequencing/synthesis/engineering of proteins and peptides (including large molecule hormones); improved delivery methods for large molecule drugs; proteomics, protein isolation and purification, signalling, identification of cell receptors.
Cell and tissue culture and engineering: Cell/tissue culture, tissue engineering (including tissue scaffolds and biomedical engineering), cellular fusion, vaccine/immune stimulants, embryo manipulation.
Process biotechnology techniques: Fermentation using bioreactors, bioprocessing, bioleaching, biopulping, biobleaching, biodesulphurisation, bioremediation, biofiltration and phytoremediation.
Gene and RNA vectors: Gene therapy, viral vectors.
Bioinformatics: Construction of databases on genomes, protein sequences; modelling complex biological processes, including systems biology.
Nanobiotechnology: Applies the tools and processes of nano/microfabrication to building devices for studying biosystems and applications in drug delivery, diagnostics etc.

Source: OECD (2005, p9)

The scientific base of biotechnology includes diverse disciplines such as microbiology, biochemistry, cell and tissue culture, molecular biology, virology, genetic engineering and immunology among others (Pittaluga & Vigorito, 2005). It has been argued that this complex knowledge base may contribute to widening the gap between developed and developing countries (Arocena & Sutz, 2002; Pittaluga & Vigorito, 2005). Therefore, the integration of distributed disciplinary knowledge and R&D capabilities within the biotechnological system through effective inter-organisational arrangements is a *sine qua non* condition for innovation, even more so for developing countries which are challenged to make the best exploitation of the innovation opportunities offered by their limited and distributed resources and capabilities. The argument in this paragraph suggests focusing on developing countries as another dimension to define the research boundaries, which cannot be considered separately to the sectoral-dimension of the research boundaries.

We turn next to defining the scope of the study in terms of the second dimension referred to above, namely the sector-specific boundaries. As was argued in Chapter 2, biotechnology innovation shows divergent dynamics depending on the sector of application, hence suggesting the need to perform specific studies at the intersection between technological and sectoral systems (Senker & Van Zwanenberg, 2001, p13). When selecting the biotechnology field, we also took into consideration that biotechnology has underpinned a significant change in the dominant paradigms driving technology development in the agriculture sector for both developed and developing countries (Arundel & Sawaya, 2009). The innovation potential offered by the biotechnological paradigm to the development of the agriculture sector is notable, notwithstanding the controversies that have been taking place regarding genetically modified organisms. Moreover, agriculture in developing countries is a much more significant source of production, employment and national income (13.4 % of the GDP), compared to developed nations where agriculture accounts for 1.7 % of GDP (Arundel & Sawaya, 2009, p67). Therefore, it has been argued that '...the application of biotechnology to agriculture in the developing world could have a major impact on people, environments, and economies' (Arundel & Sawaya, 2009, p66).

As occurred in industrial sectors, during the last few decades, the increasing complexity of technology development processes has also challenged the traditional models for agricultural innovation (Hall, 2006). In particular, the emergence and rise of biotechnologies opened up broad opportunities for the agriculture sector. The exploitation of the potential of these developments in a developing-country agriculture sector goes beyond the capabilities of individual research organisations. These organisations are therefore required to coordinate and collaborate with other actors in the innovation system in order to access and integrate complementary external capabilities into their research and innovation activities.

Similarly, it has been argued that addressing complex production problems in the agriculture sector results in complementarities among diverse knowledge and technological fields (Possas et al., 1994, p20), putting pressure on the actors of the innovation system to coordinate their innovation activities. We also recall Malerba here, to substantiate the need for sector-specific studies, since sectors exhibit different patterns with regard to the accessibility to knowledge and sources of technological opportunities (Malerba, 2005). On the basis of the argument developed so far in this section, agricultural-biotechnology (and its corresponding technological system) was selected as the combined technological and sectoral boundaries setting the empirical focus for our study. So we can turn next to discuss the third scoping dimension, that is the national boundaries delineated for our empirical study of collaborative knowledge integration.

We have argued earlier that innovation processes increasingly demand the integration of knowledge and capabilities across organisational boundaries, and that such pressure is even greater in developing than developed nations (Arocena & Sutz, 2002; Lundvall et al., 2002; Chaminade et al., 2009; Padilla-Pérez et al., 2009). This greater demand for collaboration is induced by the scarcity of resources and the existence of limited R&D capabilities and skills distributed among multiple organisations (Bortagaray, 2007). In developing countries, therefore, individual organisations and whole technological systems depend to a large extent on collaborative efforts for the combination of complementary capabilities as a means to build enough scale to exploit emergent technological and innovation opportunities (Padilla-Pérez et al., 2009; Cimoli et al., 2009). This makes this sort of country a particularly suitable context for our proposed study.

To be more precise, we conducted our empirical exploration of collaborative processes for knowledge integration within the geographical and political boundaries of a single developing country, namely Uruguay. Therefore, we discuss below the rationale for the selection of this country. In general terms, Uruguay was found to be a potentially fruitful case for addressing the research questions we put forward and particularly for applying the conceptual framework developed for our study. Previous studies have found significant barriers for the exploitation of local skills and R&D capabilities through interactive learning processes in Uruguay (Bortagaray, 2007). In particular, it has been argued that developing collaborative linkages among local actors is weakly institutionalised throughout its agri-biotechnology innovation system (Bortagaray, 2007, p273). Specifically within the public research sub-system, which accounts for most of the R&D investment in Uruguay (67 %; DICYT, 2010), institutional barriers stemming from researchers perceiving other local R&D groups mostly as competitors rather than as potential partners have resulted in innovation processes that usually take place as somewhat isolated efforts (Bortagaray, 2007, pp78, 274).

The argument above portrays the atomisation of actors within the agri-biotechnology system in Uruguay as well as the poor coordination and interactions among organisations. The isolated nature of innovation hinders the deployment of interactive learning processes (Bortagaray, 2007) and undermines the potential impact of local capabilities on innovation performance of the technological system as a whole, and hence on economic growth and development (Lundvall et al., 2009; Lundvall et al., 2009b, p18). Consequently, in her study of agri-biotechnology innovation in Uruguay, Bortagaray pointed to the need of further research on '...how and why are interactions blocked or feared...[and] what mechanisms are preventing researchers from articulating knowledge areas and cognitive approaches' (Bortagaray, 2007, pp357). The overall picture emerging from these previous findings makes clear the need to conduct a study of key factors affecting the collaborative integration of complementary sources of knowledge and R&D capabilities within the empirical boundaries of Uruguay and its emergent agri-biotechnology system. We should also acknowledge that other reasons to select Uruguay included the personal academic interests of the author and practical issues regarding the implementation of the empirical research such as the possibility of gaining access to a broad set of data sources in Uruguay.

Up to this point, we have focused on the rationale for defining the limits of our research around the agricultural-biotechnology innovation system in Uruguay. We end the section discussing the final boundary-setting dimension. Namely, beside the sectoral boundaries around agriculture (Malerba, 2005; Spielman & Birner, 2008) and the biotechnological system (Carlsson et al., 2002; Senker & van Zwanenberg, 2001), the specific component of the technological system on which we choose to focus our analysis of collaborative knowledge integration processes. To define this specific component, we drew on Senker and van Zwanenberg (2001), who studied biotechnology innovation systems in European countries. The authors explored the main determinants of biotechnology-innovation through an analytical framework that divided the system into the following four component-networks: (i) knowledge and skills – located in public scientific and technological research organisations; (ii) industry and supply; (iii) demand and social acceptability; and (iv) finance and industrial development (Senker & van Zwanenberg, 2001, p21).

It has been argued that knowledge and skills networks (Gelsing, 1989) of an exploratory nature play the most relevant role in the early stages of an emergent technological system, while exploitation-networks become relevant in the later development of the technological system (Wörner & Reiss, 1999). Additionally, for emerging technologies in small developing countries such as Uruguay, public research organisations possess most R&D capabilities, and consequently share the largest part of R&D and technology adaptation activities performed in the system while the private-sector usually exhibits a weak participation in R&D activities (Viotti, 2002; Padilla-Pérez et al., 2009; Brundenius et al., 2009). Therefore, approaches to studying emergent technological systems in these contexts must pay great attention to the dynamics of knowledge generation in the public domain and to the patterns of inter-organisational interaction and knowledge integration processes among public R&D organisations (Spielman & Kelemework, 2009, p18; Arocena & Sutz, 2002; Hall, 2006). Taking this into account as well as the fact that our research focus was on the agri-biotechnology innovation system in Uruguay which is still in an emergent stage (Bortagaray, 2007), the study of patterns of collaborative knowledge integration has looked only at the public *knowledge and skills component*, particularly at collaborations occurring in the context of publicly funded R&D projects. Another reason to focus on this single component-network of the system was to keep the amount of research work manageable within the time and resource limits of a doctoral research programme, taking into account that our proposed micro-level exploration of knowledge-assets controlled and collaboratively integrated by R&D groups represents a demanding fieldwork effort.

This research only considered collaborative R&D projects, while other types of collaborations such as technology transfer agreements (e.g. licensing and subcontracting) and technical assistance or consulting services (Faulkner & Senker, 1994; Fuck & Bonacelli, 2008) were not encompassed within the data collected, since these types of links were more difficult to identify in a systematic way. Therefore, this study focused on the analysis of knowledge-integration processes taking place in the context of horizontal links between public actors involved in research and technology development. Public research organisations need to establish synergistic linkages and complement their own capabilities in order to enable R&D processes based on distributed sources of knowledge and skills. Particular attention was given to these types of linkages on the assumption that they play a key role in allowing the exploitation of scarce and scattered sources of knowledge distributed throughout the system and their complementary aggregation for the development of system-level absorptive capacity (Viotti, 2002). Finally, regarding the relevance of informal linkages, Faulkner and Senker (1994) and Liebeskind et al. (1996) found that for the biotechnology sector, informal linkages between organisations played a significant role and were even more extensive than formal linkages. Therefore, the methodological approach considered not only formal but also informal collaborations between R&D groups or organisations[62].

To sum up, following the arguments presented in this section, the definition of the limits and general background for the empirical study of knowledge integration during collaborative R&D activities was based on the boundaries set by the intersection between the emergent biotechnological innovation system (Bergek et al., 2008; Markard & Truffer, 2008) with agriculture as the sectoral system (Malerba, 2005), within the national limits of Uruguay. Therefore, the analysis of structural and contextual system attributes such as informal institutions, science-technology and innovation policies, involved actors, and interaction support mechanisms was delimited by the boundaries of the Uruguayan agri-biotechnology innovation system. Our central analysis of the integration of disciplinary-knowledge and R&D capabilities by means of inter-organisational collaborative R&D activities was narrowed to the R&D collaborations among public research organisations encompassed within the knowledge, technological and geographical boundaries referred to above.

[62] The survey of R&D project leaders asked about both types of collaboration.

3.4 Exploratory desk work and interviews

3.4.1 Introduction: the data collection process

The initial stages of the fieldwork had an essentially exploratory nature. The main goals of these initial stages were narrowing down the *'conceptualisation of the research problem'* that we provisionally derived from the literature review (Oppenheim, 1992, p51), and gathering general descriptive information about the structural and dynamic attributes of the technological system under study. The exploratory stage encompassed the desk work activities described in Sections 3.4.2 and 3.4.3 (analysis of background conditions and identification of incumbents) and exploratory interviews with qualified informants and researchers, these being conducted as described in Section 3.4.4. Subsequently, quantitative data were gathered through a survey questionnaire delivered to R&D project coordinators in order to validate the preliminary findings drawn from the interviews and to assess the most relevant forces that may influence the process of collaborative knowledge integration. The overall data-collection process and corresponding sources for the present study are summarised in Table 3.3 below.

Table 3.3: Sources of information and data-gathering instruments

Subject	Sources	Data gathering instrument
Background information: system structure; locally available biotechnologies; higher education programmes; R&D funding; mechanisms supporting collaboration; informal institutions; attitudes towards collaboration; IPR and other relevant policies and regulations etc.	Previous policy studies or technical reports; competitive R&D funding agencies; National Agency for Research and Innovation (ANII); regulation acts.	Document review and analysis.
	Representatives of individual actors.	Pilot semi-structured interviews.
Identification of: (i) incumbent organisations, research groups, laboratories and individual researchers.	Previous policy studies or technical reports; researchers' CVs and publication records; Websites of research organisations.	Document review and analysis; National Researchers System database. Review of relevant websites.
(ii) research activities (R&D projects) and responsible organisations or R&D groups.	Records and databases of R&D projects funded by the main research and funding bodies in Uruguay.	Access, compilation and analysis of R&D projects' databases.
Exploration of main drivers and barriers for the integration and exploitation of complementary knowledge assets through R&D collaboration.	Representatives of incumbent actors identified (e.g. researchers from universities, research institutes and input-supplier firms).	Semi-structured interviews.
	Coordinators of agri-biotechnology R&D projects.	Survey questionnaire.
Identification of: (i) R&D capabilities and disciplinary knowledge available in each R&D group; (ii) inter-organisational R&D collaborations of a formal or informal nature; and (iii) other structural attributes of the group.	Coordinators of agri-biotechnology R&D projects.	Survey questionnaire.

Source: elaborated by the author

3.4.2 Exploration of the agri-biotechnology innovation system in Uruguay

Uruguay is a small developing country with 3.3 million inhabitants (INE, 2012a). Its population is highly concentrated in urban areas (94.7 %), particularly in its capital city, Montevideo, which has 1.3 million inhabitants – 39.7 % of total population of Uruguay (INE, 2012b). Such a concentration in the capital city is reflected also in the distribution of production units and research organisations throughout the country. The National Firms Register showed that 63.7 % of the Uruguayan firms are located in Montevideo (INE, 1996 cited by Pittaluga & Vigorito, 2005). Similarly, scientific and knowledge production capabilities of the country show even higher concentration in the capital city.

The following figures reflect the abovementioned concentration. The main research organisation in Uruguay is the University of the Republic (UdelaR) which is the single public university in the country. It encompasses around 80 % of the researchers and 90 % of the graduate students in Uruguay (Bértola et al., 2005). A census conducted by UdelaR in 2012 recorded 85.905 students out of which 94.9 % were based in Montevideo (UdelaR, 2013). Similarly, 88 % of the teaching and research staff of UdelaR are based in Montevideo (UdelaR, 2002).

Within the background conditions described above, the preliminary data collection stage was based on a review of previous studies and technical reports on the Uruguayan innovation system, with a focus on the agri-biotechnology field. The intention was to gain a thorough understanding of the main features of the technological system under study in order to become acquainted with the key conditions surrounding our subsequent empirical application of the conceptual framework proposed for the analysis of collaborative knowledge integration and its main shaping forces. In particular, we explored contextual descriptive features of the structure of the system such as: (i) the main incumbent actors; (ii) higher education programmes and other policies supporting the science base (Viotti, 2002); (iii) key technology and innovation policies; (iv) availability of R&D funds for public and/or private actors; (v) IPR regulations and other relevant agricultural and industrial policies (Senker & Zwanenberg, 2001); (vi) patterns of R&D collaboration among actors; and (vii) scientists' attitudes towards knowledge-sharing and institutional incentives to participate in collaborative research (Arocena & Sutz, 2002; Hall, 2006; Hessels & van Lente, 2011). The sources of data used for this background characterisation of the system included previous research and policy reports, specific organisational websites, industry databases, and academic and technical publications. Additionally, five pilot exploratory interviews with qualified informants were carried out with this same purpose of arriving at a preliminary contextual description of the technological system under study.

3.4.3 Desk work: identification of incumbent actors within the agri-biotechnology system

Prior to interviewing, the data collection approach allowed an exhaustive identification of the relevant incumbent actors of the agri-biotechnology innovation system. We gathered information from diverse sources, comprising previous studies (Pittaluga & Viogorito, 2005; Biotecsur, 2008a), websites of public research organisations, researchers' CVs (SNI, 2011) and industrial databases (MIEM, 2011). In order to complement these sources, we subsequently gained access to project databases of the most relevant R&D funding agencies and agricultural research organisations in Uruguay (see Table 3.4 below[63]). The incumbents' identification process was disaggregated to the level of individual R&D groups or laboratories, on the assumptions that in public research organisations decisions on and coordination of the research agenda take place mostly at the level of individual R&D groups.

Table 3.4: Sources of data for the identification of R&D projects and public research groups

Organisation or programme	Acronym
The National Agency for Research and Innovation (ANII)	ANII
Technological Development Programme from the National Direction of Science, Technology and Innovation (Ministry of Education).	PDT
Fund for the Promotion of Agricultural Technology (FPTA) sponsored by the National Agricultural Research Institute (INIA)[64]	FPTA-INIA
Sectoral Commission of Scientific Research of the University of the Republic (UdelaR)	CSIC[65]
The National Agricultural Research Institute R&D portfolio	INIA

Source: elaborated by the author

[63] A detailed description of the work on compiling and cleaning these R&D project databases is presented in Section 6.2.8. A survey questionnaire sent to the coordinators of selected R&D projects (as described in also in Section 6.2.8) allowed further improvement in the identification of incumbent R&D groups.

[64] These are R&D projects competitively funded by INIA but carried out by other organisations.

[65] The CSIC database covers the whole project portfolio of UdelaR (the acronym for the University of the Republic), which is the single public University in Uruguay.

Notwithstanding the fact that our analysis of collaborative knowledge integration was mainly focused on public research organisations[66], the identification of actors, descriptive work and exploratory interviews also encompassed private actors such as the suppliers of agriculture inputs that produce and/or sell biotechnologies to the agriculture primary sector. The main outcome of this stage was building both: **(i)** a single systematic incumbents' database, disaggregated to the level of R&D groups; and **(ii)** a database of scientists, R&D leaders, and other individuals involved in R&D activities performed by the incumbent entities. In table 3.5 below we present a descriptive summary of the whole set of actors identified through the work described in this section.

Table 3.5: Main organisations and number of R&D groups involved in biotechnology research

#	Organisation	R&D groups
1	Agronomy School, UdelaR[67]	16
2	School of Natural Sciences, UdelaR	24
3	Engineering School, UdelaR	5
4	School of Medicine, UdelaR	9
5	School of Chemistry, UdelaR	21
6	School of Veterinary, UdelaR	14
7	Pasteur Institute of Montevideo (IPM)	7
8	Hygiene Institute, UdelaR	3
9	Institute of Biological Research, *Clemente Estable* - IIBCE	10
10	National Agricultural Research Institute (INIA)	12
11	Technological Laboratory of Uruguay (LATU)	3
12	Ministry of Husbandry, Agriculture and Fisheries (MGAP)	4
	Other organisations	4 [68]
Total number of R&D groups identified		**132**

Source: elaborated by the author based on the complete record of identified actors (Appendix 8.2)

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[66] We refer particularly to research groups, laboratories, departments and individual scientists in public research organisations such as universities and applied research institutes.

[67] We show disaggregated figures for each School of UdelaR (University of the Republic), since they operate in a fairly autonomous way and are actually located in physically distinct sites or campuses (Bortagaray, 2007).

[68] These include one group from each of the following organisations: Ministry of Public Health; Uruguayan Wool Secretariat-SUL; Catholic University of Uruguay-UCUDAL; and the National Seed Institute.

As shown in the table above, we identified a total of 132 public R&D groups involved in biotechnology research activities, whether related to the agriculture sector or not. This total includes all sources of data we had access to, so it also encompasses R&D groups identified through the survey conducted after the interview stage. A previous study of the biotechnology innovation system in Uruguay identified 71 public R&D groups or laboratories (Pittaluga & Viogorito, 2005, p275). As far as we are aware, there have been no subsequent systematic assessments of the actors involved in biotechnology research and innovation in Uruguay. Therefore, we can justifiably claim that our study provides perhaps the most exhaustive identification of public research organisations and individual R&D groups available to date in Uruguay. From the entire set of public actors identified (132), 114 R&D groups perform research that is related to the agriculture sector to a greater or lesser extent. Besides these public research groups, 33 private organisations were also identified (MIEM, 2011), 21 of them involved in the development and/or commercialisation of biotechnologies for the agriculture sector (see appendix 8.3). Therefore, for subsequent stages of our study, the combined set of 114 public R&D groups and 21 firms represents our target population or 'sampling frame' (Oppenheim, 1992), namely all actors included within the boundaries of the agri-biotechnology innovation system in Uruguay.

Finally, we built a database of individual scientists, R&D leaders, representatives of local biotechnology firms, and other individuals involved in R&D activities performed by the incumbent entities. Our database encompassed information for 145 individuals from 52 public R&D groups (112 individuals) and 33 private actors. Seen from a broader level, 10 out of the 12 main public research organisations[69] listed in table 3.5 are represented by the representatives (112) of public R&D groups (52) included in our database. It is worth noting that this latter database was not intended to encompass every scientist and individual involved in agri-biotechnology R&D but to provide personal, affiliation and contact information for representatives of the most relevant

[69] Only organisations 11 and 12 from Table 3.5 (which comprise 7 out of 132 R&D groups) were not encompassed by our database on individuals.

R&D organisations in the technological field as potential candidates for the subsequent interview stage described in the next section.

3.4.4 Exploratory semi-structured interviews

After the work on identifying incumbents, a preliminary investigation of likely explanations for the research questions presented in Section 3.3 was carried out through a number of exploratory semi-structured interviews with members of public R&D groups and representatives of private actors involved in agri-biotechnology R&D in Uruguay. The goals of the interview stage of this study are reflected in methodological insights from Oppenheim (1992), who claims that: *'...the exploratory interview is essentially heuristic: to develop ideas in research hypotheses rather than to gather facts and statistics. It is concerned with trying to understand how ... people think and feel about the topics of concern to the research. ...* [The exploratory interviews can] *throw up new dimensions to be studied, suggest many new ideas and hypotheses'* (Oppenheim, 1992, pp67-8). Interviewees included: (i) researchers from groups, laboratories or departments in different types of public research organisations (universities; basic research institutes; technological R&D institutes; industrial support service organisations); and (ii) R&D coordinators from firms involved in biotechnology R&D and innovation, mostly suppliers of agriculture inputs or molecular diagnostic services. Interviewing was performed in two stages, the first being intended to pilot the interview questionnaire with a few respondents before conducting the remaining interviews.

Departing from the individuals' database built as described in the previous section, we selected a 'judgement sample' (Oppenheim, 1992) comprising 65 researchers representing 49 R&D groups from 10 public research organisations (out of the 12 organisations identified as listed in table 3.5). Additionally, the sample included representatives of 15 biotechnology firms related to the agriculture sector (out of 21 private actors identified – see previous section). The selection criteria were chosen so as to ensure broad coverage and include most types of organisations involved in R&D activities within the agri-biotechnology innovation system in Uruguay (Oppenheim, 1992). We subsequently sent letters to each sampled member of public R&D groups and firms' representatives, asking them for an interview (see the letter content in Appendix 8.4).

A preliminary semi-structured interview protocol was developed as a guide for the exploratory interviews. First, five pilot interviews were carried out in order to test this preliminary questionnaire and gain initial insights on agri-biotechnology R&D and innovation in Uruguay (see final interview questionnaire in Appendix 8.1). We were finally able to perform 25 interviews (including the pilot ones), 17 of them with members of public R&D groups along with 8 interviews with representatives of local biotechnology firms. In terms of coverage, it is worth noting that ten out of the twelve main public research organisations listed in table 3.5 (our target population) were included among the affiliations of our 18 interviewees from public R&D groups. Therefore, one can argue that our judgement sample is broad enough to accomplish the exploratory purposes of the interview stage.

Besides the objective described above, all interviews were intended to permit a preliminary grounded exploration of actor- and system-level attributes[70] that may have an influence on collaborative processes for knowledge integration among R&D groups in the empirical context of the Uruguayan agri-biotechnology R&D system. Besides a broad identification of the forces at play, this interview stage was intended to provide evidence for the selection of the most relevant attributes and forces shaping collaborative knowledge integration. Such a narrow selection represented the basis for the subsequent finer assessment through a detailed quantitative approach, which was specifically developed for this study as described in Section 3.5. Before this, Section 3.4.5 sets out the empirical approach followed for the analysis of the material gained from the interviews.

[70] Either those initially identified in the literature review or other unpredicted attributes.

3.4.5 Qualitative analysis of interviews

The exploratory interviews were recorded, transcribed and analysed using the conceptual framework described in Sections 2.8 (Figure 2.4) and 3.3. Besides the actual questions put to interviewees (appendix 8.1), in order to analyse the interview transcripts we read and critically examined them, first trying to gain a general understanding of background conditions around inter-organisational research collaborations and the integration of complementary knowledge assets among R&D groups, and subsequently seeking evidence on more specific issues such as: (i) What are the goals and motivating factors that drive organisations or R&D groups to pursue collaborative efforts for knowledge integration?; What are the internal and external incentives for R&D groups?; (iii) What might be preventing actors from collaboratively integrating distant complementary knowledge?; and (iv) What are the main risks they perceive when sharing and integrating knowledge through collaboration?

Addressing these questions allowed the characterisation of the most relevant types of collaborations between actors in the system, and the key drivers for collaborative knowledge integration as well as the sorts of complementarities among actors' scientific and technological capabilities that are exploited through collaborative R&D. Valuable qualitative evidence was obtained on the influence that certain factors provisionally suggested by the literature review have on processes of collaborative knowledge integration within the empirical boundaries of this study. We refer amongst others to the role of: (i) institutional incentives for scientists, particularly those related to national researchers assessment norms; (ii) scientists' perceptions and attitudes towards knowledge-sharing; (iii) institutional mechanisms or intermediary structures that support coordination and collaboration among R&D groups; and (iv) other applicable science, agriculture and industrial policies[71]. It was difficult to find clear *qualitative evidence* on the role of the attributes of the R&D group such as its absorptive capacity, the degree of the qualifications of its researchers or its relational capability, so a deeper analysis of these factors was left to the *quantitative* study.

[71] The latter three attributes were finally considered as part of the general (background??) context of the technological system studied, given the difficulties in establishing causal relations between them and inter-organisational collaborative knowledge integration.

Finally, indications of other relevant forces were gathered from the interview transcripts despite not being previously identified from the literature review. We refer, for example, to the patterns of mobility of the R&D group members, particularly among postgraduate research students, as a factor that may support inter-group boundary crossing.

To sum up, the general understanding gained through the desk work and exploratory interview stages described in Section 3.4 allowed a finer definition of the conceptual framework developed for our study. On that basis, the set of factors shaping collaborative knowledge integration to be subsequently analysed through the quantitative approach (described in Section 3.5 below) was narrowed down to only some of the factors or attributes listed in the previous paragraph, while others were moved to the background of the research. Drawing on the results of both the interview stage and the literature review, we developed likely explanations regarding the relation between the four attributes described in the conceptual framework (Section 2.8, Figure 2.4) and the extent of knowledge assets' integration achieved by R&D groups through their involvement in collaborative research projects. These potential explanations are laid out in Chapter 5 and subsequently analysed through the quantitative study, the results of which are presented in Chapter 6.

3.5 Quantitative method and final considerations

Once the conceptual framework and the set of core actor- and system-level factors to be further assessed had been narrowed down (Section 2.8, Figure 2.4), attention turned to developing a quantitative approach for performing statistical tests of the relation between the behaviour of such forces or attributes and the relative extent of knowledge integration achieved by R&D groups through their collaborative research activities. Therefore, the attributes encompassed by the framework had to be operationalised into a set of reliable quantitative indicators. A particularly challenging task was 'measuring' knowledge assets controlled by single R&D groups, and subsequently transforming these measures at the level of single R&D-groups into a quantitative relational measure of the *degree of complementarity* between the knowledge assets of every two R&D groups that jointly worked in a collaborative research project. This measure of the *degree of complementarity* between two collaborating R&D groups actually provides a quantitative indicator of the extent of knowledge integration accomplished by those two groups through their joint research activity. As noted earlier, knowledge integration has been defined *'...as a process in which previously different and disconnected bodies of research become related'* (Rafols & Meyer, 2010, p266). In order to develop these indicators, a complementary review of theoretical and methodological publications on the assessment of complementary knowledge integration was carried out. We present a comprehensive description of the quantitative approach in Chapter 6.

We have presented, throughout this chapter, a thorough description of the empirical approach we followed to address our research questions. Beforehand, we presented a rationale for the definition of empirical boundaries of our study in three dimensions, namely, the technological, sectoral and national boundaries. In brief, the methodology stages described encompassed: (i) a review of technical and policy reports intended to provide a broad understanding of the main structural and dynamic attributes of the agri-biotechnology innovation system in Uruguay; (ii) a systematic identification of incumbents (public R&D groups and private organisations); (iii) identification of publicly-funded agri-biotechnology R&D projects conducted in Uruguay; (iv) exploratory interviews intended to preliminarily assess the main forces shaping research collaboration and collaborative knowledge integration; and (v) the development of a quantitative approach to measure collaborative knowledge integration and test our proposed conceptual framework within the empirically boundaries of the agri-biotechnology innovation system of Uruguay; this quantitative assessment required the collection of data through a survey questionnaire delivered to coordinators of the relevant R&D projects identified. We turn now to present, in Chapter 4, our first set of empirical results, which provide an overview of the main structural components and dynamic attributes of the agricultural biotechnology innovation system in Uruguay.

Chapter 4 - Agriculture and agri-biotechnology development in Uruguay

4.1 Introduction

We argued earlier (in Chapter 2) for the need to narrow the boundaries of our research to a specific emergent technological field and its application in a single sectoral system within a particular country. Then, in Chapter 3 we set out a rationale for the selection of biotechnology, agriculture and Uruguay as the relevant boundaries for our empirical study of collaborative knowledge integration. Further substantiation for that rationale is provided in the present chapter. Once the empirical boundaries were set and before going down to lower levels of aggregation, our initial empirical work explored the general structure and components of the Uruguayan agri-biotechnology innovation system, with a particular focus on the organisation and activity of the public research sub-system.

This chapter is intended to document the results obtained from the preliminary empirical stage referred to above. While this work involved mostly a desk examination of previous empirical evidence, we provide supporting observations from our semi-structured interviews in order to address various exploratory questions such as: *(i)* What is the relevance of technology for agricultural development in Uruguay? *(ii)* What are the main components of the agri-biotechnology innovation system in Uruguay? *(iii)* What are the main areas and local applications of biotechnology R&D? *(iv)* Where are biotechnology R&D capabilities located? *(v)* What are the major patterns of collaboration and knowledge integration among public research organisations? And, *(vi)* which are the main system-level institutions shaping R&D activities and research collaboration? By focusing particularly on questions *i* to *iv*, the content of this chapter deliberately follows a rather descriptive approach intended to situate the further exploration of collaborative processes for knowledge integration within the relevant background conditions. Though questions *v* and *vi* are partially addressed in this chapter, a deeper examination of the dynamics of collaboration and knowledge integration among public research organisations and its driving forces is provided in Chapter 5.

The remainder of this chapter is structured as follows. Section 4.2 presents the expanded rationale for the definition of the empirical boundaries for our study. Section 4.3 illustrates the main structural components of the agri-biotechnology innovation system in Uruguay; it is divided into five sub-sections that respectively address: (4.3.1) the education domain; (4.3.2) the research sub-system; (4.3.3) the private sector; (4.3.4) science, technology and innovation policies; and (4.3.5) bridging mechanisms supporting coordination and interaction among actors. Finally, Section 4.4 concludes with a brief summary and some final remarks.

4.2 The empirical setting: agriculture and biotechnology in Uruguay

This section starts by discussing the importance of the sectoral setting we have defined and its implications for our empirical research. Agricultural production is still one of the main economic activities of many developing countries and Uruguay is no exception to this[72]. Therefore, less developed countries rely on the improvement and development of new agricultural technologies as a source of innovation and economic welfare. As part of a more general trend in scientific and technological research (Gibbons et al., 1994), agriculture is facing significant changes in the models of knowledge generation and an increasing complexity in the technology development process (Hall, 2006; Hessels et al., 2011).

Agricultural research increasingly demands multidisciplinary approaches to problem solving, skills in sustainable agriculture production systems, modern biotechnological techniques, and the availability of up-to-date research tools and equipment. These factors, together with the increasing prevalence of intellectual property rights on plant varieties, the protection of specific genetic sequences and biotechnological research techniques, constitute a highly complex environment characterised by an increasing division of labour and higher costs of the technology development process. Such an

[72] To provide some figures, agriculture-related products accounted for 85% of Uruguayan exports (from July 2013 to June 2014); this figure comprises 55% of the exports accounted for by raw primary agricultural products while industrialised agriculture products represented 30% of overall national exports (BCU, 2014).

increasingly complex context for agricultural technology development creates threats to the effective performance of agricultural research organisations and firms in the developing world as a source of new technologies (Sumberg et al., 2012; Janssen & Braunschweig, 2003; Possas et al., 1994). These organisations are not able to cope with the research and development processes alone so increasingly they need access to external sources of knowledge and capabilities, and to integrate these into their technology development processes in order to effectively keep up-to-date with the latest technological developments (Heinze & Kuhlmann, 2000; Salles-Filho et al., 2006).

Turning now to the location and technological dimensions, previous research has shown that the factors shaping collaboration and the exchange and integration of knowledge between actors in a sectoral system are situation-specific, varying across countries (Giuliani & Arza, 2008). Furthermore, agricultural technology development has a location-specific character due to differing agronomic and climatic conditions across geographic regions and countries (Possas et al., 1994[73]). In addition, since the institutional and cultural set-up affecting innovation significantly differs among countries (Senker & Van Zwanenberg, 2001), reaching a full understanding of collaborative research and knowledge integration processes within a single country, this is already a rather fertile field for social science research. Therefore, the development of biotechnologies for the agriculture sector will have singular characteristics depending on the country's institutional setting and the agronomic and climatic conditions of the corresponding geographical region, both of which also raise specific technological problems. These locational specificities of agri-biotechnology research activities underpin the relevance of empirically studying knowledge integration processes at the level of a single country. Taking into account the importance of situation-specific studies, and that the emergence of new technologies requires the exploitation of distributed sources of knowledge and competences of disconnected sub-systems (Bergek et al., 2008) – something that is particularly salient in developing countries (Arocena & Sutz, 2002, p11) –the boundaries of this research

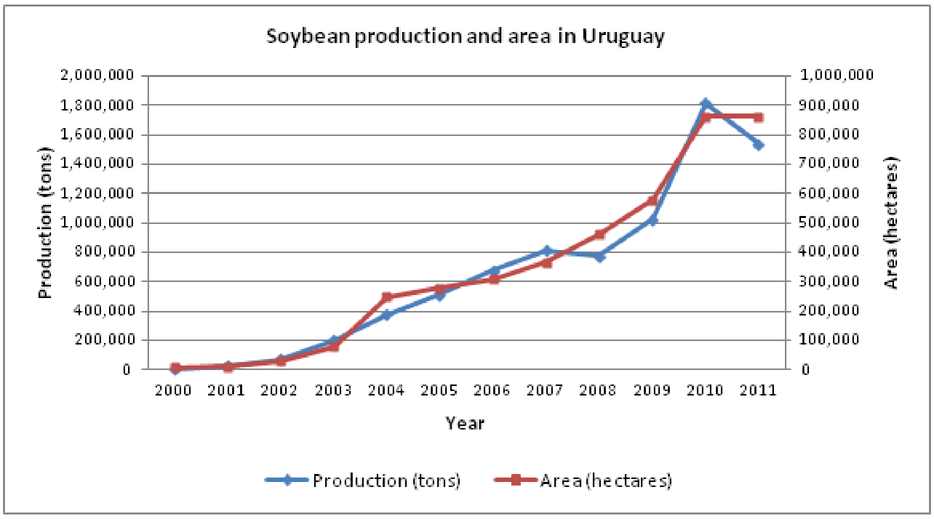
[73] The authors argue that interactions between soil, climate and living organisms create technological features that are specific to such location-specific conditions.

were set around the public research sub-system related to agri-biotechnology R&D in Uruguay.

We argued in Chapter 3 that Uruguay is an interesting case in which to empirically apply our conceptual framework. Previous studies have observed poor coordination and limited collaborative interactions among actors in the Uruguayan agri-biotechnology system, painting a picture of dispersed and relatively unconnected actors and rather isolated innovation efforts (Bortagaray, 2007, pp78 and 274). Such a weak interaction pattern undermines the potential impact of local capabilities on the innovation performance of the technological system as a whole (Lundvall et al., 2009; Lundvall et al., 2009b, p18). Despite attributing some of these interaction problems to institutional barriers, no clear answers were found in this study as to '...how and why are interactions blocked or feared...[and] what mechanisms are preventing researchers from articulating knowledge areas and cognitive approaches' (Bortagaray, 2007, pp357). Aligned with our research questions and conceptual framework, these findings clearly suggest the need for further examination of key factors that may be affecting the collaborative integration of complementary knowledge assets within the empirical boundaries of Uruguay and its emergent agri-biotechnology system. Hence, we now provide an overview of the importance of biotechnology for Uruguayan agriculture.

In Uruguay, as in other South American counties such as Argentina, Brazil and Paraguay, biotechnology has underpinned a profound transformation of the agricultural sector, mainly due to the expansion in the areas cultivated with transgenic soybeans (Arbeletche & Gutierrez, 2010). As can be seen in Figure 4.1, the adoption of this transgenic crop resulted in a sharp increase in the area cultivated with soybeans, starting from a marginal value in the year 2000 to more than 850000 hectares in 2011 (FAOSTAT, 2013). The contribution of soybeans to the gross value of agricultural production rose from almost zero in the year 2000 to as high as 27 % in 2008 (Arbeletche & Gutierrez, 2010, p114). While this significant economic impact is actually the result of the local adoption of a single biotechnology developed by a foreign company (i.e. transgenic soybeans[74]), it demonstrates the huge potential that building national capabilities may have on the development of locally adapted agri-biotechnologies and hence for the economic development of the country.

Figure 4.1: Soybean production and cultivated area in Uruguay by year



Source: elaborated by the author based on FAOSTAT (2013)

For emerging technologies to finally translate into innovations, factors such as the perceptions of future consumers play a key role in influencing the direction of the incumbent actors' expectations and hence the final technological trajectories (Geels & Raven, 2006). As a pertinent example, consumer beliefs were a key determinant in the development of agricultural biotechnologies in Europe (Senker & Van Zwanenberg, 2001). Despite having a well-developed knowledge base and scientific capabilities, negative public perceptions with regard to genetically modified organisms and the subsequent refusal of food retailers to buy food products with genetically modified ingredients represented a 'de facto' barrier that inhibited private investment and

[74] The adoption of genetically modified (GM) crops is one of the main indicators of the impact of global biotechnology developments in Uruguayan agriculture. Among the global list of countries adopting GM crops, Uruguay ranked ninth in 2007, with 0.4 million hectares, and tenth in 2011 with 1.3 million hectares (including soybean and corn - see BIOTECSUR 2008a, p32; James, 2011). Argentina, Brazil and Paraguay also have significant areas of GM crops; they ranked second, third and seventh respectively in the same global ranking with 19.1; 15.0 and 2.6 million hectares respectively in 2007 (BIOTECSUR 2008a, p32).

hindered further development of agri-biotechnology innovation capacity in European countries (Senker & Van Zwanenberg, 2001).

Since in Latin American countries such as Brazil, Argentina and Uruguay, public opposition to genetically modified crops has been rather weak, as shown above, the adoption and consumption of these crops did not suffer from the same barriers observed in Europe (Biotecsur, 2008a). This represents a more favourable context for public and/or private efforts intended to exploit local scientific and technological capabilities for biotechnology R&D related to agriculture. Signs of such an enabling context for agri-biotechnology R&D emerge from our empirical results. Particularly, from the whole population of biotechnology R&D groups (132) identified within the public research sub-system, 86% (114 groups) perform research that is related to the agriculture sector to a greater or lesser extent. Moreover, 21 out of 33 private organisations identified[75] (MIEM, 2011) are also involved in the development and/or commercialisation of biotechnologies for the agriculture sector. While these are merely introductory figures, we provide in Section 4.3 below a more systematic characterisation of the Uruguayan agri-biotechnology innovation system.

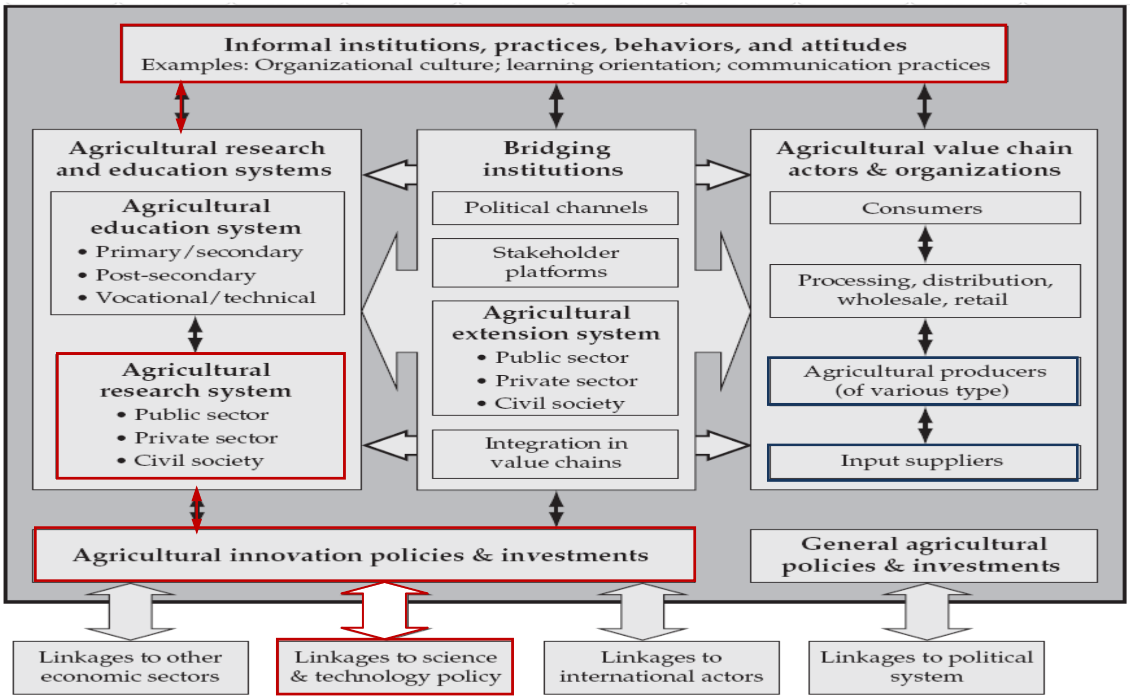
4.3 Main structural components of the agri-biotechnology innovation system

While this research mostly examines micro-level processes of inter-organisational collaboration and knowledge integration within the public research domain, our conceptual framework captured the relevant background conditions by looking from a broader *system perspective* on the whole agri-biotechnology innovation structure. Moreover, some of the forces shaping collaborative knowledge integration that we are analysing here can only be captured by taking a system-wide approach. Therefore, throughout this section we develop a general description of the main components of the technological system under study. In order to guide the identification of these components, we drew on a conceptual diagram for the structure of an agricultural innovation system developed by Spielman and Birner (2008, p6). Their conceptual

[75] The complete list of private organisations identified is presented in appendix 8.3.

framework, reproduced in Figure 4.2, identifies key components such as: (i) the education sub-system; (ii) the research sub-system; (iii) bridging or coordination institutions; (iv) actors of the agricultural value chain; and (v) formal (policies) and informal institutions (Spielman & Birner, 2008).

Figure 4.2: Components of a technological innovation system in the agriculture sector



Source: reproduced from Spielman and Birner (2008[76]).

As was discussed in Chapter 2, the main sources that drive technical change by agriculture producers are their technology- and service-suppliers (Pavitt, 1984; Possas et al., 1994). These encompass upstream suppliers of machinery, seeds, agrochemicals (pesticides and fertilisers), veterinary products, and services such as technical advice on farming practices (Possas et al., 1994, p13). Due to the varying degrees of appropriateness of different agricultural technologies, such suppliers include both private agents (producers of machinery, veterinary products, seeds and plants, and agrichemicals) and public research organisations – working on the development of

[76] The authors, in turn, adapted the framework from Arnold and Bell (2001).

locally adapted plant varieties, animal genetic improvement, biological-control agents, and improvement of agriculture production practices (Possas et al., 1994).

Since local R&D capabilities related to the supply of agricultural technologies in a developing country are located mainly in the public domain, as was argued in Chapter 3, this study has paid particular attention to *collaborative knowledge integration* processes taking place among public research organisations, including universities, basic research centres and technological research institutes. There has been extensive research on how and why private firms develop different sorts of partnerships as well as on public-private collaboration. Nevertheless, there is limited knowledge on the processes that support the system's capacity to link and exploit distributed knowledge and capabilities available in different local *public research organisations* (Heinze & Kuhlmann, 2008).

In other words, our central research concerns are on the structure and dynamics of the left side of Figure 4.2, along with the influence of institutional forces such as STI policies, incentives and scientists' views on *collaborative knowledge integration* between actors. However, a general overview of other relevant components of the system that were considered as part of the relevant background of this research is also presented throughout this chapter, including the role of input-supplier firms, individual farmers, farmer associations or cooperatives, and bridging structures supporting coordination and interaction. To begin with, Section 4.3.1 describes the education domain, looking particularly at advanced skills development at postgraduate level. The research sub-system is described in Section 4.3.2 with a particular focus on public research organisations. Within the private domain, the main activities of firms providing biotechnology supplies and services for the agriculture sector are portrayed in Section 4.3.3. We subsequently turn to illustrate, in Section 4.3.4, the most relevant policies for science, technology and innovation. Finally, Section 4.3.5 focuses on bridging institutional mechanisms intended to support interaction and coordination among actors in the system.

4.3.1 Higher education: advanced skills development

The University of the Republic (hereafter referred to as UdelaR[77]) is the single public university and the most important higher-education organisation in the country. Around 90% of the Uruguayans with a university-degree graduated from UdelaR (Bértola et al., 2005). While postgraduate training has a rather short history in Uruguay, masters or doctoral research programmes related to the biotechnology field are also mostly provided by UdelaR. It offers fifteen masters and five doctoral programmes with a potential link to biotechnology (BIOTECSUR, 2008a). Among these, just one master's programme is specifically devoted to *biotechnology*; this programme started in 2005 and is coordinated by the School of Sciences of UdelaR (BIOTECSUR 2008a).

In addition to the programmes offered by the public University, the Basic Sciences Development Programme (PEDECIBA) has, since 1986, significantly supported postgraduate training in Uruguay in many basic-science areas related to biotechnology, such as cell and molecular biology, chemistry, biochemistry, biophysics, botany, physiology, ecology, genetics, microbiology, neuroscience and zoology (BIOTECSUR 2008a). After the dictatorial regime that governed Uruguay until 1985, the PEDECIBA programme played a major role in recovering from the low levels of training in basic sciences registered in Uruguay at the end of that period. As one of the interviewees noted,

> *'...PEDECIBA was the only option. Either you had to go to foreign universities or you could do the PEDECIBA postgraduate programme'* (Interviewee A, 2011).

More recently, in 2009 PEDECIBA started a master's programme in *Bioinformatics* with the support of other local organisations, driven by the poor development of bioinformatics research capabilities in Uruguay (PEDECIBA, 2010). Brainpower in this field is so limited in Uruguay that, as explained by one interviewee, a bioinformatics specialist doing research related to the agriculture sector[78] that wants to exchange

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[77] UdelaR is the acronym for Universidad de la República, its name in Spanish.

[78] Exploiting in this way the cross-field application scope of these 'research technologies' as suggested by Rafols and Meyer (2007, p646).

knowledge and experiences with other scientists will probably find only a few peers working on other subjects such as bio-medicine, biology or other areas of application of bioinformatics (interviewee B, 2010).

On balance, it can be said that there is a reasonably well-developed provision of postgraduate opportunities that ensures a supply of well-trained researchers to the system. Nevertheless, *brain-drain* has been identified from both the review of previous studies and the interviews as a significant limitation for the development of the biotechnology system. Emigration of well-trained graduates and postgraduates is taking place in the Uruguayan biotechnology system as a result of poor or absent job opportunities for young researchers in both public research organisations and the private sector (BIOTECSUR, 2008d, p104). This was supported by three researchers interviewed (interviewee C, 2011; interviewee R, 2011; interviewee S, 2011). As noted by one university researcher,

> *'...many students that are trained here can't be retained and leave. There are a lot of people that even don't come back to the country ... Students learn how to do research and then they look for places where to continue doing research, and firms don't do it'* (interviewee A).

In fact, none of the former students of this group have gone to work in private companies. It is worth quoting Viotti (2002) here. As he noted, *'...''human capital'' would not become an effective technological absorber or improver ...without its effective engagement in productive or in science and technological activities. Though education is a necessary condition for the effective acquisition and improvement of technologies, it is not a sufficient one'* (Viotti, 2002, p667). In other words, if private innovation efforts are not strong enough, they may not provide the necessary demand for the available trained specialists in a given technological field. Although this is beyond the scope of our study of knowledge integration within the public research sector, it illustrates the restrictive conditions surrounding agri-biotechnology research and innovation in Uruguay.

Notwithstanding the limitations described above, evidence from our interviews suggests that postgraduate education programmes may influence the dynamics of interaction among actors in the system. We particularly observed that the involvement of postgraduate students in *research projects* conducted by several public R&D groups acted as an *ad-hoc mechanism* for the integration of external knowledge from local or foreign organisations into the group. Students usually perform short internships in such external groups in order to learn up-to-date research techniques and/or directly apply such techniques to the biological materials under study in their postgraduate R&D project. In this way, as experienced by three interviewees, students can internalise capabilities and skills externally available into the research activities of the R&D group (interviewee D, 2010; interviewees E and C, 2011), hence playing a noteworthy role in enhancing the ability of the R&D group hosting their postgraduate studies to collaboratively integrate external knowledge assets.

Despite other strategies also being present, our inductive empirical observations suggest that this bridging role constitutes an important channel for integrating knowledge and accessing R&D capabilities located outside the research group. Scholars studying interdisciplinarity have shown that the choice of knowledge integration strategies by the incumbent actors may differ across scientific or technological fields (Rafols, 2007). Studying knowledge acquisition strategies in emergent research fields, Rafols and Meyer suggested that policies supporting scientific research '... such as ... small grants for short term *technical exchanges*, might play a positive complementary role for knowledge transfer between disciplines' (Rafols & Meyer, 2007, p 646). In a similar fashion but in the context of this study, programmes that support the mobility of students between laboratories or R&D groups may provide the technical exchange required for granting the access to, or transfer of research-technologies and skills between organisations. This role of students suggested by the results of our inductive fieldwork is more thoroughly addressed in Chapter 5. In addition, the subsequent analysis of the survey to R&D project coordinators presented in Chapter 6 quantitatively explores whether or not *the greater the involvement of students in a research group, the larger the ability of those groups are to collaboratively integrate distant sources of knowledge and R&D capabilities.* Having briefly portrayed the education component by focussing particularly on the state of postgraduate training within the technological system being studied, we turn our attention in the next section to the main structural attributes of the research sub-system.

4.3.2 The research sub-system: investments in R&D and the role of the public sector

Uruguay has historically had low levels of investment in R&D activities, varying from 0.14 to 0.4 % of GDP during the period 1990 – 2010 and reaching the highest record (0.4 %) in the last year of this period (RICYT, 2013). Regarding the contribution of the private sector to R&D investment, comparative figures for OECD and MERCOSUR[79] countries show the significantly lower level of private investment in R&D for the latter group of countries; while in OECD countries, firms provide an average of 70% of total R&D investment, in MERCOSUR countries private actors account for less than 40% of total R&D investment (BIOTECSUR 2008e, p14). For the specific case of Uruguay, a recent publication suggests that private R&D investment is only 33% of the total national resources devoted to R&D (DICYT, 2010).

A different picture emerges if we look specifically at spending on agricultural R&D. The intensity of public spending on agricultural R&D in Uruguay reached a record of 2% in 2006 (expressed as a percentage of agricultural GDP), which is almost double the figure for 1986 (Stads & Beintema, 2009). This reveals a steep increase in public agricultural R&D funding in recent years, largely due to the creation of the national agricultural research institute – INIA (Stads et al., 2008). With regards to private investment in agricultural R&D, general figures for Latin American countries suggest that the private contribution represents 4.4% of the total agricultural R&D investment (Stads & Beintema 2009, p9). There is almost no specific information for Uruguay on this parameter, but Stads et al. (2010) claim that the private sector contribution to agricultural R&D in Uruguay is negligible.

Turning now to the biotechnology field, a recent assessment of research and innovation capabilities available in Uruguay in this technological domain (BIOTECSUR

[79] MERCOSUR is the acronym for *Mercado Común del Sur*¸ or Southern Common Market established by Argentina, Brazil, Paraguay, and Uruguay in 1991 (Connolly & Gunter, 1999).

2008e) has noted that national STI surveys have neither specific indicators of biotechnology production nor information on the funding of biotechnology research and development activities. The same study claimed that biotechnology firms' databases are also poor and provide little more than an outdated inventory of existing firms (BIOTECSUR 2008e). Given this poor availability of statistical information, substantial empirical research efforts were required in order to properly explore the patterns of inter-organisational R&D collaboration and knowledge integration within the agri-biotechnology system.

As described above, private investment in agricultural R&D is very low, so knowledge creation relies mostly on the research activities of public organisations. A similar picture is found for biotechnology R&D; a study of MERCOSUR member-countries suggests that biotechnology R&D activities are mainly performed by public research organisations (BIOTECSUR 2008e, p14). The case of Uruguay is illustrated by a recent study of biotechnology firms based in this country (Pittaluga & Snoeck, 2012[80]). The authors have shown that multinational subsidiaries located in Uruguay rely mainly on their parent company to perform R&D and to keep up-to-date with technological upgrading. On the other hand, all local companies are highly reliant on collaborative relations with national public R&D organisations in order to address the pressures to pursue technological advances and complex R&D activities required to stay competitive in the market (Pittaluga & Snoeck, 2012).

Given the heavy reliance of local firms on public R&D, a first conclusion is that characterising the developments of biotechnology based only on private activity indicators (e.g. patenting[81]) would be a highly misleading approach for Uruguay. On that basis, a previous study has analysed bibliometric indicators for the period 2000-2007 as a means to characterise R&D activities at the national level (BIOTECSUR 2008a, 2008e). Using a number of keywords related to the field, this study found between 12 (2001, 2002) and 31 (2006) publications indexed each year in the Science Citation Index (ISI-Web of Science) that were authored by researchers affiliated to Uruguayan

[80] This study was particularly focused on the animal health industry.
[81] For the period 2000-2007 only five patents were filed at WIPO by Uruguayan nationals (BIOTECSUR, 2008a, p111).

organisations. Moreover, between 55 and 81% of those publications were co-authored with foreign organisations (BIOTECSUR 2008a, p110). Such low numbers suggest that these indicators are poorly able to describe biotechnology R&D efforts in the country, underestimating the actual extent of R&D activities in the country. In fact, those low numbers are not consistent with the number of R&D groups and research projects identified and analysed in our study, as was illustrated in Chapter 3. The outcomes of Uruguayan biotechnology R&D may well be poorly indexed in global bibliographic databases such as the Science Citation Index, which is a rather common picture for many developing countries, as has been noted by Wagner et al. (2011). Therefore it can be concluded that data-sources other than patent and bibliographic databases should be looked for in order to assess the ability of incumbent organisations to exploit opportunities for complementary knowledge integration offered by locally-available biotechnology skills and R&D capabilities. These conclusions underpin the empirical approach followed in our study, particularly for the identification of R&D activities which drew on comprehensive information on R&D projects obtained from local research organisations and public R&D funding agencies or programmes.

Regarding the funding of research activities, a study of public R&D funding sources in Uruguay has shown that there are no particular public funding mechanisms exclusively targeted at biotechnology research (BIOTECSUR 2008c). Biotechnology has usually been included as one within a set of priority areas in publicly funded research grants (BIOTECSUR 2008c). In fact, biotechnology is one of the three technological areas prioritised in the national strategic plan for science, technology and innovation approved in 2010 by the Uruguayan government (DICYT, 2010). This plan guides the funding allocation priorities of the National Agency for Research and Innovation (ANII) that since 2007 has become the main source of competitive R&D funds in the country. Turning to observations during the interviews, despite the lack of specific support instruments suggested above, most of the biotechnology research groups interviewed (within the public sector) did not identify major constraints in accessing research grants. As we illustrate below, scientists' concerns are not whether they can access research grants but on the actual amount of public funds spent on biotechnology R&D.

Despite funding for agricultural R&D having increased in recent years (as mentioned above), agri-biotechnology researchers from the public-sector claimed that they still face major deficiencies in terms of infrastructure, equipment and access to trained human resources. One interviewee expressed their concerns since research grants' budgets grew at a much slower rate than the salary of junior researchers; hence the ability to fund non-permanent researchers from project budgets has significantly decreased (interviewee E, 2011). Therefore, the main funding concern of public research groups was the sub-optimal level of human resources. In particular, restrictions in getting sufficient structural funds result, as suggested by two interviewees, in a weak ability to recruit young researchers or to retain postgraduates within the group once they are trained on emergent themes and techniques (interviewees C and E, 2011). Hence, these postgraduates are not becoming '...effective technological absorber[s] or improver[s]...' (Viotti, 2002, p667). This may affect the ability of public research groups to integrate external knowledge, since a typical character of these groups recognised by most scientists interviewed is their reliance on the work of students to access up-to-date research techniques or methodologies. However, one interviewee also recognised that this limitation was partially compensated for by an increase in the availability of scholarship programmes[82] which have facilitated a continued high level of involvement of students in research teams (interviewee E, 2011).

From a broader perspective, R&D groups were also concerned about the small size of the overall community of researchers based around agriculture-related biotechnology in Uruguay, which, as claimed by one interviewee, was seen as a key limitation for a rich exchange of ideas and knowledge generation in this technological field (interviewee E, 2011). Notwithstanding these human-capital limitations, two public-sector researchers acknowledged they are usually able to access diverse funding sources such as internal funds, competitive grants or in a few cases through collaborative arrangements with private actors in order to cover other costs of their research activities (interviewees C and E, 2011).

[82] At the time this study was conducted PEDECIBA, ANII, CSIC and INIA were all offering postgraduate research scholarships.

Up to this point in this section, we have discussed the Uruguayan patterns of investment in agriculture and biotechnology research, the availability and access to funding sources such as research grants, and the funding limitations faced by public R&D groups to retain young researchers in the team. We have also presented evidence of the salient role of public research organisations in the agri-biotechnology field. Therefore, we now turn to explore in more detail the configuration of public-sector research organisations which account for most biotechnology R&D capabilities in Uruguay.

Previous studies in Uruguay (Pittaluga & Viogorito, 2005; INIA, 2001) have undertaken a rather broad identification of the actors involved in the local biotechnology sector. Pittaluga & Viogorito (2005) used previous publications, expert advice and a snowball technique to identify the main actors, since there was no comprehensive source where they could look at the whole population of agents. These authors identified 71 public laboratories or groups and 32 firms[83] involved in biotechnology research and/or commercialisation (Pittaluga & Viogorito, 2005, p275). Since that study is rather outdated, a supplementary effort was required for the identification of incumbent actors on the basis of the database of R&D projects built for the purpose of this research as well as on information obtained from the survey questionnaire delivered to project coordinators.

Biotechnology research capabilities in Uruguay are mainly located in the University of the Republic (UdelaR), which, as previously noted, is the most important higher-education and scientific research organisation in the country. UdelaR accounts for around 90% of the graduates (Bértola et al., 2005) and for more than 60% of the national research capability in the public domain (BIOTECSUR, 2008a, p119). UdelaR research groups involved in biotechnology research belong to the following schools of this university: (i) Agronomy; (ii) Natural Sciences; (iii) Engineering; (iv) Veterinary; (v) Chemistry; and (vi) the Medicine School (BIOTECSUR, 2008a).

[83] These 32 firms offer biotechnology products to the market but do not include 11 other firms classified as specialised goods and service providers such as equipment suppliers (Pittaluga & Viogorito, 2005).

All these schools are, to differing degrees, involved in agri-biotechnology research and development activities. Table 3.5 (Chapter 3, Section 3.4.3) showed the affiliation of the R&D groups identified through our fieldwork, revealing that 89 out of the 132 research groups identified belong to the schools of UdelaR mentioned above. The largest number of biotechnology R&D groups is to be found in the School of Natural Sciences, these groups being mostly focused on basic research (Bortagaray, 2007, p252). Besides the schools of UdelaR, other relevant biotechnology R&D centres or institutes include the National Agricultural Research Institute (INIA), the Institute of Biological Research *Clemente Estable* (IIBCE), the Hygiene Institute, the Technological Laboratory of Uruguay (LATU) and the Pasteur Institute-Montevideo (BIOTECSUR 2008d).The National Agricultural Research Institute (INIA) represents, perhaps, the main structural innovation in the agricultural research system of Uruguay in the last 25 years. Its foundation in 1989 was aimed at increasing the intensity of agricultural R&D investment as well as the participation of the private sector in R&D funding and decision-making (Allegri, 2010). INIA is a public-private organisation, co-funded (through a levy funding mechanism) and jointly governed by the public[84] and private[85] sectors, providing funding and administrative flexibility to national efforts on research and technology development for the agriculture sector (Allegri, 2002). Representatives of farmers are engaged at the top of INIA's organisational structure (the board of directors), as well as in regional advisory committees and work-groups which act as permanent spaces for channelling producers' demands into INIA and at the same time for monitoring the ongoing progress in research activities (Allegri, 2010). As part of the responsibilities of INIA established by law, all research activities performed by the institute should pursue the development of technological solutions for the agricultural sector in response to farmers' demands that manifest in the different participation levels described above. This mechanism for defining the orientation of research in INIA constitutes a key difference from scientific institutions such as *academic freedom* rights, which play a central role in guiding the research activity undertaken by the University of the Republic (Diario Oficial, 1958).

[84] The Ministry of Agriculture and Fisheries (MGAP).
[85] The four main farmers associations in Uruguay.

A long-standing technological trajectory of INIA has been the development and provision of genetically improved plant varieties. A number of plant-breeding programmes are in charge of developing varieties of cereal and oilseed crops, forest trees, fruit trees, vegetables, and pasture plants (Allegri, 2010). In this context, in 1991 INIA created a Biotechnology Unit intended to establish research and technological capabilities (human-skills, infrastructure, etc.) for the development and application of biotechnological tools and techniques on INIA's plant-breeding programmes (and other R&D activities such as pest and disease control) in order to enhance their efficiency and effectiveness (Francis & Bonnecarrère, 2000). Since 2005, this unit has also begun R&D activities intended to develop and apply biotechnology capabilities to national cattle and sheep breeding programmes as well as to animal health research projects (interviewee D, 2010). The biotechnology unit has a transversal role within INIA, since its research and support activities cut across a number of national research programmes (organised around specific value-chains) and five experimental stations of the institute are located in different regions of the country (Bortagaray, 2007, p254).

It is beyond the scope of this study to provide a detailed description of each incumbent organisation identified in Table 3.5. Besides UdelaR and INIA, the Institute of Biological Research, *Clemente Estable* (IIBCE) occupies a prominent position in biological sciences. In relation to the agri-biotechnology field, IIBCE undertakes studies of plant growth promoters and the biological control of plant diseases as well as biochemistry and molecular biology research applied to plant genetics, microbiology and animal reproduction (BIOTECSUR, 2008a).The activity of the Pasteur Institute of Montevideo (IPM) is focused on biomedical research (BIOTECSUR, 2008a) but performs some biotechnological research on animal health (Interviewee F, 2011) and provides access to its research facilities and analytical services to scientists from other organisations and research fields such as plant biochemistry (interviewee E, 2011) or plant molecular biology (interviewee G, 2011). Finally, the laboratories of the Ministry of Husbandry, Agriculture and Fisheries (MGAP) perform studies on soil microbiology, quality control of plant growth promoters (inoculants), plant-disease diagnostics, animal health and animal disease diagnostics (BIOTECSUR, 2008a; Bortagaray, 2007).

As shown in Table 3.5, while research capabilities in the public domain are concentrated in a few organisations, they are distributed among a large number of R&D groups. Therefore it becomes of particular relevance to understand how these public R&D groups interact and integrate complementary knowledge assets through collaborative research. Previous studies have observed that public-sector researchers in Uruguay work in small units or labs within larger organisational structures (divisions, departments or schools) and tend to focus on very specific topics that in most cases do not follow a common goal defined at higher organisational levels (Bortagaray, 2007). This way, in which the research is conducted, results in a high dispersion of resources and research efforts in locational and thematic terms, hindering potential synergies and the aggregation of capabilities across units and disciplinary boundaries (Bortagaray, 2007, p274-51).

Throughout this section we have explored the key features of the research sub-system within the boundaries of agri-biotechnology innovation in Uruguay. We reviewed some figures for the investment on agriculture and biotechnology R&D, and showed evidence of the role played by the public sector as the main performer of agri-biotechnology research. Therefore, the structure of public research organisations involved in agri-biotechnology R&D was subsequently reviewed. In Section 4.3.3 below, we provide an overview of the private domain. In particular, we portray the main activities of firms providing biotechnology supplies and services for the agriculture sector.

4.3.3 Biotechnology firms: agriculture supplies and service providers

This section is intended to provide an overview of the local market for biotechnology products or services used in primary agriculture production. The main type of private actors supplying these products and services are also introduced. Since the aim of our research is exploring collaborative knowledge integration among public research actors, this section is developed mainly for descriptive purposes. Nevertheless, we also look briefly at how private actors are able to access capabilities and knowledge of public research organisations and mobilise them to address the firm's production problems.

There is no systematic registry of biotechnology firms in Uruguay. One particular study in 2005 identified 32 biotechnology firms based in Uruguay (Pittaluga & Vigorito, 2005, p275). Moreover, a more recent study suggests that only 4% of the biotechnology researchers in Uruguay work for private organisations[86] (ANII, 2010). In order to update the inventory of firms, we relied on data provided by the Ministry of Industry, Energy and Mining of Uruguay, which identified 33 private, for-profit organisations (MIEM, 2011), 21 of them involved in the development and/or commercialisation of biotechnologies for the agriculture sector (see appendix 8.3). Hence, as observed by others (BIOTECSUR, 2008a), the bulk of firms within the Uruguayan biotechnology system are related to the agriculture and food industry, particularly to plant biotechnology, animal health, diagnostic services, microbiological products and processes, and the genetic improvement of animal breeds. A more detailed description of the types of biotechnology applications and products produced and/or traded by these firms is provided in Table 4.1 below.

[86] This reinforces our empirical strategy of focusing on the exploration of collaborative knowledge integration efforts within the public research sector.

Table 4.1: Biotechnology applications produced and/or commercialised by private actors

Area	Product categories
Plant biotechnologies	Microbial inoculants (plant growth promoters or biofertilisers)
	In-vitro plant propagation
	Genetically modified crops (adoption of foreign products[87])
Animal production	Animal vaccines
	Animal reproduction and genetic improvement
Environmental biotechnologies and bio-processes	Micro organisms for the control and processing of wastewater
	Biogas production from raw or waste materials
	Bio-fertilisers
Biotechnology service firms	Diagnostic and other biotech services

Source: elaborated by the author based on BIOTECSUR (2008a)

A study of the biotechnology innovation system in Uruguay (Pittaluga & Vigorito, 2005) has shown that Uruguayan firms, either producers or adopters of biotechnology products, establish more collaborative relations with public research organisations compared with other sectors such as the software and pharmaceuticals industries. In other words, firms in the Uruguayan biotechnology innovation system – which is still an emerging system – place considerable emphasis on accessing knowledge and capabilities from public research organisations (Pittaluga & Vigorito, 2005). However, despite public and private actors interacting frequently, it has been claimed that these interactions are essentially isolated efforts intended to solve rather specific problems; in other words, these actors '...do not engage in sustained synergistic linkages' oriented to addressing long-term goals (Bortagaray, 2007, p317). Moreover, the willingness of private actors from the primary industry to invest in R&D was perceived to be very low by public research groups interviewed. One public-sector researcher claimed that firms are usually averse to the long-term R&D commitments required by biotechnology research (interviewee C, 2011). It was also noted by three interviewees that Uruguayan private organisations have a weak ability to coordinate and articulate

[87] Since all genetically modified crops used in Uruguay have been developed by foreign companies (MGAP, 2012) we are interested in studying collaborative knowledge integration for local research and technological development, the set of agri-biotechnology firms identified here (21) does not include those commercialising GM plant varieties.

demands for biotechnology research (interviewee C, 2011; interviewee S, 2011), suggesting that they may not be able to envisage technological opportunities opened by potential R&D collaborations with public research organisations (interviewee X, 2011).

Such poor coordination and articulation of research demands among private actors was corroborated by a recent study of agri-biotechnology innovation in Uruguay that analysed the role of the Uruguayan Association of Biotechnology Firms, AUDEBIO (Pittaluga & Snoeck, 2012). This study found that there was a complete lack of collective actions among different members of AUDEBIO involved in the animal vaccine sector, given their inability to identify common interests and the very weak role played by AUDEBIO. This was corroborated in three interviews during this study (interviewee H, 2011; interviewee W, 2011; interviewee Y, 2011). The authors cited before showed that, as institutional mechanisms for the governance of biotechnology innovation in the private arena, both AUDEBIO and a Life Science Cluster sponsored by the government since 2006 were not particularly effective in overcoming *coordination failures* relating to the resolution of common problems in the sector (Pittaluga & Snoeck, 2012). Similarly, a study of European – agri-food related – biotechnology innovation systems has shown not absent but weak horizontal collaboration of firms with other private actors, while firms' collaboration with public sector organisations was found to be an almost ubiquitous attribute (Senker & van Zwanenberg, 2001).

From the point of view of public research groups, despite the fact that some may have a well-developed density of links with private actors, only a few groups consider knowledge exchange with firms as important. Conversely, most of them do see interactions with other public actors as a highly valuable source of external knowledge and capabilities (Pittaluga & Vigorito, 2005, pp279-80). This was corroborated in the present study; two public – mainly academic – groups claimed that they do not perform an active search for private agents with whom to collaborate unless they face a pressing need to access external funds (interviewee C, 2011; interviewee E, 2011). Instead, these public groups passively receive demands from private actors that may eventually approach them. In fact, difficulties in approaching private actors as well as in clearly identifying their demands for biotechnological research were acknowledged by one of the public groups interviewed (interviewee E, 2011). We argue that this passive attitude from the public research side may be underpinned by informal academic institutions and the formal researchers' assessment system which are examined in Section 4.3.4.

As a balancing force, the weak ability of some academic groups to interact with private agents that we described above was in one reported case resolved by collaborating with public applied-research organisations that have closer ties with private actors and their demands – primary industry (interviewee E, 2011). Therefore, as we discuss in more detail in Chapter 5 (Section 5.2), these public applied-research organisations may act as intermediaries between private actors and academic groups. In these cases, despite the fact that a direct link between the academic group and the private actor may be absent, local knowledge capabilities in the academic group are, to some extent, mobilised towards private innovation demands, through the intermediating and steering role of the applied research group.

The rather poor ability of private actors to articulate their actual demands for biotechnology research that we noted above, and the passive attitude recognised by some public research groups towards identifying the needs of private actors hinder the development of an inter-actor interface and thus the establishment of collaborative interactions between academics and the – primary – production sector. Hence, interaction failures are often observed within the agri-biotechnology innovation system and as a result, poor guidance and feedback is provided by the industry on the research efforts carried out by public organisations. Interaction or network failures have been defined as situations when '...possibilities for interactive learning and innovation are under-utilised and firms may fail to adapt to new technological developments' (Woolthuis et al., 2005, p614). The observed network failures emerge in spite of the existence of commodity technological boards that were explicitly created as system-level governance structures[88] intended to promote the interaction between the agriculture industry and public research organisations. Such interaction failures were observed during two interviews as a significant limitation on the

[88] These coordination mechanisms are analysed in more detail Section 4.3.5.

consolidation of clear technological trajectories and hence as a barrier to the development of the agricultural-biotechnology innovation system as a whole (interviewee D, 2010; interviewee E, 2011).

The generally weak articulation of demands for research by private actors and their limited ability to identify technological opportunities are not homogeneous attributes for all private organisations. Firms with a well-established group of skilled workers and sound technological resource endowments have a higher absorptive capacity (Rothwell & Dodgson, 1991; Veugelers, 1997; Giuliani & Arza, 2009). Therefore, they are able to perform a better *identification of local knowledge capabilities* available in public actors and exploit them in their innovation processes, through the establishment of collaborative arrangements. This was actually the case in a number of examples identified during four interviews where public research groups became involved in collaborative arrangements with big companies, particularly local or regional subsidiaries (in MERCOSUR countries) of multinational companies (interviewee I, 2010), as well as some large local firms – e.g. the animal vaccines sector or among big forest tree producers (interviewee J, 2011; interviewee C, 2011). In these cases, the specific demands and funding provided by the private actors resulted in a change in the research trajectories of academic research groups towards problems of production. Moreover the change in the research orientation of public research groups extended beyond the end of the private funding support to research activities conducted by the public R&D groups (interviewee I, 2010; interviewee E, 2011; interviewee C, 2011).

To sum up, in this section, we have reviewed the private domain of the agri-biotechnology system. We looked at the set of firms that commercialise agri-biotechnology products in Uruguay and the type of biotech products they make available in the market, either developed through their own R&D processes or produced by foreign organisations. We noted that more than 60% of the whole set of biotechnology firms located in Uruguay (MIEM, 2011) produce and/or commercialise products for the agriculture sector, which lends support to the definition of technological and sectoral boundaries for our empirical study around the intersection of biotechnology and agriculture. In addition, we reviewed the patterns of interaction of private actors both with other firms and with public research organisations. We argued that while articulation of research demands, coordination and collaboration among private actors is weak, their innovation efforts rely to a large extent on the collaborative access to skills and R&D capabilities of public research organisations. This, along with our argument in the previous section, suggests in figurative terms, that *the R&D lab of private producers and users of agri-biotechnologies in Uruguay is mostly located outside the firm, namely within public research organisations*. It follows that since public R&D capabilities are distributed across many actors, a more effective integration of complementary knowledge assets through collaborative efforts among public research organisations will probably result (as assumed in this research) in improved performance of the technological innovation system as a whole. Finally, we argued that informal and formal academic institutions may influence the motivation of public research groups to interact and integrate capabilities with other actors. Therefore, in section 4.3.4 below, we turn to illustrate another component of the technological system under study, namely the relevant *institutions*. Although informal academic institutions are also addressed, we particularly focus on the formal institutional background defined by science, technology and innovation policies pertinent for the boundaries and purpose of our study.

4.3.4 Science, technology and innovation policies

In the following paragraphs we provide an overview of relevant policies operating within Uruguay in support of industrial and agricultural innovation such as intellectual property regulations, incentives for private investments, regulations for the introduction and use of genetically modified organisms, and tax exemptions for biotechnology R&D. We also address key formal institutions shaping scientific research and technological development such as R&D funding bodies and formal incentives for the scientific community. Finally, some informal academic institutions are also discussed.

Looking first at industrial innovation policies, a significant increase in tax exemptions for firms that invest in innovation activities and training of their staff was included in a new tax system established by law 16.906 in 2007 (BIOTECSUR 2008c). Regarding intellectual property, the national law 17.164 (enacted in 1999) regulates the protection of inventions within Uruguay following the general lines of the TRIPS[89] Agreement among members of the World Trade Organisation – WTO (ANII, 2010). Despite the regulations in force, Uruguay has a rather poor record of patenting, and biotechnology is no exception to this general pattern[90]. A study of MERCOSUR member-countries showed not only that patenting is very low in this region, but also that around 70% of the biotechnology patents are granted to non-resident applicants (BIOTECSUR 2008e, p14). Therefore, that study concluded that patenting is a poor indicator for characterising biotechnology R&D activities in this type of developing country (BIOTECSUR 2008e).

Such limited attention to patenting is reflected in the fact that most of the university research groups interviewed do not envisage any relevant influence of IPR regulations[91] on the development of collaborative research. In addition, these groups recognise the relative lack of organisational capabilities for embedding IPR issues in R&D projects; limitations in terms of managing and funding the required procedures to apply for a patent are also highlighted. In fact, most of the few biotechnology patents registered in the Uruguayan Office for Industrial Property Rights (DNPI) have been registered by foreign organisations (Pittaluga & Snoeck, 2012). This is consistent with previous studies, which found that in academic as well as in industry spheres, there is very poor knowledge of intellectual property regulations and procedures, a failing partly attributed to the limited availability of advice and to an inability to cover the costs of the patenting process (BIOTECSUR 2008d, p104).

As an applied research organisation, INIA has a longer tradition in protecting its core technological products, namely (non-GM) plant varieties. Plant variety technologies have a separate ('sui generis') property right system, agreed by WTO member-countries within the terms of the TRIPS Agreement (Tripp et al., 2007, p355). But when

[89] WTO Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS).

[90] Between 2000 and 2007, only four biotechnology patents were granted by the local patent office, three of them to non-residents (BIOTECSUR, 2008a, p111).

[91] An exception to this is the School of Chemistry, UdelaR, which has a more established history of collaborative relations with industry and of the protection of research outcomes (Bortagaray, 2007).

the protection of other type of technologies is considered, the situation of INIA does not differ from that of other public research organisations in Uruguay, since it also has weak capabilities on intellectual property protection of its technologies.

Other relevant policies supporting biotechnology research and innovation are described in Table 4.2 below. With regards to regulations in the development and local use of plant biotechnologies, in 2000, the Uruguayan government approved a regulatory framework that established procedures for risk assessment and the approval of genetically modified crops. A moratorium on the approval of new GM events was then declared by the Government in January 2007, which lasted until July 2008 when a new framework was approved; the new regulatory framework set up an inter-ministerial National Bio-safety Committee and its technical advisory arm, the National Commission for Risk Management (Diario Oficial, 2008). Until the moratorium in 2007, there were three GM varieties approved for commercial use[92] (BIOTECSUR 2008a). After the new regulatory framework was set up, another five events were approved for commercial use[93] (MGAP, 2012). As suggested by one interviewee, regulations on genetically modified crops do not result in significant restrictions on the genetic transformation of plants for public research purposes at a laboratory-level. Additionally, the approval procedure for research-purposes is more flexible when applying for the use of transformed *model plants* such as Arabidopsis or Physcomitrella, while for the field experimentation with transformed *commercial crops* the bio-safety conditions required are more severe (interviewee E, 2011).

[92] Corn events MON810 and Bt11 (approved in 2003 and 2004 respectively), and soybean event GTS 40-3-2 (authorised in 1996) (BIOTECSUR 2008a, p115).

[93] Besides those for commercial use, other events were approved for restricted use: 5 for seed production with export destination, 6 for research purposes, and 11 for cultivated field trials (MGAP, 2012).

Table 4.2: Policies supporting biotechnology R&D and innovation in Uruguay

Legal instrument	Goal
National law number 16.462 - article number 61 (year 1992)	Declares biotechnology as a sector of national interest, particularly '...the production, development and research on different areas related to biotechnology'.
National law number 16.906 - article number 455 (year 2007)	Establishes the framework for the promotion and protection of private investments in general.
National strategic plan on science, technology and innovation - PENCTI (approved in 2010)	The PENCTI defines in general terms the national strategy for the development of scientific and innovation capacity in the country. The plan defines biotechnology as one of its strategic priority areas.
National law number 17.164 (1999)	Patent law for inventions, utility models and industrial designs.
National law number 16.811	Regulation of intellectual property of plant varieties. Administration and control delegated in the National Seeds Institute (INASE).
National decree 353/008 (approved in July, 2008)	Regulatory framework and procedures for risk assessment and approval of genetically modified crops.

Sources: elaborated by the author based on ANII (2010) and Diario Oficial (2008)

The focus of the present study is on the exploitation of local advanced knowledge capabilities for agri-biotechnology development and innovation. Nevertheless, all transgenic varieties approved up to now in Uruguay have been entirely developed by foreign organisations, without any involvement by local R&D capabilities. Therefore, the local adoption of GM crops is considered as part of the relevant context of the technological innovation system under study, but it does not play a significant role in the realisation of potential complementarities between local organisations for agri-biotechnology R&D.

Despite the well-developed regulations on the use of genetically modified crops described above, some limitations on innovation in other biotechnologies have arisen due to the lack of proper regulations for the introduction to the market of locally developed biotechnological products. In some cases, as reported by four interviewees, such weak or non-existent regulatory frameworks have resulted in new biotechnological products developed by local firms being unable to obtain registration and approval for commercialisation in the local market, while imported products have an easier introduction due to the acknowledgment of foreign procedures (interviewee H, 2011; interviewee U, 2011; interviewee V, 2011; interviewee W, 2011). These institutional barriers may well undermine the expectations and innovative efforts of local biotechnology firms (Geels & Raven, 2006; Bergek et al., 2008). A lack of local regulations ends up favouring foreign technological developments to enter the market, while it hinders local technologies from doing so. On balance, the regulatory system performs well by adopting external biotechnologies but from the perspective of promoting endogenous innovation, it somehow deters the exploitation of R&D capabilities in local technological developments, thereby hindering the development of local innovation capacity in the field. Therefore, such a weak regulatory framework constitutes a system-level barrier to innovation.

Looking from a broader perspective, previous studies have claimed that science, technology and innovation policies have not been a priority on the agenda of the Uruguayan government for a long time and that '[t]he policy has been the lack of one'[94] (Bortagaray, 2007, p301). Nevertheless, some changes have slowly begun to take place during the last decade, mainly after the creation, in 2007, of the National Agency for Research and Innovation (ANII) (DICyT, 2010). Since 2005, the government has developed a new national policy of Science and Technology; the creation of both ANII and the National Researchers Assessment System (SNI is its acronym in Spanish[95]) in 2007 represented the main structural and operational instruments of that new policy. This policy defined biotechnology as one of three strategic priority themes (DICyT, 2010).

Since its creation, ANII has promoted a number of instruments in support of research and innovation, such as competitive funds for basic and applied research, the creation of a national scholarship system, funding of R&D projects conducted by private actors, and the support of collaborative or associative initiatives (BIOTECSUR, 2008c). 'One of the main goals of ANII is the consolidation of the national scientific and technological system and its relation with the national production and social problems' (Bernheim et al., 2012, p5). Regarding the support for public sector research, a salient instrument of

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[94] Along these lines, the same study argued that regulations and organisations tend to persist without significant changes a for long time in Uruguay, so the absence of disruptive changes is part of the nature of the system as a whole (Bortagaray, 2007, p300).

[95] The researchers' assessment system (SNI) was created by the national Act No. 305 / Law 18172 promulgated on 31st of August, 2007 (Bernheim et al., 2012, p5).

the new STI policy was, as noted above, the creation of the National Researchers Assessment System (SNI). The SNI is intended to assess and categorise the Uruguayan scientific community, promoting its development through a series of economic incentives based on researchers' performance in terms of certain knowledge-production indicators (Bernheim et al., 2012, p5). Scientists are assessed mainly on the basis of their record of: (i) publications in peer-reviewed journals; (ii) technical production[96]; (iii) specialised training of students; (iv) their own academic training; and (v) relationship of their research to societal problems (Bernheim et al., 2012, p11).

A recent study of the impact of the SNI compared the performance of researchers over two periods, namely 2006-2008 and 2009-2011 – the later period being the one when researchers were actually under the influence of the new assessment system. The results of this study show that 62% of the researchers in the system increased their scientific production, which is mainly explained by the increase in peer-reviewed publishing; the overall increase in *peer-reviewed publishing* was 16% (Bernheim et al., 2012, pp1-2). Notwithstanding the assessment criteria referred to above (criteria ii and v), the report showed a decrease of 12% in the production of *technical publications*, which are supposed to be more closely related to the solution of local production or technical problems. The authors argued that researchers are concerned about the low value given to this type of knowledge production in the overall assessment process (Bernheim et al., 2012, p2). In fact, the correlation coefficient between the rank or degree[97] granted to researchers and their production of peer-reviewed publications for the period 2009-2011 was 97% (Bernheim et al., 2012, p12), providing evidence that peer-reviewed publishing is by far the main determinant of the final categorisation of researchers in the system while the other proposed criteria seemingly exert a negligible influence.

Another salient finding of the cited study regards the selection of the journals where scientists publish their peer-reviewed work. While publications indexed in the Science

[96] 'Technical production' involves the transfer of knowledge to innovation activities or the transformation of research outcomes into a product with commercial or social value. The types of technical production include technical reports, technical advice and consultancy (Bernheim et al., 2012, p17).
[97] The system has four degrees for active researchers.

Citation Index (ISI, Thomson-Reuters) increased by 16% in the period, there was a decrease of 5% in the number of publications indexed in Latindex, a bibliographic database specialising in Latin American scientific and technical journals (Bernheim et al., 2012, p15). This indicator, together with the decrease in the production of technical publications (12%) suggests that *scientific production in Uruguay is increasing its performance in global peer-reviewed journals but this is apparently happening at the expense of a decrease in the relevance of this research to solving local social and technological problems*. This clearly reflects the contradictory influences exerted by scientific institutions, as suggested by Hessels et al. (2011). While the SNI system places strong emphasis on academic performance assessments, particularly in terms of publishing in peer-reviewed academic journals, at the same time, it supposedly encourages researchers to perform application-oriented and socially-relevant research. Socially-relevant research themes are also promoted by the R&D funding instruments offered by ANII (interviewee E, 2011). Hessels et al. (2011) found that for some research fields, these combined incentives result in contradictory pressures on researchers causing tension at the moment they define the actual orientation of their research efforts (Hessels & van Lente, 2011). Relevant questions on this issue were presented by the latter two cited studies and discussed in Chapter 2, but it is worth recalling them here:

> *'Do new criteria, relating to the societal relevance of research results, currently count significantly in...retrospective evaluations of individuals, projects or organisations?'* (Hessels & van Lente, 2008, p758);
>
> *'Have the changes in the science-society relationship made practical applications into a source of credibility for academic scientists...?'*[98] (Hessels & van Lente, 2011, p216).

The results of the impact assessment of the SNI undertaken by Bernheim et al. (2012) suggest that the answer to these questions in the case of Uruguay is *'No'*. While the SNI criteria for the assessment of knowledge production include the production of

[98] The second question was addressed comparatively for three sub-fields of chemistry research in the Netherlands.

socially-relevant technical publications, the results of the impact assessment indicate that the production of this type of knowledge by the general scientific community has actually been decreasing during the last few years. It remains of concern what the influence of this scientific policy could be on the processes of *collaborative knowledge integration* in the agri-biotechnology field, which are the phenomena under exploration in this research.

Complementary knowledge integration is assumed here to be a process that mainly pursues addressing societal problems (Van den Besselaar & Heimeriks, 2001; Leydesdorff & Schank, 2008, p 1816). But we have shown above that socially-relevant research outcomes have been apparently undermined by the researchers' assessment system in Uruguay (Bernheim et al., 2012). This would seem to confirm the rationale for our quantitative assessment, as presented in Chapter 2 (section 2.7.3) and re-iterated in the box below. A deeper development of the quantitative approach briefly described in the box and the analysis of its outcomes are presented Chapter 6.

Our study pays particular attention to:

> *Whether or not there is an influence of traditional scientists' assessment norms and incentives well established in the global scientific community – mostly based on peer-reviewed publications records – in supporting or hindering collaborative efforts that attempt to integrate distant complementary knowledge. ...*

Such an influence is exerted before a decision to collaborate with a potential partner (that has distant complementary knowledge assets) is taken. From the empirical point of view, this can be explored in qualitative interviews but presents difficulties when assessed through a quantitative approach. Therefore, we took an ex-post assessment perspective by exploring the influence of these institutional incentives after the collaborative effort took place. With this aim, we developed a comparative approach that allowed us to quantitatively distinguish between:

(i) *R&D groups that collaboratively integrate highly complementary knowledge (relatively high cognitive distance from its R&D partners); and*

(ii) *R&D groups that collaboratively integrate less complementary knowledge assets (comparatively lower cognitive distance from its R&D partners), namely those that achieve lower degrees of knowledge integration in their collaborative R&D activities.*

Once we characterised and segregated R&D groups accomplishing distinctive degrees of collaborative knowledge integration we were subsequently able to explore:

> *How the influence of traditional academic assessment norms may explain such differences between R&D groups in the extent of collaborative knowledge integration.*
>
> We assessed the *influence of traditional academic assessment norms* on R&D groups' behaviour by measuring the relative extent of *compliance* that individual R&D groups show with such rules and incentive mechanisms (performance in scientific assessment exercises).

Source: reproduced from Chapter 2 in this report (Section 2.7.3) with minor changes

Besides examining the existence of formal institutions, it is worth analysing the actual perceptions and views of interviewed researchers with regards to STI policies. Although this will be addressed in more depth in Chapter 5, we present some preliminary empirical observations on this. The new institutional conditions and changes in the years after the creation of ANII (described above) were the focus of the main concerns of one respondent when asked about science and technology policy and institutions in Uruguay (interviewee E, 2011). ANII's support for R&D projects has emphasised applied research for the solution of locally relevant problems, and has particularly promoted the integration of knowledge located in diverse actors in the system since its funding programmes positively value project proposals presented by inter-organisational and/or interdisciplinary consortia exploiting synergies and complementarities (DICYT, 2010, pp34-5). This new emphasis of ANII's funds on the applicability of research results in local innovation processes being recognised by one university researcher as a possible incentive to collaborate with other local research organisations (interviewee E, 2011). Nevertheless, the academic freedom and autonomy rights granted by law to UdelaR and its members[99] as well as the availability of alternative funding sources – either local or foreign – may reduce the influence of this potential driver of collaboration. This is of particular relevance due to the high concentration of Uruguayan R&D capabilities in the academic sector that was described earlier. As one university researcher observed,

[99] Academic freedom and autonomy rights are granted by the *organic law* of UdelaR, Law 12.549 approved in 1958 (Diario Oficial, 1958).

> '...in the university there is no obligation to collaborate with other laboratories...no real pressure exists...you have complete freedom...you can spend all your life in the School without having collaborated with anybody, and I think nothing would happen' (interviewee E, 2011).

This suggests that the intent of ANII R&D funds to promote research collaborations may be far from being effective.

In summary, we have explored in this section a set of STI policies that support agri-biotechnology innovation in Uruguay. With regards to IPR regulations, we noted that patenting is a poor indicator of local biotechnology innovation in Uruguay, since patents are very infrequent and most patent applications are made by non-resident organisations or individuals (BIOTECSUR 2008e). We also underscored the contrasting regulatory conditions for market introduction and commercial use of different agri-biotechnologies. While biosafety norms for the introduction of foreign genetically-modified crops are well-developed and operational, some new locally-developed biotechnology products have been unable to gain approval for commercialisation due to weak or non-existent regulations for their introduction to the local market. Therefore, these weak regulations constitute a system-level barrier to endogenous innovation in emergent technological fields.

We also explored recent institutional developments supporting the development and integration of the scientific and technological bases in Uruguay. We particularly pointed to the creation of ANII and the National Researchers Assessment System (SNI) as salient policy developments. Critically reviewing a study of the impact of the new incentives for the scientific community established by the SNI (Bernheim et al., 2012, p15), we argued that the observed increase in the scientific production of Uruguay in global peer-reviewed journals may be taking place at the expense of a decrease in the relevance of this research to *solving local societal and technological problems*. Since collaborative knowledge integration is mostly intended to *address locally relevant production and social problems*, it follows that the new emphasis of the academic incentives set by the SNI might be exerting an influence on the extent of knowledge integration achieved in the agri-biotechnology system. While such a likely influence is quantitatively analysed in Chapter 6, in the next section we explore the role played by institutional mechanisms intended to foster interaction, coordination and cohesion among actors in the technological system under study.

4.3.5 Mechanisms supporting interaction among actors

Since the 1990s, new forms of inter-organisational interaction have emerged in the agricultural sector of Uruguay, intended to promote the development of specific value chains. We refer to what came to be called 'sectoral technological boards', a sort of interaction and coordination structure formed around specific commodity value-chains and integrated by public research organisations, private actors, and (in some cases) government bodies (Bértola et al., 2005). As an example, the *Wheat Technological Board* was created in 1998 with the main aim of promoting the development and dissemination of novel technologies (Bértola et al., 2005, p52). The *Barley Technological Board* was created in 1992, with the involvement of the Agronomy School of UdelaR, the national agricultural research institute (INIA), and from the industrial side, the Technological Laboratory of Uruguay (LATU) and four brewing industry firms. This collaborative initiative developed a joint barley breeding programme that resulted in more than a 100%[100] increase in barley malt exports between 1990 and 1998 (Bértola et al., 2005, pp52-3).

The Technological Boards (TB) are multi-organisational agreements that establish a formal coordination structure intended to promote interaction between public R&D organisations and private actors in the agriculture sector (farmers' associations, agri-food industry firms and their industrial associations). The overall goal of these coordination structures is the synergistic identification of technological problems faced by national agri-food value chains in order to subsequently guide and align joint R&D efforts carried out by public and private organisations. At the moment, fourteen

[100] Barley malt exports increased from US$24 million in 1990 to US$52 million in 1998 (Bértola et al., 2005, p53).

technological boards exist, covering almost all agri-food value chains relevant to the Uruguayan economy (Facultad de Agronomía, 2013[101]).

The involvement of biotechnology R&D groups in these interaction-support structures was explored through semi-structured interviews with individual actors, given the relevance of these mechanisms for the integration of capabilities across organisational boundaries and innovation in the agricultural sector. Based on comments from four interviewees, we found that the involvement of biotech research groups in the activities of these structures depended on the importance given in the agenda of each board to biotechnology developments. In any case, the typical picture observed from the interviewed biotechnology research groups and firms is that they have marginal or often no involvement in the board's discussions about priorities and the coordination of research activities and projects supported by the commodity boards (interviewee E, 2011; interviewee J, 2011; interviewee K, 2011; interviewee R, 2011).

This may suggest a weak ability on the part of these *technological boards* to integrate emergent themes and advanced knowledge generation capabilities either into their collaborative R&D agenda or in the supported discussions among stakeholders from traditional agricultural value chains. In fact, some examples were identified where field-researchers[102] who play a leading role within the *technological boards* showed some resistance to including topics that involve lab-researchers in the boards' agenda (interviewee E, 2011). In such a case, instead of a weak ability to integrate biotechnology themes in the research agenda, it is more a deliberate intent to leave the biotech researchers community out of the discussions of the technological board. Such an attitude might be underpinned by the competitive academic environment we described before, which hinders the collaborative integration of knowledge assets among public R&D organisations.

Despite the general boards' aim of coordinating and integrating multiple actors, it was claimed that within UdelaR, researchers from only a narrow set of disciplines were

[101] http://www.fagro.edu.uy/investigacion/MESAS/
[102] Field researchers are seen by interviewees as a somewhat separate scientific community with different research practices and motivations compared to (biotechnology) laboratory researchers.

attracted or invited to become involved in *technological boards*. This undermines the potential of these structures to function as a means of integrating and exploiting the complementary R&D capabilities and skills on emergent technologies available in different public research groups across the technological system. Additionally, as observed during one interview, researchers in biotechnology-related disciplines (mainly from UdelaR) in some cases showed little interest in becoming involved in these public-private 'interactive spaces' or regard them as time lost on unproductive matters (interviewee J, 2011). These findings suggest the existence of obstacles to crossing disciplinary boundaries between different communities of researchers in the public domain with probably divergent research routines and motivations.

Notwithstanding the poor ability to integrate *emergent biotechnology themes*, these boards have underpinned the establishment of collaborative efforts on *traditional agronomic research topics* such as crop productivity or disease and pest tolerance addressed through conventional plant breeding projects (interviewee E, 2011). This can be seen as a weak ability of value chain stakeholders to envisage the potential innovation opportunities offered by the advanced R&D capabilities available in the country and to articulate research demands to exploit such knowledge bases. Conversely, research groups may not have been clear enough in showing the innovation opportunities that biotechnology research can offer to value-chain stakeholders. We can argue that here is an opportunity for *collaborative knowledge integration* that is not being properly exploited by the agri-biotechnology innovation system. Since most of the public biotechnology R&D groups interviewed showed a weak involvement in this sort of collaborative support structures, we did not undertake a more detailed exploration of their role in the subsequent quantitative empirical stage of the research (Chapter 6).

Comments from one interviewee provide evidence of this lack of interaction between biotechnology researchers and the interactive space generated by the commodity technological boards. A researcher from a university laboratory talking about a specific crop's technological board claimed that: *'...neither had we known about them nor had they known about us. They had no idea that we were doing that kind of things, or that it was possible to do such things in Uruguay...isolate a gene, clone it, and transform* *a...[crop plant]'* (interviewee E, 2011). This makes it clear that *interaction interfaces* between organisations from both sides – those having biotechnology R&D capabilities and those that may obtain benefits by accessing such capabilities from external actors – were not properly developed by these coordination support structures.

It follows that these structures developed to support coordination and interaction have not been able to overcome certain system failures (Woolthuis et al., 2005) resulting from inadequate interactions among public research actors with complementary knowledge assets. The evidence presented suggests that the *commodity technological board* as an interaction support structure has failed for some time in developing an effective interface between sectoral demands and ongoing efforts on advanced agri-biotechnology research and technology development in the public sector. It became clear from the interviews that some commodity boards did not provide a clear identification of public biotech R&D capabilities and their potential complementarity with other actors in the sector[103]. In other words, they failed in working as an actual interaction space, providing visibility and legitimacy to technological opportunities and potential benefits offered by biotechnologies, hence failing also in terms of generating demands from value-chain stakeholders. As was argued above and expressed by three interviewees, this may result to a certain extent from the narrow disciplinary approaches of some academics, their sense of appropriation over certain themes and their consequent perception of researchers from other disciplines as competitors rather than complementary partners (interviewee A, 2011; interviewee E, 2011; interviewee T, 2011).

Other mechanisms supporting access to complementary advanced R&D capabilities are the so-called *technological platforms* (Capdevielle et al., 2008; Panizza, 2010). As was argued in Chapter 2, when the integration of knowledge across different fields needs to be supported, '[c]*omplementary policies, such as instrumentation platforms* [or open door facilities]*...might play a positive complementary role for knowledge transfer between disciplines'* (Rafols & Meyer, 2007, p646; Rafols, 2007, p408). Given the rapid

[103] We refer here to private actors such as farmers, grain brokers, seed companies and the food-processing industry.

advances of biotechnology developments, analytical techniques and devices required for R&D activities are expensive and rapidly become obsolete. As a result, most public research groups, institutes and firms in a small country such as Uruguay are not able to acquire individually all the research technologies they need for their R&D activities. This has led the country to mobilise multi-organisational commitments and investments for the development of a small number of *instrumentation or technological platforms*, as referred to by Rafols (2007) above. A particular case is the *Integrative Genomics Platform* developed between LATU, INIA and Pasteur Institute - Montevideo (IPM), which in 2007 set up jointly owned functional genomics facilities within the molecular biology lab of IPM (Panizza, 2010). The shared goal pursued by this *technological platform* is scaling up investments to a level sufficient to develop infrastructure and acquire advanced equipment and experimental devices in order to provide centralised access to advanced analytical techniques in the form of services to public research groups and private organisations in Uruguay and neighbouring countries.

Despite a number of research technologies and analytic services of this sort being available in the country, it was observed that some research groups and firms continue to prefer foreign providers of such services. Two of these organisations argues that accessing foreign analytical techniques can be more quickly achieved, at a lower cost, together with higher quality results (interviewee A, 2011; interviewee I, 2010). In such cases a potential complementarity between national capabilities is left unexploited, probably as a result of the limited learning of the analytical technique by the local platforms, a weak development of the inter-organisational interface for the actual delivery of the service (service delivery management), and poor cost-competitiveness (Panizza, 2010). This, to some extent, points to a characteristic of public organisations that is hindering the exploitation of local complementarities, namely their weak relational capability (Dyer & Singh, 1998; Lorenzoni & Lipparini, 1999; Powell, 1998). Such a weak relational capability of *technological platforms* was noted by a consultancy team that assessed the availability of advanced biotechnology equipment in Uruguay and the performance of analytical services that provide access to them for other public and private organisations (Panizza, 2010). However, we were able to identify only two small *analytical service platforms* in Uruguay (Capdevielle et al., 2008), so they were not considered as salient mechanisms supporting collaborative knowledge integration in Uruguay, and were not explored in more detail in subsequent stages of the research.

4.4 Concluding remarks

After first substantiating our definition of the sectoral, technological and national boundaries for our empirical study around agriculture biotechnology in Uruguay, we subsequently explored in this chapter the *general structure and main components of the Uruguayan agri-biotechnology innovation system*. The relevance of biotechnology for agriculture innovation in Uruguay was discussed, drawing on figures on the adoption of plant biotechnologies and its impact on the gross value of agriculture production in the country. Moreover, we noted that the majority of the biotechnology research groups and firms identified are related, to some extent, to the agriculture sector. The chapter presented the results of the first exploratory stage of our fieldwork, which mainly involved an analytical review of previous studies and technical reports on agriculture and biotechnology innovation in Uruguay. Some preliminarily supporting evidence obtained from interviews with representatives of incumbent actors was also presented. We pursued a mostly descriptive approach intended to illustrate the relevant background conditions surrounding the central phenomena we want to understand further, namely collaborative knowledge integration processes.

The most salient components of the system that were examined encompassed: (i) the education domain with a particular focus on postgraduate-level training; (ii) the research sub-system; (iii) the private domain – the array of biotechnology firms and their main products and services supplied to the agriculture sector; (iv) policies supporting science, technology and innovation; and (v) bridging mechanisms – institutional instruments promoting interaction and coordination among actors. We paid particular attention to public research organisations, since they account for most of the biotechnology R&D capabilities in Uruguay.

With regards to advanced skills development by the education system, while we observed a rather well-developed range of postgraduate research programmes related to the biotechnology field, representatives of public research groups stressed their difficulty in retaining young researchers after they finished training. From its side, the private sector provides a very low demand for postgraduates trained on biotechnology-related knowledge fields. This lack of coherence between the development of advanced skills and their effective engagement in the scientific or production structures is beyond the scope of this research but is surely undermining the absorptive capacity of the technological system as a whole. Despite this structural weakness, we noticed an interesting role of postgraduate programmes in the dynamics of knowledge integration among actors in the system. In particular, we argued that postgraduate students acted, in many cases, as an *ad-hoc mechanism* fostering the integration of external knowledge or research capabilities from local or foreign organisations into the R&D activities of the group hosting their postgraduate *research projects*. We analyse this role in more detail in Chapters 5 and 6.

From a general examination of the knowledge-base structure in Uruguay on which agri-biotechnology R&D stands, we noted, on the one hand, that most capabilities and investments on agri-biotechnology R&D are concentrated in the public sector. Conversely, for its innovation efforts, the private sector relies heavily on access to knowledge assets and the R&D efforts of public research organisations. Within the public domain, a previous study found that research efforts and resources are physically dispersed among rather small R&D groups that work on very specific themes weakly related to other groups' research (Bortagaray, 2007, p274-51). Moreover, during our interviewing work some public research groups acknowledged a rather passive attitude towards identifying private technological needs. Given this pattern of public research activity, the synergistic integration of capabilities between groups and disciplines is often hindered (Bortagaray, 2007). The same study argued that private-sector actors have a weak ability to act collectively as well as to articulate long-term research demands; as a result, most R&D collaborations between public and private actors have been characterised as basically isolated efforts aimed at addressing short-term goals (Bortagaray, 2007, p317). We argued that these dynamics of public and private R&D efforts hinder the development of an effective interface between actors and provide poor guidance for the research efforts carried out by public organisations, hence undermining the consolidation of clear technological trajectories and the development of the agri-biotechnology innovation system as a whole.

Despite the coordination and interaction constraints discussed in the previous paragraph being found both within the public-sector research setting and between public and private actors, we focus our empirical analysis on the interactive dynamics among public research organisations. This specific empirical concern is based on the evidence that the public sector in Uruguay is a key supplier of technological solutions for the agriculture sector and in particular that it is the main locus of agri-biotechnology R&D capabilities, resources and research efforts. We illustrated this pattern emphasising that the R&D lab of private producers and users of agri-biotechnologies in Uruguay is mostly located within public research organisations. Specifically, we argued that it is of particular relevance to pursue further our understanding of the processes that underpin the system's capacity to link and exploit distributed skills and R&D capabilities locally available in different public research organisations[104]. The overall argument (substantiated earlier) is that a more effective integration of complementary knowledge assets through collaborative research efforts in the public domain should result in improved performance of the technological innovation system as a whole.

We also examined the institutional component of the system, particularly the relevant STI policies such as investment promotion policies, intellectual property norms, and regulations for market introduction of biotechnology products. We paid special attention to recent institutional developments aimed at strengthening the scientific and technological bases in Uruguay, especially the creation of ANII and the National Researchers Assessment System (SNI). While a recent study of the impact of the SNI (Bernheim et al., 2012) found that Uruguay is increasing its scientific output in global peer-reviewed journals, we argued that this is apparently happening at the expense of a decrease in the relevance of this research to solving local social and technological

[104] The need for further research on this was noted by Heinze and Kuhlmann (2008).

problems. Since collaborative knowledge integration efforts are mostly intended to address locally relevant production and social problems, we argued that the new emphasis of the academic incentives set by the SNI might exert a negative influence on the extent of knowledge integration achieved in the agri-biotechnology system. This likely influence is explored further in Chapter 6.

Finally we examined the role played by a number of institutional mechanisms – in particular, the technological boards – promoted and established by the government with the aim of supporting coordination and interaction among actors in the system. We noted that *bio*tech research groups have marginal or frequently no involvement in the board's discussions about priorities and the coordination of research activities and projects supported by the commodity boards. We suggested that this may result from a weak ability of the boards to integrate emergent themes into their agenda or from a more deliberate intent to leave the biotech researchers community out of the technological board. The latter attitude might be underpinned by a competitive academic environment, which hinders the collaborative integration of knowledge assets among public R&D organisations. In general terms, we argued that the *commodity technological boards* have mostly failed in developing an effective interface between sectoral demands and ongoing efforts on advanced agri-biotechnology research and technology development in the public sector.

To sum up, we have explored the main structural components of the agri-biotechnology innovation system in Uruguay. The evidence presented substantiates the need to pursue a deeper understanding of *how* research organisations and lower-level R&D groups in the public sector interact for the integration of complementary knowledge assets, and *what* forces may be driving this integration process. Therefore, in the following chapter we analyse the results of our interviews, looking particularly at the dynamics of R&D collaboration among public research organisations and the main factors shaping the ability of R&D groups to collaboratively integrate complementary knowledge assets.

Chapter 5 - Results: Qualitative examination of collaborative knowledge integration

5.1 Introduction

Our research has taken a system perspective to explore *how local complementary capabilities are integrated and exploited through inter-organisational collaborative R&D arrangements within an emergent technological innovation system*. The previous chapter illustrated our initial empirical results through a mostly descriptive view of the main components of the agri-biotechnology innovation system in Uruguay. Although it also provided preliminary observations of the *dynamics of collaboration and knowledge integration* among public research organisations, it is the aim of Chapter 5 to present the results of a deeper examination of such integration processes.

Previous research has stressed the need to foster our understanding of such integration processes. Studies, particularly in Latin America, have highlighted the problem of poor or sometimes non-existent processes of coordination, integration of knowledge assets and weak linkages among actors (Salles-Filho et al., 2006; Lundvall et al., 2002; Arocena & Sutz, 2002). Therefore, despite agriculture being increasingly viewed from a systemic perspective, we argued earlier that when the focus is on emergent technological systems in developing countries, there is a need for further studies of the interactive dynamics among actors and the attributes of the system and their incumbents that may affect the collaborative integration of distributed sources knowledge within the system. To address this need, sections 5.2 to 5.4 present the results of an analysis exploring how complementary capabilities or potential synergies are being exploited within the public research sub-system, as well as identifying relevant institutional and organisational forces supporting or hindering such exploitation. This examination is based on qualitative data collected in the course of 25 exploratory semi-structured interviews with members of public R&D groups (17) and representatives of private actors (8) involved in agri-biotechnology R&D in Uruguay[105].

[105] For details of the interview methodology, see Section 3.4.4.

The qualitative analysis of the interview data was carried out so as to address the following guiding questions: (i) Do complementarities among public research organisations exist? (ii) How do they emerge? (iii) What are the rationales driving collaboration between public R&D organisations or groups? (iv) How are complementarities between public R&D groups exploited? (v) What are the major patterns of collaboration and knowledge integration among public research organisations? And (vi) what are the main forces shaping the degree of knowledge integration achieved by public research groups through their collaborative R&D activities? (The interview protocol employed is presented in appendix 8.1.)

Our qualitative results identifying likely answers to these questions are presented below and structured as follows. Section 5.2 explores the existence of complementarities among actors in the system and how they arise. Section 5.3 looks at how capabilities and skills of potentially complementary organisations are exploited through collaboration processes, while section 5.4 analyses the most salient factors shaping the collaborative integration of local knowledge assets within our empirical setting. Finally, a summary and main conclusions from this chapter are set out in section 5.5.

5.2 Emergence of complementarities among actors and drivers of R&D collaboration

In this section, we discuss evidence mainly from the interviews regarding the distributed character of knowledge assets, and the consequent rationales and motivations driving the formation of collaborative relations between complementary public research groups. To begin with, a common theme emerged from discussions with two public-sector interviewees, namely their clear perception about a trend towards increasing specialisation of research groups in specific areas and research techniques (interviewee E, 2011; interviewee L, 2011). In particular, a member of a public R&D group acknowledged that they increasingly try to specialise in particular analytical techniques and methods, and argued that this move is the result of an increasingly competitive academic community in Uruguay (interviewee E, 2011).

These observations are in line with the changing trends in the way scientific knowledge is produced that have been explored by other STI scholars (Gibbons et al., 1994). We refer particularly to the rapid advances and increasing complexity in biotechnology research techniques and methodologies, which have resulted in a growing need for public research groups to focus their efforts and specialise in particular techniques and processes. From a system-level perspective, this involves developing a set of specialised capabilities distributed throughout the system, with complex complementary relations between actors (Powell, 1998; Hessels & van Lente, 2008).

It can be inferred from previous research that the marked specialisation we observed may well result in an increasing degree of complementarity among research techniques and technologies available in different research groups and organisations within the wider technological system (Powell, 1998, p229; Colombo et al., 2006; Heinze & Kuhlmann, 2008). Such technological complementarity, or (what is essentially the same) potential synergies, should be realised and exploited through different sorts of formal and informal collaborative relations between organisations – building economies of scope – if the exploitation of knowledge resources available and system-wide innovation are to be enhanced (Dyer & Singh, 1998; Gulati & Gargiulo, 1999; Acha & Cusmano, 2005).

Since the increasing specialisation and complementarity among public research units discussed above open up opportunities for the synergistic integration of capabilities among actors, we explored the interactive dynamics that may support the exploitation of such opportunities throughout the system. To start with, we looked at the rationales and motivations followed by public research groups or organisations when establishing collaborative research arrangements. The main driving forces identified during our interviews include the group's interest to: *(i)* taking part in research done outside the organisation by accessing complementary R&D capabilities – i.e. *division of labour* (interviewee D, 2010; interviewee E, 2011; interviewee N, 2011); *(ii)* accessing complementary capabilities in order to learn new research skills, usually by sending students to be trained in external groups on specialised research techniques, while applying such techniques in their own biological materials – i.e. *learning* (interviewee A, 2011; interviewee C, 2011; interviewee G, 2011); *(iii)* exchanging biological materials or supplies (interviewee E, 2011; interviewee G, 2011); *(iv)* linking R&D capabilities in order to be more competitive in calls for research grants (interviewee J, 2011; interviewee M, 2011; interviewee N; 2011); *(v)* jointly committing resources in order to achieve sufficient scale for the solution of common restrictions (interviewee B, 2010; interviewee E, 2011); (*vi*) accessing information on the needs of the private sector identified by other organisations, in order to provide guidance on its research efforts (interviewee E, 2011; interviewee L, 2011); and (*vii*) accessing funding for the group's research activities from private actors (interviewee C, 2011).

The rationales identified by our interviewees show clear similarities with those identified in scholarly studies of scientific collaboration among public research organisations that were discussed in Chapter 2 [106] (Heinze & Kuhlmann, 2008; Katz & Martin, 1997; Laudel, 2002). Our qualitative evidence suggests that existing complementarities or potential synergies among research and technological capabilities distributed throughout the agri-biotechnology system are perceived by the public-sector researchers interviewed as clear drivers of the collaborative R&D links they pursue. This provides a fertile empirical setting to address our central concern, namely exploring the extent to which these collaborative efforts are able to integrate *distant* complementary knowledge-assets as well as the relevant forces shaping this integration process.

From a lower level look at our interview data, it is worth portraying the actual views put forward by two of the university researchers interviewed:

> '...the objective is to access their knowledge; go to learn something; or to have part of the work that we can't do, done by them; or to send students' (interviewee C, 2011);

> '...when we are invited by - or in search of - partners, our idea is always to be able to complement what we do with others; we have always partnered laboratories that do things that we can't...and explore if we can keep

[106] See Table 2.1 in Section 2.4.

> something,...exchange biological...or non-biological materials...that are useful for our laboratory' (interviewee E, 2011).

Moreover, despite there not being clear-cut patterns, we observed slight variations in the rationales followed by different types of research organisations. For example, two groups from applied-research organisations emphasised the formation of synergistic relations mostly aimed at accessing and integrating from external sources certain capabilities required to develop new biotechnology-based products that they acknowledge not possessing in-house (interviewee D, 2010; interviewee I, 2010). This type of collaboration has been defined in the literature as *deep collaboration* (Rafols, 2007) and involves a *division of labour* among rather specialised R&D groups (Laudel, 2001, 2002). From their side, two researchers at the main university (UdelaR) tended to direct their collaborative efforts largely towards building new internal skills in the group by means of accessing and learning about specific analytical techniques required for their disciplinary research projects (interviewee A, 2011; interviewee G, 2011). In these cases, the most important goal is *'in-house learning'*, which involves the transfer of know-how between groups (Rafols, 2007, p402; Laudel, 2002, p9).

Through our conceptual and methodological approach, we have focused our attention on exploring the existence of complementarities mostly among distributed *R&D capabilities* and *disciplinary skills*, namely those knowledge assets required for the actual implementation of the research results. This means that we did not pay as much attention to skills or the ability of R&D groups to define – before starting an R&D project – the actual topics or questions to be addressed by their research efforts. Nevertheless, our qualitative findings suggest that besides complementarities between R&D capabilities, there is a degree of complementarity within the system between public actors with differing abilities to identify and understand producers' needs.

We observed that two academic research groups faced difficulties and have a weak ability to interact with the private sector (interviewee E, 2011). Therefore, potential complementarities emerge from the interest of these academic groups[107] in accessing

[107] Such an interest has been stimulated by R&D funding programmes that emphasise the productive application of results.

information about the technological needs of the production sector collected by other research organisations such as INIA through its well-developed network of links with final users of agri-biotechnologies (interviewee E, 2011; interviewee L, 2011). When such envisaged complementarities are realised, R&D groups that are less connected with agriculture producers increase their ability to steer and focus their biotechnology research efforts on the actual needs of the agriculture sector (farmers). This can be understood as a collaborative relation motivated by the *relational capability* [108] of the potential partner, particularly its differential capability for interacting, identifying and retrieving actual demands from private actors. We acknowledge here the existence of this sort of complementarity (among groups with differing *relational capability*), but in order to focus the scope of our research, the quantitative analysis (Chapter 6) explores only the collaborative integration of R&D capabilities and disciplinary skills as well as the factors shaping the degree of integration of those knowledge assets.

5.3 Realising complementarities: collaborative exploitation of local R&D capabilities

In the previous section we began to explore the dynamics of collaborative knowledge integration within the agri-biotechnology system by looking at the rationales for the establishment of R&D collaborations among public research organisations. In an effort to move this exploration ahead, we subsequently analyse interview data, looking at how complementary capabilities or potential synergies are actually exploited throughout the agri-biotechnology public research sub-system. With this aim, examples of collaborations described by the interviewees are illustrated here, providing empirical evidence of collaborative processes for knowledge integration and their diversity in terms of: boundaries crossed through inter-group interaction[109]; types of capabilities or resources integrated; means to actually integrate external knowledge

[108] We discuss the relevance of 'relational capability' within our empirical setting in Section 5.4.3. Here, we note that some collaborative relations of R&D groups are intended to access the ability of other public organisations to establish effective relationships with private agents.

[109] Knowledge integration between R&D groups was observed both within a single organisation and across organisationsal boundaries. In the latter case, inter-organisational collaborations with local and foreign partners were observed. Although international collaborations are analysed, to some extent, in this qualitative chapter, we concentrate our attention on local collaborations.

assets; and outcomes of the collaborative process. The variety of goals pursued by R&D groups when collaborating was already analysed earlier.

The results of the interviews have shown that the access to complementary capabilities is undertaken through formal or informal collaborative arrangements with national or foreign groups. In some cases (2), the nature of the collaborative effort is based on reciprocity between partners, namely a non-market exchange where, as an example, a research group providing access to certain analytical capability is rewarded with sharing the research results and other outcomes of the project such as co-authorship of scientific publications (interviewee D, 2010; interviewee F, 2011). In other cases (4), the complementary R&D-capability may be accessed through a market transaction where, to mention some cases, a national *technological platform* (analytical service labs described in Chapter 4) or a foreign service laboratory provides access to specific analytical techniques or other research technologies (interviewee D, 2010; interviewee A, 2011; interviewee G, 2011; interviewee I, 2010).

Specific instances of actual complementarity and synergistic knowledge integration between R&D groups located in different public research organisations were identified during the interviews. As noted by one interviewee talking about the development of functional markers for plant breeding,

> '...we don't do that...we passed that to the work of... [an external researcher] who is really good on that, and she has somehow specialised in that' (interviewee E, 2011).

The same researcher illustrated how his group accessed capabilities on the bioinformatics analysis of gene sequences from another group:

> '…we started to present joint projects with the group...some years ago. They have strengths in the molecular part [while] we are stronger in the more biochemical-physiological part, so we got together and started to jointly present projects...and it [the partnership] was strengthened a bit' (interviewee E, 2011).

Drawing on the types of scientific collaboration conceptually defined by Rafols (2007, p403), our observations suggest that the R&D groups referred to above performed *'deep collaboration'* efforts, namely research on jointly defined topics and involving a significant degree of division of labour among groups.

Some public-sector researchers interviewed also identified collaborative efforts involving less intense, informal interactions intended to access external capabilities from other public research groups. Drawing again on Rafols, this can be described as *service collaboration*, where '...one laboratory supports the research of another by providing materials, access to and use of instruments, data and analyses, or general know-how. ... [T]he researchers providing the services act only in a supportive or advisory capacity and do not participate actively in the design and final interpretation of the results' (Rafols, 2007, p402). Within our empirical setting, it seems to be a rather frequent exchange mechanism that the researcher borrowing the analytical facilities pays back the partner with some laboratory supplies needed by the lending laboratory (interviewee E, 2011) or with including the scientific counterpart as co-author in a subsequent publication (interviewee N, 2011). This informal management and pay-off of collaboration results from the fact that most public laboratories do not have internal structures and processes to offer easier access to their facilities through market-mediated transactions. Some exceptions are the labs of the Chemistry School and LATU[110], which have professionalised provision of analytical services, giving access to some advanced techniques faster and more efficient (interviewee E, 2011). In other words, these latter labs have been better in purposely building *inter-organisational interfaces* intended to facilitate inter-laboratory interactions and external groups' access to their in-house facilities, skills and other R&D resources (this is encompassed by the concept of *relational capability* analysed in section 5.4.3).

In addition, we looked at the *potential* offered by advanced biotechnology research techniques for their applications across sectoral boundaries and distant knowledge fields, since previous studies have suggested that this potential of emergent technologies opens up ample opportunities for inter-organisational collaboration

[110] Technological Laboratory of Uruguay.

(Rafols & Meyer, 2010; Leydesdorff & Rafols, 2011). Our empirical research identified examples where this sort of potential cross-sector complementarity was exploited through partnerships between organisations belonging to different sectors, particularly human health and agriculture technology fields. In one case, a public research group working on the isolation of bio-molecules for their use in the control of plant diseases established a collaborative relation with a medical research lab specialising in the development of synthetic molecules for the treatment of human diseases; the collaboration was intended to exchange biological and synthetic molecules and test their respective value for plant and human disease treatment (interviewee D, 2010). While describing this collaboration, the involved researcher claimed that

> *'[sectoral]...knowledge barriers are getting blurred. When we go to basic [research, biotechnology] applications on different areas, on agriculture or on biomedicine, are merging'* (interviewee D, 2010).

Such unclear barriers were also suggested by a member of a biotech firm who claimed that

> '… when you go to basic labs, and production labs too, the differences, the frontier between issues concerning the animal, the human, the plant, and the industrial matters don't exist. Therefore, working on a cell, a culture, a virus that parasites a cell, a bacterium, an enzyme, a protein; it doesn't matter what the origin is, or what it will be used for... That world below certain things doesn't have a frontier that matters' (interviewee P, 2011).

That firm has been carrying out biotech R&D on diverse fields such as animal health, bio-control microorganisms, plant degradation processes and human vaccines.

Also benefiting from the potential cross-sector application of biotechnology research techniques, a plant biotechnology R&D lab sent one of its junior scientists to be trained on massive DNA sequencing and bioinformatics. As explained by the group leader,

> '…he is doing an internship in a research centre that actually works on cancer; it has nothing to do with his research interests but he can learn to do massive

> sequencing and bioinformatics analysis…while he will collaborate with the cancer project, he will also get his plant samples sequenced, an analysis that would cost around US$10000. This is great for us! On the one hand he learns, but the host lab also runs the analysis of his samples' (interviewee G, 2011).

This example and the ones presented in the previous paragraph suggest not only that agri-biotechnology R&D groups clearly face a need to somehow access external complementary R&D capabilities, but also confirm that *inter-organisational research collaboration* of different forms represents a central *mechanism* granting such access and integration of complementary knowledge assets into the groups' R&D activities. The findings suggest that R&D collaborations are often implemented through one or more of the following mechanisms or strategies: (i) division of research activities among specialised complementary R&D groups (*deep collaboration*); (ii) training of researchers or students in external labs; and (iii) exchange of research materials. The access to advanced analytical services was also observed but we pay less attention to this type of interaction since most providers of analytical services are foreign laboratories while our attention is focused on the integration of local R&D capabilities.

Up to this point we have analysed knowledge integration processes that cross the boundaries of the organisations housing the collaborating R&D groups. However, our interviews showed that, besides the need to integrate knowledge assets across organisational boundaries, the high degree of complementarity among biotechnology R&D capabilities distributed across the system also shapes the dynamics of knowledge integration – exploitation of complementarities – within a single organisation. Thus, motivations similar to those identified in the previous section are driving the establishment of collaborative relations among complementary R&D groups within a single public research organisation.

We analyse the case of biotechnology research in the National Agricultural Research Institute (INIA) as an example of knowledge integration across research groups within a single organisation. In order to briefly illustrate the internal dynamics of interaction and knowledge integration among internal research teams with different disciplinary background, we quote the claims of one researcher of this organisation:

> '...biotechnology research offers, in fact, a set of tools that can be applied to speed up processes…in order to look for diverse solutions to biological problems... The knowledge that the biotechnology group has been developing – through diverse specialisations – and subsequently integrating with the plant breeding teams has resulted in a good interactive climate that allows a better response to the solutions that the organisation is pursuing...Hence, I think that it is the nature of biotechnology that leads to integration...it calls to integrate different disciplines' (interviewee D, 2010).

During the first years after its creation, the biotechnology unit of INIA made cumulative efforts to learn, specialise and master a number of research techniques and methodologies. The main 'users' of the outcomes from the R&D efforts of this group are plant-breeding teams within INIA (internal demand) who may benefit from the application of traditional and modern biotechnological techniques[111] complementing and enhancing the efficiency of their traditional breeding processes (interviewee D, 2010; interviewee I, 2010).

The development of molecular-markers associated with traits of value for plant varieties pursues their further use by plant-breeding programmes through marker-assisted selection (*MAS*) processes (interviewee I, 2010). The actual implementation of plant breeding processes based on *MAS* methods implies a complex process that demands much interaction and joint learning between two internal research-communities, biotech-researchers and plant-breeders (interviewee I, 2010). In this interactive learning and research process, the biotechnology group and plant breeders jointly define clear directions and objectives for the research efforts undertaken by the biotechnology group so as to fulfil the needs of plant breeders and, through them, the demands of agriculture producers (interviewee D, 2010; interviewee I, 2010). So, drawing on previous studies, these internal knowledge integration efforts can be described as *creative deep collaboration*, which involves a joint definition of research goals and division of labour among complementary R&D groups (Rafols, 2007; Laudel,

[111] These techniques refer mainly to in-vitro plant propagation and molecular-marker techniques (interviewee D, 2010).

2002). Nevertheless, these synergistic processes have not always worked smoothly so we look at this case again in the analysis of forces driving or hindering knowledge integration presented in the next section (5.4.2).

As a result of the interaction with plant-breeders described above, the biotechnology research group of INIA has improved its understanding of the technological demands of the agriculture primary sector and hence the group's ability to align and focus its research efforts on addressing actual problems of local production. This confers a differential capability to this biotech group compared to R&D groups from other public research organisations in the Uruguayan agri-biotechnology innovation system. This differential capability was acknowledged by two members of academic research groups from UdelaR interviewed which see it as a complementary knowledge-asset and consequently have established collaborations with INIA in order to enhance the contribution of their research results to local innovation processes (interviewee E, 2011; interviewee L, 2011).

Illustrating this integration dynamics, a member of a university laboratory noted that:

> '...this issue of working with students sponsored by INIA has somehow *introduced us also to other crops and themes*, in other product areas ... After a number of collaborative projects with INIA, we have been truly involved inside the needs ... That contact with INIA has benefited us in knowing what is really going on' (interviewee E, 2011).

The same scientist claimed that:

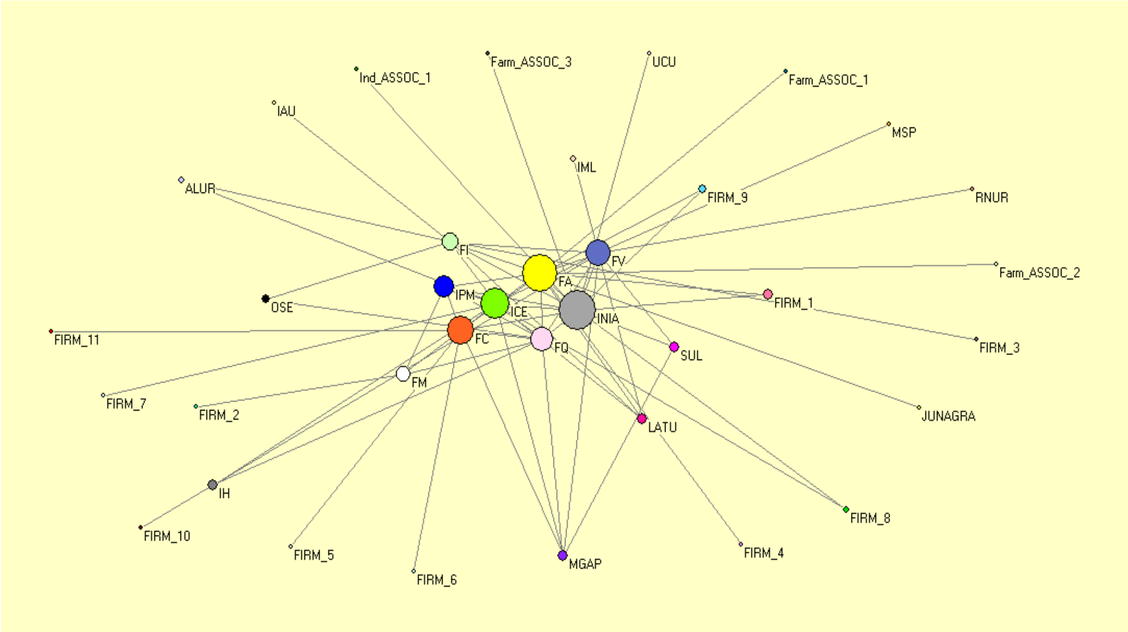
> '...based on the whole history of relationships that we have with INIA and through INIA with producers... [our objective is now] that all information that we generate could be used in plant breeding programmes...so the idea is that we should be able to develop functional markers...' (interviewee E, 2011).

These observations suggest that by means of collaborative efforts, the academic group is realigning its research goals from largely disciplinary ones towards concerns on achieving results more applied for the solution of problems faced by local farmers. Therefore, we can claim that through this capability, INIA not only complements efforts of other public – mainly academic – actors but from a broader perspective it may also play an *intermediary trajectory-signalling role* for the whole technological system around plant variety breeding. It *translates technological demands* from producers into demands for near-basic research which are then captured by other public research groups, mobilising R&D capabilities and re-steering their research agenda towards the solution of local production problems. Whereas this intermediary and translation role of applied research groups was observed within the field of plant-breeding and plant variety development, we should note that such a role of applied-research groups was not found in other technological fields such as the development of animal vaccines or plant-growth promoters.

From an empirical perspective, the internal integration dynamics observed for the case of plant breeding in INIA suggests that exploring knowledge integration should take into account not only the collaboration process across organisational boundaries, but also how the boundaries of specific research groups or communities are crossed even within a single organisation. This gives support to our methodological approach that considers as the unit of analysis not the organisation but a lower-level entity, namely the R&D groups which, as previously described by Bortagaray (2007), are generally formed around specific knowledge fields or disciplines. Such an approach allows us to assess collaborative knowledge integration between groups, regardless of whether they are part of a different or the same organisation.

To sum up, the qualitative analysis presented in this section confirms that complementarities do exist between R&D groups both across organisational boundaries and within a single organisation. Moreover, the patterns of interaction between organisations found in our study suggest that collaborative research arrangements represent a valuable way to exploit the potential offered by these complementarities. With the aim of portraying the importance of research collaboration within the agri-biotechnology research sub-system in Uruguay, we present below a graphic representation of all collaborative R&D links established among local incumbents in the system during the implementation of R&D projects contained in our survey response data (Figure 5.1). With a descriptive intent, the figure shows how the *main R&D organisations* identified in Table 3.5 (section 3.4) are linked to other organisations in the agri-biotechnology innovation system.

Figure 5.1: Map of inter-organisational R&D collaborations



Source: elaborated by the author using *Pajek* based on survey data. See reference for organisational acronyms in appendix 8.2.

While the links were actually identified at the level of R&D groups (132), the figure aggregates for each organisation all the links established by its internal R&D groups. Each organisation (36) is represented by a distinctively coloured node. The size of the nodes is proportional to the total number of links established during the participation of R&D groups from each organisation in R&D projects encompassed in the survey. The larger nodes at the centre of the figure, show that the more active actors in building collaborative links include the National Agricultural Research Institute (INIA), the Biological Research Institute 'Clemente Estable' (ICE), the Pasteur Institute of Montevideo (IPM) and six Schools of UdelaR, namely the Agronomy (FA), Veterinary (FV), Natural Sciences (FC), Chemistry (FQ), Engineering (FI) and Medicine Schools

(FM)[112]. This is a rather descriptive and preliminary illustration that provides a system-wide view of all research collaborations identified through the survey; the whole set of linkages is the subject of our subsequent quantitative examination of the degree of knowledge integration accomplished by each R&D group through its research collaborations (Chapter 6). However, before turning to the quantitative analysis, it remains to qualitatively explore the drivers and barriers that may shape the degree of *collaborative knowledge integration*, that is to say, the extent to which complementarities between research groups' knowledge assets are exploited through collaborative R&D activities. We address this in section 5.4 below.

5.4 Factors shaping the integration of local knowledge assets through collaborative R&D

5.4.1 Foreword: how have we arrived here?

This section takes us to the central concerns of our study. We explore the results of the interviewing stage in order to provide preliminary answers to our main research question defined in chapter 2 (section 2.1), namely: *How and why does the extent of scientific and technological complementarity exploited through R&D collaborations differ among collaborating actors of the agri-biotechnology innovation system in the context of developing countries?* In the previous two sections we explored the existence of complementarities among public R&D groups along with their rationales for establishing R&D collaborations. While actual collaborative research efforts integrating complementary knowledge assets were briefly described and analysed above, we now present an overall examination of interview data particularly aimed at *identifying key forces that may be shaping the processes of collaborative knowledge integration*. In other words, we explore factors that might affect the degree of

[112] The marginal positions of firms in Figure 5.1 reflect the fact that they are less active performers of research activities as noted in Chapter 4 but also results from their exclusion from the survey given our focus is on collaboration among public research actors. Hence, the firms included in the figure were identified as collaborators by public R&D groups that answered the survey.

complementarity among local actors that is actually exploited through R&D collaborations within the agri-biotechnology public research sub-system.

As was previously argued, the *primary argument* behind this goal is that research oriented to solving local production problems requires the integration of distant complementary knowledge (Van den Besselaar and Heimeriks, 2001). In other words, we assume that the larger the degree of complementarity among the knowledge assets integrated through collaboration, the greater the impact will be on the solution of production problems and consequently on innovation performance of both individual organisations (Hage & Hollingsworth, 2000; Rosenkopf & Nerkar, 2001; Nooteboom et al., 2007) and the whole system (Carlsson & Stankiewicz, 1991; Lall, 1992; Cimoli et al., 2009). Conversely, a low degree of *collaborative knowledge integration* is understood in this research as an indication that opportunities for complementarity between actors in the system remain unexploited. These situations have been defined as a *'network failure'* in the system (Woolthuis et al., 2005, p610; see chapter 2, section 2.3.1). More precisely, '[a]*s a result of ... network failures, possibilities for interactive learning and innovation are under-utilised and firms may fail to adapt to new technological developments'* (Carlsson and Jacobsson, 1997, cited by Woolthuis et al., 2005, p614).

In order to focus our analysis on why these *failures* in collaborative knowledge integration may occur within a technological innovation system, we defined in chapter 2 (section 2.7), the following specific research questions:

> *How do system-level institutions and incentives for public sector researchers shape the extent of integration of complementary knowledge assets achieved by R&D groups through collaborative research activities within a developing-country agri-biotechnology innovation system?*
>
> *How do organisational-level attributes shape the extent of integration of complementary knowledge assets achieved by R&D groups through collaborative research activities within a developing-country agri-biotechnology innovation system?*

As argued in chapters 2 and 3, we followed two complementary approaches to identify relevant forces driving *collaborative knowledge integration*. Firstly, we identified a number of relevant factors through a review of previous scholarly studies. We then complemented the evidence found in the literature with an inductive interpretation of the results of our exploratory interviews. Hence, the analysis of interview data presented in this section allowed us both to deductively assess the relative importance in our empirical setting of the driving forces identified from previous research, and to inductively identify other relevant influences on the dynamics of collaborative knowledge integration in the Uruguayan agri-biotechnology research sub-system.

We arrange our analysis into four aggregate factors' categories as conceptually defined in the analytical framework presented at the end of chapter 2 (section 2.7; Figure 2.4). For the purpose and boundaries of our research, these types of forces were understood as those playing the most relevant influence on the degree of *collaborative knowledge integration* achieved by an organisation or R&D group. The conceptualised categories encompass: (*i*) structural attributes of the R&D group; (*ii*) the R&D groups' relational capability; (*iii*) system-level institutions and incentives; and (*iv*) compliance of the R&D group with scientific reward institutions. Formal and informal institutions and incentives (iii) are examined in section 5.4.2. While the compliance of R&D groups with formal reward policies (iv) is more deeply analysed in chapter 6, we discuss the implication of these reward policies also in section 5.4.2. Within the *structural attributes* (i) we concentrate on those related to the absorptive capacity of an R&D group, that is to say, its ability to identify, assimilate and exploit external sources of knowledge (Cohen & Levinthal, 1990; Cockburn & Henderson, 1998; Szulanski, 1996). Since absorptive capacity is difficult to assess qualitatively, we analyse it through our quantitative approach presented in chapter 6. However, we do discuss in this chapter the role of R&D groups' *relational capability* (section 5.4.3), a concept that – while theoretically based on the notion of absorptive capacity – has been defined as the ability of an organisation to establish interactive relationships, access other actors' knowledge resources (Dyer & Singh, 1998, p672; Lorenzoni & Lipparini, 1999, p317), and to internalise them into the organisation (Grant, 1996). Finally, in close relation with the concept of relational capability, our empirical observations suggested that an

R&D group's research students play a valuable role working across the boundaries of their sponsor groups. Hence, section 5.4.4 analyses how research students may shape collaborative knowledge integration processes. Section 5.5 ends the chapter by presenting some brief closing comments.

5.4.2 Institutions and researchers' views towards collaborative knowledge integration

Scholarly research discussed in chapter 2 (section 2.7.3) suggests that *institutions* shape the exploitation of opportunities for innovation and economic development offered by complementary capabilities functionally in place throughout the whole system (Lall, 1992; Padilla-Pérez et al., 2009; Bortagaray, 2007, p354). The incentive structure defined by formal and informal *institutions* (North, 1994) plays a key role enabling or hindering the aggregation of complementary actor-level technological capabilities into system-level innovation capability (Lall, 1992; Cimoli et al., 2009, pp337-43; Bortagaray, 2007, p354). Therefore, we explored qualitatively (chapters 4 and 5) and quantitatively (chapter 6) how system-level *institutions* may be fostering or hindering processes for collaborative knowledge integration within the empirical setting of the Uruguayan agri-biotechnology public research system.

Informal (North, 1994) or *soft institutions* (Woolthuis et al., 2005, p610) originate from values, non-written rules, perceptions, trust in other actors, and routine practices that affect the way individuals and organisations share knowledge and learn, thus exerting an influence on the processes of knowledge integration through inter-organisational R&D collaborations (Laudel & Gläser, 1998; Malerba, 2005; Hall, 2006). Regarding this type of institution, we focused the qualitative work presented in this section specifically on examining how particular views and practices of researchers may place their research somewhere between in-ward disciplinary approaches and more integrative research efforts that cross the boundaries of knowledge fields and organisations. Closely related to this, we also explored how collaborative knowledge integration may be shaped by formal (North, 1994) or *hard institutions* (Woolthuis et al., 2005, p610). We concentrated on public policies since previous studies have highlighted their major role in fostering economic development by means of supporting technological learning, the development of indigenous technological capabilities, and complementary interactions among actors, as well as the exploitation of local innovation opportunities (Cimoli et al., 2009, pp337-43).

With regards to informal institutions, the interviews pointed to a number of forces that tend to maintain researchers' activity within their disciplinary boundaries. In particular, we observed that the attachment to long-established research practices, differences in motivations and goals, the compatibility of research routines of different R&D groups and the culture, beliefs or non-written rules of different scientific communities are affecting the exploitation of potential complementarities among R&D groups within the technological system under study. We illustrate below how these forces shape the dynamics of collaborative knowledge integration, to begin with, by looking at the case of biotechnology research in INIA (described in section 5.3 above) that progressively developed a synergistic relation among complementary R&D groups within the organisation.

We introduced, in section 5.3, the knowledge integration efforts between two internal research communities of INIA, namely the biotechnology researchers and plant-breeders. Plant-breeding teams may complement and enhance the efficiency of their traditional breeding processes through the application of traditional and modern biotechnological techniques developed or adapted by the biotechnology group (interviewee D, 2010; interviewee I, 2010). These collaborative integration processes faced a number of obstacles that we describe below.

We noticed that the transfer of traditional types of biotechnologies developed by the biotechnology lab of INIA, such as disease-free plants propagated through tissue-culture delivered to the productive sector and internally to plant-breeding programmes, has been relatively successful and has not faced significant difficulties (interviewee D, 2010). This somewhat resembles a linear innovation process, where a traditional biotechnology technique, the in-vitro tissue-culture, is mastered by the biotech group and subsequently applied and embodied into disease-free quality plants. This end biotech-product is finally delivered to internal plant-breeding programmes, to plant-suppliers or directly to farmers, not requiring major interaction efforts with the end-users.

Nevertheless, when the development of modern biotechnologies is explored, specifically molecular markers for marker-assisted selection processes (MAS), the results from the interviews suggest that the adoption of this sort of plant-breeding technology is slowly taking place but not without difficulties, mainly resulting from the *resistance* of traditional plant breeders to adopting the molecular-marker technology into their breeding programmes (interviewee I, 2010). It was suggested that plant-breeders are rather attached to traditional field-based breeding methods and routines that do not involve the use of biotechnologies (interviewee I, 2010). This can be seen as a form of a *disciplinary barrier* to the adoption of new ways of carrying out plant-breeding research that goes beyond traditional field experiments, a sort of path-dependent technological trajectory of this research community. As a result of this resistance and attachment to well-settled research practices, the integration of complementary capabilities required the development of an interaction *interface* between communities of '...plant breeders that don't know about biotechnology...[and] biotechnologists that don't know about plant breeding' (interviewee D, 2010).

The comments of one researcher working on plant molecular genetics provide evidence that, despite the potential complementarity between both research groups, it was only gradually – and only after a number attempts of the biotech-group to obtain a mid-way technological solution with potential application – that plant breeders started to *recognise* and *legitimise* the potential advantages of biotech techniques (interviewee I, 2010). As suggested by previous studies, the legitimacy of new technologies plays an important role in building collaborative relations in emergent technological systems (Bergek et al., 2008; Geels & Raven, 2006; Senker et al., 1999). As a result of this enhanced legitimacy, plant breeders started to progressively identify and present demands for the application and integration of biotech techniques into the breeding processes. This is not a transfer process that we can refer to as a *black-box* and *ready-to-use* technology for the plant breeder (like in the case of in-vitro plant propagation). Conversely, in order to move forward the MAS technology to an actual innovation, plant breeders should be open to changing their traditional disciplinary research routines towards an interactive breeding process between field-research and the biotechnology laboratory. Thus, MAS in fact implies a *research process-innovation* which demands that both R&D groups should work and learn together how to effectively integrate their capabilities.

The argument above illustrates how knowledge integration in many cases requires efforts of researchers to overcome the difficulties imposed by their traditional *disciplinary boundaries* and the corresponding research routines, views and informal rules. Depending on the group and area of research, previous research has suggested that we may probably find different pictures regarding the efforts, motivation and actual ability to overcome these disciplinary boundaries and thus to achieve a larger degree of collaborative knowledge integration (Hessels et al., 2011; Hessels & van Lente, 2011). In fact, we observed that the attachment of breeders of crops other than rice and vegetables (e.g. wheat and other winter crops) to their traditional research routines in a sort of myopia, lock-in or path-dependent trajectory, led them to neglect, for a long time, the potential of integrating their capabilities with the biotech group (interviewee I, 2010). Here the inter-group interaction failed since breeders' groups, reluctant to modify their conventional practices, found their research routines incompatible with the work of the biotech team, hence resulting in an – internal – network failure. This provides a clear example where potential complementarities are left unexploited within the technological system (or even worse, within a single organisation) as a result of research groups that narrowly focus their R&D activities on disciplinary-bounded goals and research practices.

While our analysis above refers to barriers for knowledge integration within a single organisation, as expected, *incompatible work routines* were also identified between R&D groups from different public research organisations. University researchers consider this incompatibility as an obstacle during collaborations between basic and applied research groups working on problems directly relevant for the productive sector. As claimed by one interviewee, while some research activities performed completely within the lab have rather short knowledge-production cycles and allow researchers a '...quick generation of results, quick publication, and [hence] to *keep in* *the system alive*...', applied field research demands longer time spans (determined by the crops' biological cycle) and more complicated experimental designs in order to obtain robust results (interviewee E, 2011). As suggested by the same interviewee,

> '...the way that field-researchers work is different, so sometimes you may work well, and sometimes you don't work [together]...because there is not a *shared view* between both parties...because you have *different goals'* (interviewee E, 2011).

These claims reflect the fact that both types of R&D groups have different views, goals and incentives. While the applied research group pursues the solution of local problems for agriculture production, the activity of the university R&D group mostly looks for a faster production of research results and scientific publications in order 'to keep in the [incentive] system alive' (interviewee E, 2011).

The examples analysed above suggest that the difficulties in integrating complementary disciplines from different positions in the basic-applied continuum are present both in academic research groups and in applied research organisations. In both environments, the researchers' priority seems to be the R&D agendas of their own research communities or disciplines, while interaction with other complementary research communities is sometimes seen as a time-consuming activity that researchers are not able or willing to undertake. However, this disciplinary-bounded research approach is emphasised in academic R&D groups.

The empirical results suggest that the *views, routines and incentives* of academic researchers tend to keep their R&D activities bounded within narrow disciplinary themes. As one university researcher noted,

> '...in general, the researcher that is in the laboratory has a limited willingness either to disseminate his results to the general society, or to pass on the results to researchers...from different areas. Therefore...that has led us to somehow *generate our own demands ... We used to convince ourselves that what we were doing was what was actually needed*' (interviewee E, 2011).

Such an inward focus of researchers on addressing problems of their own knowledge field may well constrain knowledge integration through the establishment of collaborative relations between groups at the basic end of the research spectrum and applied biotechnology R&D groups, or between the latter and field research groups that may benefit from adopting new biotech tools for agriculture technology developments (e.g. plant and animal breeders).

This weakness is recognised by the same interviewee as an embedded institution or *tradition* of academia:

> '...I think that…the academia in general…or particularly the University because of its history – with very few exceptions – has little interaction with society. ... It seems that it was on a castle, *isolated*, and since *here are the most intelligent people*[113]*...*it has been generating its own knowledge environment' (interviewee E, 2011).

Hence, academic researchers recognise their limitations in relation to their *narrow disciplinary focus* and their relative *isolation from complementary research fields*, while they are also aware that this undermines their contribution to addressing problems of society in general. The argument developed in this and the former paragraphs agrees with a previous study of the Uruguayan agri-biotechnology system which observed that the work of academic researchers is highly *dispersed* in terms of location and resources, since their R&D efforts are conducted within disciplinary-rooted labs and almost *isolated* from other local research groups (Bortagaray, 2007, p251, 274). The author attributes this *isolated* characteristic, not only to the fragmented structure of the University[114], but also to the prevailing *work rationale of scientists* that hinders local efforts to integrate complementary knowledge fields, as well as to the absence of formal mechanisms promoting such collaborative efforts (Bortagaray, 2007, p274). What this study has left unexplored was what factors are underpinning such disciplinary-focused work rationales (Bortagaray, 2007, pp357) and to what extent

[113] A sarcastic reference made by the interviewee to what seems to be a rather institutionalised view within the scientific community.

[114] The Schools of the University of the Republic (UdelaR) are spread throughout the capital city of Uruguay instead of being part of a single campus (Bortagaray, 2007).

they actually affect the degree of knowledge integration achieved through collaborative research. We address these gaps qualitatively in this chapter and though a quantitative approach in chapter 6.

To this point, we have been discussing the role of informal institutions such as values, non-written rules, academic views, work rationales and established research practices that may affect the way individuals and organisations share knowledge. We claim that the influence of *informal institutions* on R&D collaboration and knowledge integration analysed above is rooted to a large extent in *formal institutions*, particularly public science and technology policies and incentives to scientists. Hence, in the remainder of this section we discuss qualitative results supporting this claim.

Evidence from the interviews (2) suggests that the narrow disciplinary focus of some academic R&D groups discussed above is, to some extent, the result of their research activity being directed mainly towards priority themes defined by global scientific communities and/or their preferred disciplinary peer-reviewed journals (interviewee C, 2011). It is also suggested that *formal incentives and rewards* to researchers *may* reinforce this disciplinary orientation of research (interviewee E, 2011). If so, opportunities for collaborative knowledge integration with other disciplines or research perspectives in the public or private domains could be left unexploited while R&D efforts to address local production problems are probably undermined. Therefore, we analyse below interview observations supporting these suggestions.

While partly driven by *informal institutions*[115] we observed that the narrow disciplinary focus and isolated research patterns of some academic R&D groups were also legitimised and underpinned by institutions of a formal nature, particularly public science and technology policies. Amongst others, we refer to *research assessment mechanisms* locally in force that, as illustrated in chapter 4, mostly value the researchers' absolute record of publications in peer-reviewed journals (Bernheim et al., 2012, p12; cited in section 4.3.4). Along these lines, some researchers at? the university suggested that *research assessment norms* in the academic sector require

[115] Such as researchers' views, goals, motivations and attachment to traditional R&D practices.

that every individual researcher should have her *own original research line*. As actually argued by one university scientist:

> '...the problem that this section has, the whole University, is that we are obligated to be individualistic. Because everything is made so that I should be assessed for what *I do*, for what *I teach*, for *my own research line*...so everybody needs to be inventing new research lines. ... [It] should also be promoted that people work on team research lines because it is impossible to continue working individually; but for the Full Time [compensation] you need to have a research line, for the PEDECIBA[116] you need a research line,...*own [research line]!*. So, everybody in the National Researchers System should have their own research line... So this is happening in this Section to some extent. There are basically four laboratories… in that area work…[three people] but note that they work on three different lines. Sometime ago we wanted to do things together but it happened as I told you; since we are asked for an individual line, then you are required to produce in that line, otherwise they take you out' (interviewee L, 2011**).**

As a result of this sort of incentive to academic researchers, another interviewee claimed that the structure of the scientific base in Uruguay encompasses an excessively broad *thematic diversity*, while being unable to build up enough scientific critical mass in particularly relevant research areas so as to properly address pressing problems (interviewee C, 2011**)**. This sort of fragmentation of University research was previously observed by Bortagaray (2007, p278-9) who argued that '[s]ometimes a single unit has more than one emphasis [but] still researchers tend to focus on a specific area within the unit. ... [W]ithin the larger department, the only clear overlapping between units are the techniques they might have in common, rather than research goals or problems... Thus...research-making takes place in extreme disconnection from...other units in parallel departments, and chances of cross-fertilisation, synergy or even having critical mass are lost in that deepening of the way

[116] The *Full Time* regime and the PEDECIBA programme allocate salary compensation and research resources to university researchers (see Chapter 4 for a description of PEDECIBA) .

research is practised without broader/horizontal roots in the larger structure... not to mention the multiplied dimension of these problems at the larger level of the university between schools'. Our results and the previous findings cited above suggest that the local structure of *formal incentives* to public-sector researchers underpins the isolated character of the research efforts of many scientists and R&D groups (discussed above), particularly in the academic sector. The evidence also indicates that these incentive rules force researchers to focus their activity on very specific disciplinary themes and hinder their ability to integrate complementary knowledge sources through collaborative efforts, while formal support for more integrative team research is claimed to be absent.

Moreover, these formal assessment institutions in force have led researchers to develop a *sense of property* over particular themes (interviewee O, 2011) which gives rise to attitudes of *'professional jealousy'* and *distrust* that in some cases hinder the exploitation of potential synergies among local R&D groups (interviewee A, 2011; interviewee Q, 2011; interviewee T, 2011). These attitudes were clearly the concern of one interviewee who claimed that

> '...with s,ome groups we can't collaborate...here in Uruguay! Because they steal from you...because we *compete for the same topics*...so instead of collaborating we *compete*... [therefore] you need to settle in a niche quickly' (interviewee A, 2011).

Such observations are also in line with the previous work of Bortagaray who found similar attitudes and a *competitive environment* – instead of a collaborative one – well established among academic researchers within the Uruguayan agri-biotechnology system (Bortagaray, 2007, p274-5). Concerning an attempt to access the skills of a local group for learning purposes, the interviewee cited above argued that:

> '...sometimes you want to but you can't. ... It was easier for me to travel to [a foreign country] in order to learn [a specific technique][117] than doing it here [in

[117] Details of this collaborative exchange are omitted in order to ensure the confidentiality of the interviewee.

> a local research group]...easier to relate to the [foreign] research group because they have other themes ... and because ... instead of establishing a collaboration, they [the local research group] see the training as a competition' (interviewee A, 2011).

Here, owing to the competitive academic environment, a local organisation went for accessing foreign capabilities that are, in fact, available within the country, so potentially complementary local capabilities were left unexploited by local actors (interviewee A, 2011; interviewee T, 2011). From a system perspective, this constitutes a *network failure* (also referred to as interaction or coordination failures), namely situations where potential synergies and opportunities for economies of scale and scope are not properly exploited by the relevant actors in the system (Woolthuis et al., 2005; Salles-Filho, 2006; Zhang et al., 2007). The attributes of the system or organisations that are hindering the exploitation of such complementary capabilities evidently need to be explored in this research.

Following the logic of such an over-competitive academic environment, public research groups try to *specialise* in particular analytical techniques in order to acquire some sort of 'comparative advantage'. It was argued that:

> '... it might be a matter of survival ... you keep generating a series ... of techniques that others handle to a limited extent or do not master, in order to identify yourself with something particular' (interviewee E, 2011).

The same interviewee emphasised this attitude, claiming (as we already noted before) that one of his individual goals is *'... to keep the system alive!'* (interviewee E, 2011). Similarly, another scientist highlighted that there is a 'fight for survival' among local researchers (interviewee Q, 2011). This agrees with the views towards collaboration across knowledge-fields previously observed by Llerena and Meyer-Krahmer (2003), who claimed that researchers may be discouraged from getting involved in collaborations with partners from other knowledge fields, in order to avoid weakening specialisation, *academic performance* and thus *reputation* within their respective disciplines. In their study of collaborative research and innovation 'federation' in the French pharmaceutical industry, the authors argued that common *incentives* in public-sector research mainly reward discipline-oriented outcomes and that rigid disciplinary structures of some university schools and faculties even reinforce the institutional obstacles to *collaborative knowledge integration* (Llerena & Meyer-Krahmer, 2003, pp79, 85).

So, while the specialisation of R&D groups, their focus on very singular research lines and the resulting thematic diversity and dispersion referred to above might generate opportunities for complementarities between groups, an over-competitive academic environment would seem to undermine knowledge integration, namely the collaborative exploitation of complementary knowledge assets among research groups. Supported by previous studies, our observations suggest that *formal research assessment mechanisms* are most likely underpinning the observed disciplinary views and motivations of individual scientists as well as the persistence of a competitive academic environment, factors which are deterring researchers from engaging in more integrative collaborations and broadening the distance between complementary research communities.

These national assessment norms, in general, but particularly the National Researchers Assessment System (SNI) described in chapter 4 (section 4.3.4) rewards, above all, the publication record of scientists in peer-reviewed journals (Bernheim et al., 2012, p12) and has a particular influence on the scientific system (UdelaR). Consequently, publishing, in itself, ends up being the main goal, regardless of the research trajectory or the potential contribution to local innovation processes. As noted by some interviewees cited above (2), these institutions deter laboratory-based researchers on the basic-side from getting involved in more applied collaborative research that takes longer to produce publishable results but offers higher innovation potential (Interviewee C, 2011; Interviewee E, 2011). This provides preliminary evidence of an *institutional failure* that may be hindering the mobilisation of knowledge capabilities locally available in actual innovation processes, hence resulting in a clear network failure that is probably undermining the system-level innovation capacity. This is particularly relevant for a small developing country such as Uruguay, given its limited R&D capabilities and the high reliance of the private sector on public-sector research for their innovation activities.

Consequently, our quantitative analysis presented in chapter 6, further examines whether or not there is an influence of local *scientists' assessment norms and incentives well established in the global scientific community* – mostly based on peer-reviewed publications records – *in supporting or hindering collaborative efforts that attempt to integrate distant complementary knowledge*. We assess this with the aim of drawing lessons for policy makers on required interventions to address potentially relevant institutional barriers to inter-organisational interaction and knowledge integration.

We discussed in Chapter 4 how, while the SNI system places strong emphasis on publishing in peer-reviewed academic journals, at the same time it supposedly promotes the linking of scientists' research with the solution of societal problems (Bernheim et al., 2012, p11). Moreover, some interviewees (2) perceived that R&D funding instruments offered by ANII also promote socially-relevant research themes (interviewee E, 2011; interviewee L, 2011). In fact, a recent report by this Agency (ANII) claimed that '[o]ne of the main goals of ANII is the consolidation of the national scientific and technological system and its relation with the national production and social problems' (Bernheim et al., 2012, p5). Moreover, ANII's funding programmes positively value project proposals presented by inter-organisational and/or interdisciplinary consortia exploiting synergies and local complementarities (DICYT, 2010, pp34-5). This configures a complex set of system-level institutional forces that may exert *conflicting incentives* on the public research system – as suggested by previous studies discussed in chapter 2 (Hessels et al., 2011; Hessels & van Lente, 2011). Given such contradictory stimuli, when scientists define the actual orientation of their R&D efforts, they have to cope with '...a *tension* between satisfying the needs of application-oriented funding sources and reaching high scores on evaluations dominated by bibliometric indicators...' (Hessels et al., 2011, p555). Evidence from our qualitative work that has been discussed in this chapter suggests the existence of such a conflict of incentives within our empirical setting.

This is supported by the views of an academic researcher who claimed that:

> '…we have sustained ourselves a lot through external funding *... we can perfectly well get funding in basic areas having nothing to do with production*' (interviewee E, 2011).

Here, formal institutions described in chapter 4 such as academic freedom norms of the University, along with the availability of foreign funding sources allow the research group to keep a strictly disciplinary trajectory – more rewarding in terms of publishing – regardless of its relevance for local innovation processes. Asked about her views on local incentives to collaborate, another scientist claimed that:

> '... nothing pushes me, only my personal interest. All the collaborations that we have are kept because we are interested on them ... I am totally insensible to that sort of [institutional] pressures' (interviewee C, 2011).

These observations illustrate the complexity of system-level forces shaping research trajectories argued above; formal incentives placed mainly by the National Researchers' Assessment System (SNI) endow individual research groups with legitimating stimuli that come into *conflict* with other local support mechanisms which emphasise innovation-oriented R&D efforts and try (apparently rather unsuccessfully) to focus such efforts on a limited number of priority areas (DICyT, 2010).

These *clashing stimuli* are likely to undermine the performance of the whole technological innovation system. As a clear illustration of this, in 2007 the Uruguayan Government decreed, through a national act, that the development and use of biological control agents should become an issue of *national interest* for agricultural production. This means that the R&D investments in this area are granted tax exemptions for private actors, but at the same time it sends a clear signal to public research organisations. Nevertheless, the technological path promoted by this explicit political support was not fully consistent with the priority subsequently given to the topic by at least part of the national research capacity around this technological area. For one of the research groups with advanced research capabilities in the development of biological control agents, this theme, compared with others, was less prioritised by the group. As explained by one of the group's researchers,

> 'that [theme] is less rewarding in terms of publications ... yes! It pays off little ... *it's hard to publish* that kind of work ... the *more publishable works* are those that go to more basic issues ... that we don't do' (interviewee C, 2011).

These perceptions affect the likelihood of collaborations having primarily publishing-driven R&D groups integrating their capabilities with those of other actors interested in this technology, hence resulting in the emergence of a local *network failure*. In fact, the research group latterly quoted is willing to devote efforts to this theme only when external R&D funding is directly offered to the group (interviewee C, 2011).

In summary, in the empirical context of a developing country, in this case Uruguay, *conflicting influences* on the *direction and selection of research themes* occur between themes related to locally relevant research problems and those that are more likely to be published in high impact peer-reviewed international journals – themes which are in many cases less relevant to local innovation processes. Our findings suggest that, on balance, formal incentives mostly based on publication records may often exert a stronger influence hindering knowledge integration endeavours intended to address locally relevant problems or to pursue local innovation goals. This is supported by Bernheim et al. (2012, p15), who assessed the impact of the National Researchers Assessment System (SNI) created in 2007. As discussed in chapter 4 (section 4.3.4), the report illustrated that publishing in international peer-reviewed journals increased in Uruguay – attributed to the new incentives to the scientific community established by the SNI – but the results also suggest that this rise may be taking place at the expense of a decrease in the relevance of this research to *solving local societal and technological problems*. Since collaborative knowledge integration is mostly intended to *address locally relevant problems*, it follows that the new emphasis of the SNI might exert an influence on the extent of knowledge integration achieved in the agri-biotechnology system.

As was argued here and in chapter 2, previous studies that looked either at specific collaborative initiatives (Llerena & Meyer-Krahmer, 2003) or at specific research fields within a nation (Hessels & van Lente, 2011; Hessels et al., 2011) have already noticed the contradictory institutional incentives that public researchers may face. However, these studies employed case study and survey methodologies with neither an assessment of the knowledge assets being integrated nor an indicator of the extent of collaborative knowledge integration. This gap in the scholarly literature was already identified by Colombo et al. in 2006 but still requires further research contributions (Colombo et al., 2006, p1193). We contribute to addressing this gap through our quantitative assessment of the *degree of knowledge integration* accomplished by R&D groups through their collaborative research activities, along with exploring how this indicator of the *ability to integrate local capabilities* is shaped by the institutional forces analysed in this chapter.

We have analysed, in this section, the results of our interviews, looking particularly at evidence on the influence that informal and formal institutions may exercise on research collaboration and knowledge integration among public R&D groups. With regards to informal institutions, we concentrated on examining particular perceptions, attitudes and routine practices of researchers that may shape the ability of R&D groups to collaboratively integrate complementary knowledge assets. In close relation, we subsequently analysed how this interplay between informal institutions and knowledge integration is emphasised or lessened by formal institutions, particularly public policies defining research assessment rules and rewards for public sector scientists. Coming back to our conceptual framework and research questions, *institutions* were defined as relevant *system-level factors* shaping the integration of complementary knowledge. In order to move our study forward, we should now examine the role of *organisational-level attributes* on our central matter under study. Therefore, in the next section we look at the relational capability of R&D groups and its relation to collaborative knowledge integration.

5.4.3 Relational capability

Organisational science studies have defined *relational capability* as the ability of an organisation to establish interactive relationships and access other actors' knowledge resources and capabilities (Dyer & Singh, 1998, p672; Lorenzoni & Lipparini, 1999, p317), and to internalise them into the organisation (Grant, 1996). We claimed that assessing local *relational capabilities* is particularly relevant for our empirical setting since Uruguay is a small developing country where biotech capabilities are distributed among diverse actors. Therefore, national organisations *should interact*, and be able to coordinate and integrate their knowledge assets in order to improve the exploitation of local technological capabilities, thereby enhancing the innovation potential of the whole system.

Previous research studies reviewed in Chapter 2 have tested whether the accumulation of *relational capability* allows organisations to form new collaborations (Gulati, 1995; Ahuja, 2000) but have left unexplored the extent to which that relational capability results also in an increased ability to access distant complementary knowledge assets. Our conceptualisation of *collaborative knowledge integration* inherently suggests that it is not only the formation of collaborations that matters, but also the *quality* of such linkages, specifically if they are actually allowing the exploitation of potential inter-organisational synergies and the realisation of opportunities offered by the system for combining complementary knowledge resources. So, we want to explore whether higher levels of relational capability result in increased degrees of collaborative knowledge integration. We address that question in the quantitative assessment (Chapter 6) while below we qualitatively examine relevant dimensions of *relational capability* pointed out by the interviewees: how it is built up by R&D groups and what may hinder its development as well as how it shapes collaboration and the exploitation of local complementarities.

An interesting observation from the interviews is that research groups see the collaborative integration of complementary capabilities within or across organisations as a 'practice' (interviewee E, 2011) or as a '...technique in which we should be proficient...' (interviewee D, 2010). It was acknowledged that interacting with some complementary groups '...involves a change in the way work is done' (interviewee E, 2011); as a consequence, knowledge integration was hindered in some cases by research groups being resistant to changing their habitual research practices. These observations, along with the poor compatibility of research practices and motivations among complementary actors illustrated in the previous section, suggest that research groups are compelled to develop specific *skills on building inter-organisational interfaces* that effectively enable collaboration and knowledge-sharing with complementary groups.

Generating such *interfaces* may require, amongst other things, enhancing the group's understanding of the R&D needs of other groups and/or the technological demands of final users (interviewee D, 2010; interviewee I, 2010), developing compatible experimental protocols, agreeing on shared and individual group goals, and defining how information generated by each group will be integrated (interviewee E, 2011). As discussed in section 5.3, achieving an effective collaborative integration of capabilities previously acquired requires a large and cumulative dedication of researchers' time on interaction and *joint learning* among groups (interviewee I, 2010). Additional empirical observations support this need for previous interactive *learning*; while a University researcher claimed that their 'lack of *practice*' in integrating different disciplines and capabilities has resulted in unsuccessful collaborations, he also acknowledged that collaborative projects with most partners having quite different objectives, are a clear opportunity to *learn* about '...the interaction with other laboratories, the interaction with firms, ... and the relation with other countries ...' (interviewee E, 2011). In fact, the development of relational capability has been claimed to involve a process of *'learning how to collaborate'* by the organisation (Powell, 1998, p238) in order to develop partnering capabilities (Hall, 2006) or 'collaborative know-how' (Simonin, 1997, p1150). Hence, interactive *organisational learning* during collaborative knowledge integration efforts becomes a central process in the development of relational capability[118], and thus for the effective exploitation of external and internal complementarities.

We presented above theoretical and empirical evidence that *building relational capability involves a difficult learning process* that calls for R&D groups to make a determined *commitment of time and research efforts* of their members. It follows that

[118] On this basis, in our quantitative analysis (Chapter 6) we assess the relational capability of an R&D group through the total number of collaborative links it established during the period under study.

an organisational-level attribute shaping the building of relational capability would be the *motivation* for researchers to commit the resources referred to above and hence, the formal incentives functioning within the organisation that may underpin or hinder such *motivations*. Although in the previous section (5.4.2) we explored the role of formal incentives from the viewpoint of the whole system, it is worth making some observations regarding organisational-level incentives. Our qualitative results suggest that almost no researchers interviewed were able to identify within their organisations any *formal stimuli* explicitly promoting the formation of local inter-organisational relations (interviewee E, 2011; interviewee C, 2011). In other words, the establishment of collaborative initiatives and hence the commitments required to build relational capability are mostly left to the interests and motivations of individual researchers.

Another dimension of *relational capability* that came up from the empirical interviews concerns the *flexibility* of public R&D organisations, particularly in the research agenda they pursue. We found that some public research groups and firms faced difficulties in accessing local infrastructure and technical capabilities locally available in public research organisations. As an example, local firms that developed new biotechnology products were not able to access public facilities for the subsequent field-testing and validation of the new technologies, so they were forced to look for these capabilities mostly in research organisations from neighbouring countries[119] (interviewee H, 2011; interviewee P, 2011). These cases constitute *network failures*, namely unexploited opportunities for local inter-organisational integration of complementary knowledge assets. Such a failure to access local testing capabilities in the public sector was argued to result, among other things, in limited *organisational flexibility*, and particularly from R&D groups and their researchers being rigidly stuck in long-term research projects, thus exhibiting a limited willingness to use their infrastructure and capabilities in activities that fall outside the specific goals of their projects' portfolio (interviewee H, 2011; interviewee V, 2011). Similarly, other interviewees (2) attributed the *network failure* described above to public research organisations and broader science and technology policies offering a poor response to changing demands from the agriculture

[119] In a few cases, field-testing and validations were provided by local private actors having less developed capabilities than those existing in the Uruguayan public research sub-system.

sector, thus showing a weak adaptation to changes in the technological innovation system (interviewee P, 2011; interviewee Y, 2011). In general terms, it can be said that most public R&D groups or laboratories interviewed have a poor ability to grant easy access to their in-house R&D capabilities to external research groups or firms that may require it.

The argument above shows that the poor *flexibility* of public R&D groups undermines their *relational capability*, namely their ability to exploit potential complementarities through inter-organisational collaborations. Moreover, it suggests that developing this organisational-level capability is intertwined with the institutional forces analysed in the previous section (5.4.2), particularly with science and technology policies that may (or may not) stimulate R&D groups to pursue a more integrative and collaborative research agenda. This is aligned with the study of Bortagaray (2007), who claimed that the 'inertia and rigidity' of the institutional setting have hindered the development of skills, inter-organisational interactions and complex technological capabilities in the Uruguayan agri-biotechnology system (Bortagaray, 2007, pp299, 351). Notwithstanding the qualitative results from our and Bortagaray's studies, we have pointed to the need for further quantitative assessments of collaboration and knowledge integration among R&D groups as well as of how these processes are shaped by the organisational capabilities and system-level institutional drivers analysed in section 5.4. Such a quantitative approach is developed in chapter 6.

We have explored the role and diverse facets of building *relational capability*, which was defined at the outset of this section as the organisational ability to establish operational inter-organisational relations and to access R&D capabilities and resources from external actors (Dyer & Singh, 1998, p672; Lorenzoni & Lipparini, 1999, p317; Grant, 1996). From our qualitative results we showed that researchers perceive collaborative knowledge integration as a practice or technique (a relational capability in our conceptual terms) that R&D groups should develop through interactive learning processes. We identified other relevant dimensions that shape the building of relational capability and collaboration interfaces such as researchers' motivations and formal organisational incentives to collaborate, along with the flexibility – or rigidity –

of public R&D groups to adjust their research agenda or usual research practices so as to respond to external actors that demand accessing their R&D capabilities.

Finally, as an intertwined dimension of the ability of a research group to establish collaborative links with other actors, the interview results suggested that when postgraduate research students integrate an R&D group, they usually play a significant role as bridges to other groups. We noticed that they actively pursue and grant access to complementary capabilities from external actors. Given the potential importance of this bridging role, we explore it in detail in a separate section below.

5.4.4 The role of research students as enablers of collaborative knowledge integration

A number of ways to identify and/or collaboratively access external skills and capabilities were mentioned during the interviews. A recurrent pattern noticed in the examples of collaboration referred to by the public sector researchers interviewed was the role played by *research students* in the group[120] as the key element that ends up bridging both parties in a collaborative endeavour. For example, dynamic interactions between basic and applied research groups identified were frequently embodied in postgraduate students who act as intermediary agents performing the actual inter-group transfer of information, knowledge and skills; this was reported by four interviewees (interviewees A, C, E and L, 2011).

This *mechanism of collaborative knowledge integration* is particularly relevant for emergent opportunity areas. An example of this relates to the access of capabilities on bioinformatics which are absent in most research groups. A number of groups (4) that recognised the lack of internal capabilities in this theme, used different support mechanisms in order to attract the interest and commitment of *postgraduate students* who may already have the required skills or might be sent to take up internships or short training programmes in external research groups, acting hence as *intermediaries*

[120] Either a present or former research student.

in order to gain access to those advanced research skills (interviewee G, 2011). As mentioned by one member of a biotechnology laboratory in UdelaR:

> '... the good thing about having students is that you can ... – when there are things which you can't devote time to –, [there are] young people that come with other training ... and you can send them to be trained in a specific area ...' (interviewee A, 2011).

Another researcher argued that every inter-group collaborative '... linkage actually consolidates when you share human resources. ... you start training a person that will go to work in another laboratory ... that's how you really generate the actual linkages to do joint research' (interviewee E, 2011). In a similar fashion, a member of an applied research group argued that postgraduate students who undertake their research projects within the organisation represent a continuous inflow of knowledge for the research group as well as a source of collaboration opportunities with complementary academic groups (interviewee D, 2011). This evidence suggests that when a group wants to *acquire or gain access to new complementary capabilities not available in the group*, a central strategy to do this is through gaining the interest of *students* to do their postgraduate research within the group activities who will then grant the collaborative access from external actors to such *advanced complementary skills* required by the focal group.

It is not only accessing *advanced R&D capabilities* that postgraduate students mediate. During the empirical work, it was observed that their contribution to knowledge integration throughout the whole technological system also includes overcoming barriers to the realisation of potential local complementarities among more *conventional R&D capabilities* and facilities of different organisations that were not being exploited. Unexploited complementarities can be seen as *network failures* that result from a number of factors identified in previous sections, such as institutional barriers to sharing knowledge and facilities or weak organisational flexibility. In several cases (2), such *network failures* were overcome through the access of research groups to support mechanisms that fund the work of a *research student* for one or more organisations (interviewees C and D, 2011). This sort of mechanism achieves the commitment of complementary organisations in a joint initiative with shared results, while the research student actually overcomes the *network failure*, since his work bridges and integrates the skills and capabilities of the groups involved. Both components of this sort of collaboration, namely the funding mechanism that stimulates joint commitment in a project application and the bridging work of the research student, can be seen as a coordination-support mechanism that allow the development of an *effective inter-organisational interface* between research groups or organisations. Such an interface was previously missing, thus hindering the exploitation of potential synergies.

Besides those presently working in the R&D group, even former research students may play the intermediary or bridging role described above (interviewee C, 2011). In this way, the relationship developed between a research group and its research students during their postgraduate internships builds a relevant part of the groups' *relational capital*. This relational capital might be subsequently put to work in the establishment of collaborative relations with organisations or laboratories that employ a research group's former students.

The student-embodied integration of complementary capabilities was observed for both: collaborations among public research groups, and in some cases for collaborative arrangements between public and private actors. We discussed in chapter 4 (section 4.3.3) factors inhibiting the establishment of collaborative interaction between public research groups and the private sector. During the interviews we also found evidence of contributions from – mainly postgraduate – *students* in building missing bridges between academics and private actors. As suggested by one interviewee, these students carry out their research within projects jointly conducted either by an academic group and an applied research group or by a public research group and a firm (interviewee E, 2011). While applying the knowledge and technological capabilities available in the public research group, students steer their research projects towards the solution of actual problems of biotechnology firms or agriculture producers (interviewee E, 2011). In this case, the bridging role performed by students might also have implications for the research trajectories of academic groups and their potential contribution to the solution of local technological demands.

Situating the observed role of postgraduate students within the overall interactive dynamics of the local innovation system, we should mention here the weak pattern of mobility of researchers and other knowledge workers during their careers. Previous studies on the Uruguayan science, technology and innovation system have noticed the poor mobility records of scientists and other skilled workers as a typical attribute of Uruguayan agri-biotechnology innovation (Bortagaray, 2007). In most cases, the single mobility aspect of Uruguayan scientists is a period abroad doing postgraduate studies (Bortagaray, 2007). Such limited mobility of skilled workers has been pointed out as a significant barrier to knowledge diffusion and the formation of collaborative relations between organisations in Uruguay (Bortagaray, 2007; Pittaluga & Snoeck, 2012). Our interview results are consistent with these previous studies, suggesting that the weak mobility of researchers within the system exerts a negative influence on the development of collaborative networks, or at least does not promote it. When interviewees were asked about their relationships with colleagues from previous jobs, they usually disregarded their role in explaining the collaborative linkages supporting their present R&D activities[121].

Since this is a general mobility feature for the whole research system, it does not seem to explain differential patterns of collaborative knowledge integration within the biotechnology innovation system, so it was not explored in more detail. However from a system-level perspective, our qualitative findings suggest that the shortcomings resulting from the poor mobility records of researchers might be overcome by research groups to some extent, through the work of students that enhance the ability of the R&D group hosting their postgraduate studies to collaboratively integrate external knowledge assets. In other words, the *bridges* to local complementary actors that are *missing* due to a poor mobility record of researchers may be built through the involvement of students in the R&D group activities.

[121] A contrasting picture was observed by Bortagaray (2007) in New Zealand and to a lesser degree in Costa Rica, where the mobility record of scientists and knowledge workers across research organisations, the private sector and government actors play a key role in supporting innovation by means of building the acquaintance networks from which scientists and knowledge workers look for and exploit potential collaborations.

Previous studies reviewed in Chapter 2 provide a conceptual and empirical basis for the role of students that we observed here. Studying a collaborative network in the automotive industry, Harryson et al. (2008) found that to achieve effective integration and exploitation of complementary knowledge, every single knowledge transfer across organisational boundaries required to some extent the *'transfer of human knowledge carriers'* (Harryson et al., 2008, p766). Studies of regional and sectoral networks suggest as well that the mobility of knowledge workers across organisational boundaries is a major driver of local knowledge transfer and spill overs (Almeida & Kogut, 1999). From the organisational management literature, Lam highlighted that strategic mechanisms set up by knowledge-intensive firms to facilitate accessing and sharing knowledge with public science are mostly based on appointing individual *'...linked scientists...[who] provide the human resource links enabling firms to connect their internal R&D with the external academic knowledge base'* (Lam, 2005, p267). Besides scientists with permanent positions in public research, the author observed that the *linked-scientist role* is frequently played by postdoctoral researchers or doctoral students (Lam, 2005). In a similar fashion, within the context of agri-biotechnology innovation in Uruguay (as discussed above), our qualitative results suggest that this sort of bridging or boundary-spanning role between complementary public research groups[122] is, to a considerable extent, played by postgraduate students.

Taking into account the salient role of students, the postgraduate education and scholarship programmes reviewed in chapter 4 (section 4.3.1) and the research projects of postgraduate students should be valued not only as mechanisms supporting the generation of local skills and human capital through the actual training, but beyond that as a valuable contribution to the overall *cohesion of the system*. Through these programmes, postgraduate students enhance their involvement in ongoing R&D efforts in the country. While performing internships or short periods of training in external actors, they move, exchange and reproduce knowledge across organisational boundaries. To sum up, the evidence suggests that the student-

[122] And to a lesser extent between public research and firms.

embodied bridging mechanisms analysed in this section are underpinning more flexible and effective *collaborative knowledge integration* processes throughout the whole technological system under study. Consequently, in chapter 6, we will quantitatively explore the relation between the number of students involved in a research group's R&D activities and the extent of collaborative knowledge integration achieved by the group.

5.5 Closing remarks

Throughout this chapter we have developed a thorough analysis of the results from our interviewing work. We started by exploring whether or not potential complementarities exist between actors of the technological system under study, focusing particularly on public research groups, and examining the main rationales for collaboration between different actors. Then, we examined *how* research collaboration takes place and the most salient patterns employed by R&D groups to collaboratively integrate complementary knowledge assets distributed throughout the local agri-biotechnology public research sub-system. Finally, we analysed qualitative evidence pointing to the most relevant forces shaping the processes of collaborative knowledge integration, that is to say, the *drivers and barriers* that influence to what extent complementarities among actors in the system are actually exploited through local R&D collaborations.

Chapter 6 - A quantitative look at collaborative knowledge integration

6.1 Introduction

This chapter is aimed at developing a cross-sectional quantitative approach to addressing our research questions and presenting the main results from its empirical application. As proposed in our research questions (Section 2.7) and conceptual framework (Section 2.8, Figure 2.4), we want to shed light on how the extent of collaborative knowledge integration achieved by R&D groups is shaped by the following groups of factors: (i) structural and relational attributes of the R&D group, namely their absorptive and relational capabilities; (ii) system-level institutions and incentives – particularly public policies supporting interaction and knowledge integration among organisations and knowledge fields; and (iii) compliance of the R&D group with scientific reward institutions. In the previous chapter, we presented thorough qualitative evidence on the influence of informal institutions, local scientists' assessment norms, and the subsequent compliance of R&D groups with these formal incentives in supporting or hindering collaborative efforts that integrate distant complementary knowledge assets (items *ii* and *iii* above). With regards to structural attributes, we observed the relevance for R&D groups of building relational capability and flexible interaction interfaces, in order to properly access complementary knowledge assets, or to grant external actors the collaborative use of its skills and research facilities. In close relation to the R&D groups' relational capability, or as a dimension of it, our evidence showed that postgraduate students play a salient intermediary or bridging role between R&D groups, by performing the actual transfer of information, knowledge and skills across the organisational boundaries of otherwise unconnected groups.

The quantitative approach developed in this chapter is intended to provide statistical validation for the qualitative findings summarised above. In addition, it will assess how the extent of collaborative knowledge integration achieved by an R&D group is related to its absorptive capacity, a factor that was not examined in our qualitative chapter (5). Hence, in section 6.2 we comprehensively describe the cross-sectional quantitative approach developed so as to allow the carrying out of certain statistical tests proposed above within our empirical context.

To achieve this, the attributes encompassed by the conceptual framework had to be operationalised into a set of reliable quantitative indicators. A particularly challenging task was 'measuring' knowledge assets controlled by each R&D group, and subsequently transforming these measures at the level of single R&D-groups into a relational measure of the *degree of complementarity* between the knowledge assets of every pair of R&D groups that jointly work in a collaborative research project. Such a measure of the *degree of complementarity* between two collaborating R&D groups actually provides a quantitative indicator of the *extent of knowledge integration* accomplished by those two groups through their joint research activity.

The remainder of the chapter is structured as follows. After describing and substantiating the quantitative approach developed (6.2), we present the statistical results in section 6.3, and contrast them with our conceptual framework, giving a brief interpretation of how they contribute to addressing our research question. Finally, Section 6.4 ends the chapter, providing very brief closing comments.

6.2 Quantitative approach

6.2.1 Introduction: assessing knowledge integration

As suggested above, developing measures of *collaborative knowledge integration* represented a salient methodological challenge. Hence, we begin our description of the quantitative approach by explaining how such indicators were defined and operationalised. The reader should bear in mind that this study looks particularly at the extent to which public R&D groups involved in collaborative research activities integrate complementary knowledge assets[123] distributed throughout the agri-biotechnology system. In other words, with our indicator of *collaborative knowledge integration* we want to assess the ability of every single R&D group to integrate distant

[123] Understood as rather dissimilar disciplinary knowledge and R&D capabilities.

complementary knowledge through their collaborative R&D activities. This means that our *final unit of analysis* is the single R&D group (let's say group ***i***) that undertakes collaborative R&D within the technological system under study. But in order to compute this group-level measure, our database should provide a number of measures of knowledge integration at the level of pairs of organisations, namely all pairs formed between group ***i*** and all ***j*** R&D groups it collaborates with (***j*** = 1 to ***n***)[124]. As a result, every sub-set of two R&D groups or organisations collaborating in a specific R&D project – hereinafter referred to interchangeably as a *pair* of collaborating organisations or a collaborating *dyad* (Gulati, 1995) – was defined as our *intermediate unit of analysis*.

Looking for a way to assess complementarity or knowledge integration at the level of collaborating *dyads*, we conducted a further review of scholarly publications, concerning relevant conceptual and methodological perspectives that might be applied or adapted to our empirical study. We brought together insights and contributions from diverse bodies of scholarly research such as: (i) organisational science scholars who study resource (inter-) dependence theory involving concepts of complementarity and collaboration between organisations (Teece, 1986, p286; Dyer & Singh, 1998, p666; Gulati & Gargiulo, 1999, p1460); (ii) studies of technological similarity and knowledge transfer between organisations (Mowery et al, 1996; Mowery et al, 1998; Nooteboom et al., 2007); and (iii) scholars using bibliometric methods to study either collaboration in public research organisations (Heinze & Kuhlmann, 2008, p897), or interdisciplinary research and the relation between different fields of scientific knowledge (Rafols & Meyer 2007, p646; Leydesdorff & Rafols, 2011; Wagner et al., 2011). Overall, when the level of analysis is either the organisation (Jaffe, 1986; Bloom et al., 20013), specific knowledge fields (Porter & Rafols, 2009; Rafols & Meyer, 2010), or the global structure of science (Leydesdorff & Rafols, 2009), the methodological approaches of these academic studies are based on different sorts of indicators of *distance* or *similarity* (closeness) between units.

[124] As will be explained below, we finally compute an aggregated average indicator of the ability of each R&D group to collaboratively integrate distant complementary knowledge across all its research partners.

Drawing on these conceptual and methodological contributions, the extent of *collaborative knowledge integration* was operationally measured for every pair of collaborating R&D group (dyad), through indicators of both *similarity*[125] and *difference*[126] between their available knowledge assets[127]. To start building such indicators, we first drew on a study of Rafols and Meyer (2010, pp266-7), who on the basis of previous work of Stirling (1998, 2007) and Nesta and Saviotti (2005), developed a composite *diversity index*[128] as a measure of the *relative degree of knowledge integration* observed in published academic articles as their unit of analysis. The authors included three dimensions in their measure of *diversity*, namely *variety*, *balance* and *similarity* (or difference[129]) among the categories of knowledge integrated within the unit under analysis (scientific publications for their case). We then made a substantial effort to adapt this indicator from a measure taken at the level of a single scientific publication into an indicator to be observed at each pair of collaborating R&D groups.

The identification of knowledge assets at the R&D group analytical level deserved a careful methodological design. The diversity indicator of Rafols and Meyer (2010) is based on the structure of scientific knowledge categories used by bibliometric databases (ISI Web of Science). Correspondingly, we needed a suitable taxonomy or classification system to characterise (through a survey) the knowledge-base of agri-biotechnology R&D groups within our empirical context, which we present in the next section.

[125] Similarity is understood as relatedness or overlap between actors' knowledge assets.
[126] Difference is measured as the extent of non-overlap (absence of overlap) between actors' knowledge assets.
[127] As will be explained below, we distinguish two broad dimensions of an R&D group's knowledge assets, namely R&D capabilities and scientific disciplines.
[128] The generalised Stirling diversity index (Rafols & Meyer, 2010, pp266-7).
[129] Rafols and Meyer (2010, p267) refer to measures of both similarity (s) and difference (d) where $s = (1 - d)$.

6.2.2 Identification of knowledge assets in R&D groups: a classification system

Taking in account a survey-based assessment of R&D groups, we needed to include in the survey-questionnaire a robust approach for the identification and mapping of the knowledge assets internally developed or controlled by each R&D group that performs collaborative research activities within the agri-biotechnology system. Studies of resource complementarity among firms have mapped capabilities through the analysis of patenting activity, looking particularly at the breadth of technological and knowledge fields encompassed by the firms' patent portfolio (Mowery et al, 1996; Mowery et al., 1998; Zhang et al., 2007). This approach was disregarded for the present study since patenting is very weak in developing-country agriculture and at the same time it is not a suitable indicator to assess knowledge assets in public research organisations.

As argued earlier (Section 2.6.2), other approaches focus on studying knowledge integration, for example, at the level of knowledge fields, on the basis of bibliometric data. Both this and the patents approach are based on robust classifications of scientific or technological fields respectively. These approaches are suitable when studying rather broad scientific or technological areas, and when robust data on patents or scientific publications is available. Nevertheless, neither of these conditions is met for this research. It has been argued that the use of bibliometric indicators can only provide a distorted assessment of knowledge integration since bibliographic databases such as Scopus or ISI are not able to homogeneously account for the contributions from the diverse range of relevant fields of knowledge or from non-English journals (Wagner et al., 2011, p24), the latter being particularly relevant for the context of developing countries. In fact, discussing the biases of scientific publications' databases, Wagner et al. (2011, pp23-4) argued that bibliometric research *'...may be missing the most socially relevant ... interactions because of limitations in the current contents of bibliographic databases'.* Hence, it is argued that the goals and boundaries of the present research require a highly localised approach – in scientific, technological, sectoral, and geographical terms – for the identification of R&D capabilities and disciplinary knowledge bases internally available or operational in each R&D group.

Therefore, the approach used for such identification was based on classifications of knowledge assets relevant to the agri-biotechnology field that were specifically developed for our study. Rafols and Meyer (2007) argue that knowledge integration is a multi-dimensional concept that cannot be captured by a single indicator. Following their argument, we set out to assess *two key dimensions* of the knowledge base of each research group and developed the corresponding knowledge-asset classification systems for both dimensions described below:

(i) the first dimension is defined by the set of *scientific disciplines* encompassed by the R&D group, namely the complete disciplinary backgrounds of all group members (Rafols & Meyer, 2007);

(ii) the second dimension used to characterise the knowledge base is defined by the set of *R&D capabilities* or research technologies available in the research group.

Leydesdorff and Rafols found that collaboration plays a relevant role in the diffusion of *'research technologies'* understood as the methods, materials and instruments required to undertake research activities (Leydesdorff & Rafols, 2011, pp847 & 850[130]). Given the relevance for explaining collaboration and integration across knowledge fields that such *research technologies* have, we adopted the concept for the present research, but referred to it using the clearer and more general term of *R&D capabilities*. Following the same authors, the concept of *R&D capabilities* is defined for the purpose of this research as the methods, techniques, materials and instrumentation available within the research group to carry out the project R&D activities (Rafols & Meyer, 2007, pp637 and 642; Leydesdorff & Rafols, 2011, pp847 and 850). The classification of R&D capabilities was developed following all elements of this definition. It has been argued that rather standardised and codified R&D capabilities have a higher likelihood of being transferred and applied to diverse research fields or scientific disciplines (Rafols, 2007). This cross-discipline character of R&D capabilities given by their potential application in more than one scientific field

[130] The authors' definition of research technologies draws on the concept of 'instrumentalities' previously defined by Derek de Solla Price (Price, 1984, p13).

underpinned our decision to consider scientific disciplines and R&D capabilities as two separate dimensions portraying the knowledge assets controlled by R&D groups.

We consequently developed taxonomies or classifications for both knowledge dimensions, namely scientific disciplines and R&D-capabilities. We first built preliminary drafts for these two classifications, relying on a number of sources such as: previously developed classifications of biotechnologies (OECD, 2005[131]**;** Derwent Biotechnology Abstracts); classification of subject areas and journal lists from the Web of Science (Thomson-Reuters, 2012); scientific, policy and industrial publications on the biotechnology field (Pittaluga & Vigorito, 2005; Biotecsur, 2008a; Bortagaray, 2007); local researchers' CVs (SNI, 2011); interview data; information from a database of local R&D projects developed for this study; and other reports or surveys on emerging technologies (OECD, 2011; Statistics Canada, 2005). Both preliminary classifications were then subjected to a review and pilot use by three biotechnology experts in order to arrive at two final validated versions.

The resulting final classifications are detailed in tables 6.1 and 6.2 below and were included in the form of check-box lists in the survey questionnaire sent to the leaders of R&D projects (appendix 8.5). Project coordinators were asked to indicate which R&D capabilities and disciplines were present or operationally available in their groups when the project was implemented. In the case of R&D capabilities, respondents were also asked to indicate the degree of development of each capability on a 5-point Likert scale (Simonin, 2004).

[131] List-based definition of biotechnology techniques (OECD, 2005).

Table 6.1: Classification of scientific disciplines related to biotechnology

Disciplines and specialties		
Bacteriology	Entomology	Animal breeding
Biophysics	Enzymology	Metabolomics
Bioinformatics	Epidemiology	Mycology
Biostatistics	Evolution sciences	Microbiology
Biomathematics	Pharmacology	Neurosciences
Cell and membrane biology	Physical-chemistry	Parasitology
Botany	Plant physiology	Animal pathology
Molecular biology	Genetics	Plant pathology
Biochemistry	Structural genomics	Proteomics
Biotechnology	Functional genomics	Radiology
Environment sciences	Comparative genomics	Animal Reproduction
Food science and technology	Histology	Animal health
Cytogenetics	Bioprocess engineering	Toxicology
Cell and tissue culture	Reactors engineering	Transcriptomics
Ecology	Immunology	Virology
Embryology	Plant breeding	Other

Source: elaborated by the author based on OECD (2005)[132] and Biotecsur (2008a), and aided by expert advice

[132] OECD (2005): list-based definition of biotechnology techniques. The draft list was subsequently tested and corrected with the help of three experts in the field.

Table 6.2: Classification of R&D capabilities related to biotechnology

DNA and/or RNA techniques		
	Hybridization techniques (southern and northern blotting; cold probes)	Gene silencing (knock-out, RNA interference, etc.)
	Hybridization techniques - radioactive probes	DNA transfer (transformation, transduction, conjugation, etc.)
	Recombinant DNA techniques	Plant transgenesis
	DNA expression vectors	Animal transgenesis
	DNA mutation techniques	Genomic libraries
	High density molecular markers: SNPs	cDNA libraries
	Medium or low density molecular markers: RFLP, AFLP, SSR, RAPDs, etc.	Libraries for Next Generation Sequencing
	DNA/RNA capillary sequencing (Sanger method)	Bioinformatics
	Massive DNA/RNA sequencing (next generation sequencing-NGS)	Molecular techniques for identification and characterisation of organisms
	Gene expression profiling (Microarrays, Real-Time PCR, ESTs, SSH, etc)	Molecular techniques for pathogen and disease diagnosis
Cell and tissue culture		
	Animal cell culture and engineering	Plant tissue culture and engineering (micro-propagation, embryo rescue, etc)
	Animal tissue culture and engineering	Microbial culture
	Plant cell culture and engineering (protoplast fusion, etc)	In-vitro fecundation and embryo manipulation
Study of proteins, peptides and other bio-molecules		
	Recombinant protein expression	Protein structure and conformation analysis
	Protein / peptide sequencing or synthesis	Enzymatic process engineering (enzyme kinetics)
	Protein quantification (ELISA or radioimmunoassay)	Identification and quantification of metabolites and hormones
	Protein identification (immunoblot, immunohistochemistry, etc.)	Analysis of food chemical composition
	Protein / peptide isolation and purification	
Microorganisms and microbiological or enzymatic processes		
	Plant growth promoters	Biological products formulation
	Agents for biological control of pests	Fermentation on solid or liquid substrates
	Bioactive compounds production	Wood bio-processing and y bio-bleaching
	Bio-fuels and y bio-refining	Bio-remediation, bio-filtration, or biodegradation
	Microbial processes engineering and bio-reactors	Enzyme and other metabolites production
	Biological process scale up (pilot or industrial)	Food safety
	Recovery and purification of bio-products	
Immunoassays and vaccines		
	Viral vaccines (attenuated or inactive virus)	*In-vitro* immunoassays
	Bacterial vaccines	*In-vivo* immunoassays
	Recombinant sub-unit vaccines	Antibody engineering
	Immunodiagnostics (immunological techniques)	Cell receptors, cytokines and cell communication
	Immunodiagnostics (molecular techniques)	
Laboratory analysis techniques and instruments, products assessment methods		
	Flow cytometry	Nuclear magnetic resonance spectroscopy (NMR)
	Fluorescence microscopy (epifluorescence, confocal, etc.)	Chromatography (HPLC, gas chromatography, etc.)
	X-rays Crystallography	Thermocycler for Real Time PCR
	Mass spectrometry	Bio-sensors: bio-molecule y pathogen detection techniques
	Radioimmunoassay	Bio-assays: evaluation and validation of biotechnologies

Source: elaborated by the author based on OECD (2005)[133] and Biotecsur (2008a), and aided by expert advice

[133] OECD (2005): list-based definition of biotechnology techniques. The draft list was subsequently tested and corrected with the help of three experts in the field.

The two knowledge-asset classifications presented above became crucial instruments for characterising the knowledge base of each R&D group through the survey questionnaire delivered to R&D project coordinators. For the purposes of this research, it is assumed that this method allowed an identification of knowledge assets broad enough to construct appropriate indicators for the degree of complementarity between actors' knowledge resources. It has been argued that for a specific R&D field or technological sector, this sort of localised identification approach ensures greater precision in the measures of knowledge complementarity, while the potential generalisation of results will be diminished given the local character of the units of analysis (Rafols et al., 2010).

We have defined the categorisation scheme for R&D groups' knowledge assets but, before operationalising measures of knowledge integration previous studies have proposed the use of measures of *distance* or *similarity* among knowledge assets' categories employed within the classification system (Rafols & Meyer, 2010). This is required since '...for emerging fields, the inclusion of distance among categories lessens the effect of inappropriate categorisation...: if a ... category *i* is very similar to an existing category *j*, their distance d_{ij} will be close to zero, and its inclusion in [the] categories list will result in only slightly increased [knowledge integration measures]...' (Rafols & Meyer, 2010, p266). The development of these measures of similarity between knowledge-categories is explained below.

6.2.3 Similarity between knowledge assets categories: mapping the knowledge space

We followed approaches used by scholars who have studied either the structure of firms' knowledge bases (Nesta & Saviotti, 2005) or the global structure of scientific knowledge (Porter & Rafols, 2009, p725), in order to assess the degree of similarity or relatedness between knowledge categories encompassed by the classifications we developed for *R&D capabilities* and *scientific disciplines*. Nesta and Saviotti (2005, p124) used the term 'coherence' in reference to *'...the relatedness amongst individual pieces of scientific and technological knowledge'*. We apply here part of their operationalisation approach to developing a measure of the degree of similarity (relatedness) between every combination of two knowledge-categories from our classifications.

In this way, taking as an example all categories in the classification of R&D capabilities used in this research (Table 6.2), every sub-set of two capabilities ***i*** and ***j*** is assumed to have a *degree of similarity* or *'presumptive degree of association'* (Porter & Rafols, 2009, p725) if they happen to be present (or internally developed) together in the same research group. The higher the number of research groups that have those two capabilities internally developed (in relative terms compared to all R&D groups surveyed), the higher is assumed to be the *degree of similarity* between both R&D capabilities (see the computation algorithm below). In other words, the relatedness between two classes of R&D capabilities (or disciplines) is measured by the frequency of co-occurrences of both capabilities in the same research group or organisation, among the whole set of R&D groups in the system under study. Following the operationalisation approach of Nesta and Saviotti (2005, p128) for *relatedness* between technology classes[134], we defined the universe of R&D groups encompassed by this study (those that replied to the survey) as comprising a total of ***G*** groups. We finally operationalised a metric for the *degree of similarity* between each pair of capabilities along the whole set of organisations in the system employing *Salton's cosine similarity* index, as was done by Porter et al. (2006) and Rafols and Meyer (2010, p273). The resulting notation for the *matrix of similarities* between capabilities ***i*** and ***j*** ($\boldsymbol{S_{ij}}$) over research groups or organisations (g=1...G) is as follows:

$$S_{ij} = \frac{\sum_{g=1}^{G} A_i . A_j}{\sqrt{\left(\sum_{g}^{G} A_i\right)\left(\sum_{g}^{G} A_j\right)}}$$

where:

G = the total number of research groups encompassed by our study

A_i = 1 if capability i is available in research group g and 0 otherwise

A_j = 1 if capability j is available in research group g and 0 otherwise

[134] Nesta and Saviotti (2005) drew on similar developments made by Teece et al. (1994).

Following this same operationalisation approach, a second *similarity matrix* was computed for the whole set of *discipline categories* asked about in the survey questionnaire (Table 6.1). Subsequently, departing from the matrix of similarities or relatedness (S_{ij}) between pairs of knowledge assets' categories (R&D capabilities or disciplines) described above, aggregated metrics of *similarity* and *difference* among the R&D capabilities (and disciplines) for each pair of collaborating R&D group were computed. In other words, we use system-level measures of knowledge-class relatedness to compute the dyad-level knowledge integration measures. The operational specificities of these measures are described in the following two sections.

6.2.4 *Similarity* between collaborating R&D groups

As was noted in section 6.2.1 above, we developed and operationalised two different indicators of *collaborative knowledge integration*. The first indicator assesses the *similarity between* two *collaborating R&D groups*, by measuring the degree of overlap between the knowledge bases of both actors, for each knowledge dimensions (with separate measures for R&D capabilities and disciplines). The second indicator assesses the degree of *difference between collaborating groups* (i.e. the absence of overlap) through a measure of the extent of non-overlapping knowledge assets (Chung et al., 2000; Gulati & Gargiulo, 1999) present in both actors undertaking the collaborative research project. Below we describe the operationalisation of the indicator for *similarity*, between partners, while the indicator for *difference* is presented in section 6.2.5.

Our similarity indicator, as mentioned above, is based on conceptual and methodological developments intended to assess the *diversity* in an organisational knowledge base (Nesta & Saviotti, 2005) or in particular knowledge or technological domains (Stirling, 1998, 2007; Rafols & Meyer, 2010). Along these lines, Porter and Rafols (2009) and Rafols and Meyer (2010) developed indicators intended to measure *knowledge integration*[135] taking published scientific papers as their unit of analysis. For the context of our research, we defined the intermediate unit of analysis at a different level, namely at each sub-set of two R&D groups that collaborate during the implementation of an R&D project. It is in this unit of observation (referred to as *dyad* in the collaboration networks' literature), where knowledge-asset integration is realised through collaboration. Therefore, an adapted dyad-level indicator was developed in order to fit the empirical context, goals and unit of analysis of the present research. The actual operationalisation is described in the following paragraphs.

Departing from S_{ij}, the matrix of measures of similarity between knowledge-asset categories (for R&D capabilities and disciplines) at the system[136] level (computed using Salton's cosine), it was possible to calculate the degree of *similarity* between pairs of collaborating R&D groups identified through the survey. Following Zhou et al. (2012)[137], who were inspired by Stirling (2007), the similarity (φ) between two groups (X,Y) in terms of capabilities – or disciplines – (***i,j*** = 1...N) will be:

$$\varphi\,(X,Y) = \frac{\sum_{i,j}^{N} x_i y_j S_{i,j}}{\sqrt{\left(\sum_{i,j}^{N} x_i\, x_j S_{i,j}\right)\left(\sum_{i,j}^{N} y_i\, y_j S_{i,j}\right)}}$$

where:

x_i = strength of capability[138] or discipline *i* in research group *x*

x_j = strength of capability or discipline *j* in research group *x*

y_i = strength of capability or discipline *i* in research group *y*

y_j = strength of capability or discipline *j* in research group *y*

N = number of capability or discipline's categories in the respective classifications

$S_{i,j}$ = Salton's cosine similarity index between capabilities *i* and *j* (see previous section)

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135 Porter and Rafols (2009, p723) named their indicator as the 'integration score', which measures the extent of interdisciplinary knowledge integration at the level of specific scientific disciplines.

136 I mention system-level here with reference to the whole set of R&D groups or organisations surveyed and therefore used to compute the S_{ij} matrix.

137 Bloom et al. (2013, p.1359, equation 3.4) arrive at the same formulation, generalising the measure of cosine similarity previously used by Jaffe (1986) and many others (they call it the 'uncentered correlation', p1350) with a cross-correlation matrix inspired by the Mahalanobis distance (p.1358).

138 Strength was measured on a Likert scale with values from 0 (not developed) to 4 (very well developed).

This operationalisation of the *similarity* indicator takes the knowledge assets mapped in two individual research groups that worked together in a research project, and computes an aggregated dyad-level measure[139], that provides a metric for the *degree of overlap* between every two organisations' knowledge assets (R&D capabilities or scientific disciplines). Moreover, as can be seen from the equation, in order to avoid biases, the similarity measure has been normalised so that its value has 1 as an upper limit for the similarity of a lab with itself. The internal homogeneity of the research groups (also defined as 'concentration' by Zhou et al., 2012) was introduced in the denominator for normalisation purposes.

With regards to the identification of collaborative links between R&D groups, we should note that *'star*[-shaped] *representation of the single R&D project'* was assumed (Acha & Cusmano, 2005, p11). This means that we assume that collaborative links exist only between the R&D group coordinating the project and each participant R&D group identified by the project leader in the survey-questionnaire, while no direct links are assumed to exist among those identified participants (Acha & Cusmano, 2005)[140]. Moreover, the exchange of knowledge through these links is assumed to be bi-directional, namely from the group coordinating the project towards the identified collaborating groups and vice-versa[141].

6.2.5 *Difference* between collaborating R&D groups

A key phenomenon that this research sought to explore was the integration of knowledge across organisational boundaries, namely the exploitation of complementary (non-overlapping) distributed R&D capabilities and knowledge

[139] The availability of R&D capabilities in each group is measured on a 5-point Likert scale, in order to take into account the balance among capabilities, as suggested by Rafols and Meyer (2010). The availability of disciplines in each group was assessed with a binary metric that takes the value 1 when the discipline is available in the group and 0 (zero) otherwise.

[140] Assuming such a 'star-shaped' representation may be a shortcoming of this research, it might misleadingly overlook direct knowledge flows among the partners identified by the leader of the collaborative project.

[141] In the networks literature these are defined as non-directed links. It will be explained later that this assumption has implications for how our aggregated actor-level indicator of collaborative knowledge integration is computed.

through collaborative R&D activities. It has been argued that the potential complementarity between actors can be measured through the *degree of non-overlap* of skills, resources and capabilities between actors (Chung et al., 2000; Gulati & Gargiulo, 1999). Following these authors, it is assumed here that the higher the extent of non-overlap of knowledge assets between two actors, 'the more likely they are to possess complementary capabilities and resources' (Gulati & Gargiulo, 1999, p1462), and the higher the expected gains from potential collaborations and synergies between them (exploitation of complementarities)[142]. This suggested importance of non-overlapping knowledge for the potential impact of collaborations motivated our decision to use two indicators to assess complementary knowledge integration.

Most studies of inter-organisational complementarity base their empirical research on a single dimension of complementarity, either similarity (e.g. Jaffe, 1986; Mowery et al, 1996; Mowery et al., 1998) or distance (e.g. Gulati & Gargiulo, 1999; Chung et al., 2000). For this study we considered both types of measure as separate dimensions of knowledge complementarity. The measure of *difference* or non-overlap can provide complementary information to the measure of *similarity*. As a simple example, if we have two dyads AB and CD that have the same value for the measure of similarity (or overlap), it is possible to find, for example, that the dyad CD has a significantly higher degree of difference (or non-overlap) in its knowledge base than AB. As noted in the previous paragraph, this could be interpreted as actors C and D (in dyad CD) having higher expected gains from a potential collaboration and synergistic exploitation of complementarities than actors A and B (in dyad AB).

Taking this into account, the second dimension of *collaborative knowledge integration* between two research groups (a dyad) was assessed through an indicator of the *degree of difference* or non-overlap between both groups' knowledge bases (R&D capabilities and disciplines), which is understood as a source of complementarity or synergy between groups. This sort of measure should reflect the extent of *'...acquisition of external supplementary* [unrelated] *knowledge...'* through

[142] Provided there is a certain minimum threshold of common knowledge (Grant & Baden-Fuller, 2004; Noteboom et al., 2007).

collaboration, thus allowing the identification of innovative collaboration efforts for the integration of distributed and dissimilar R&D capabilities or disciplines (Rafols & Meyer, 2010, p282). The mathematical operationalisation of the indicator of *difference* between two R&D groups could be achieved using a Euclidean type of distance measure, but in order to take into account the similarities between knowledge assets categories we followed recent studies (Bloom et al. 2013[143]) that used instead the *Mahalanobis distance* (Rubin, 1980):

$$d(\vec{x},\vec{y}) = (\vec{x} - \vec{y})\, S^{-1}\, (\vec{x} - \vec{y})^T$$

where S is the covariance matrix. The covariance matrix uses the mean, which is problematic in matrices with many zeros. Therefore, we used the Salton's cosine similarity matrix described in section 6.2.3. As a result, the measure of *difference* (δ) between R&D groups X and Y can be expressed as:

$$\delta\,(X,Y) = \sum_{i,j}^{N} |x_i - y_i|\,|x_j - y_j|\,(1 - S_{i,j})$$

where:

x_i = 1 if capability (or discipline) *i* is available in research group *x* and 0 otherwise

y_i = 1 if capability (or discipline) *i* is available in research group *y* and 0 otherwise

x_j = 1 if capability (or discipline) *j* is available in research group *x* and 0 otherwise

y_j = 1 if capability (or discipline) *j* is available in research group *y* and 0 otherwise

N = number of capability or discipline's categories in the respective classifications

$S_{i,j}$ = Salton's cosine similarity index between capabilities *i* and *j*

$(1 – S_{i,j})$ = disparity – or difference – between capability (or discipline) categories *i* and *j*

[143] Bloom et al. (2013) adapted a measure of proximity between firms proposed by Jaffe (1986) into a distance measure inspired in the Mahalanobis distance.

Again, in order to facilitate comparisons the measure was normalised following Zhou et al. (2012). The resulting formulation is:

$$\delta\ (X,Y) = \frac{\sum_{i,j}^{N} |x_i - y_i|\,|x_j - y_j|(1 - S_{i,j})}{\sqrt{\left(\sum_{i,j}^{N} x_i\, x_j S_{i,j}\ \right)\left(\sum_{i,j}^{N} y_i\, y_j S_{i,j}\ \right)}}$$

In sections 6.2.4 and 6.2.5 we presented our approach to assess the extent of collaborative knowledge integration achieved by a pair of R&D groups working together in a collaborative research project. In the next section, we explain how these dyad-level measures are then transformed into group-level indicators according to our final unit of analysis.

6.2.6 Knowledge integration: from dyad to aggregated group-level measures

In the previous two sections, we presented the mathematical operationalisation for the indicators of *similarity* and *difference* we developed to assess collaborative knowledge integration. Computing these indicators for each knowledge dimension described in 6.2.2, namely R&D capabilities and scientific disciplines, produces four different dyad-level knowledge integration measures which we summarise in Table 6.3. These are dyad-level measures but given that our end unit of analysis is the single research group, we subsequently needed to aggregate the dyad-level metrics into measures for each single R&D group (i.e. shifting from dyadic to monadic level analysis).

Table 6.3: Dyad-level measures of collaborative knowledge integration

Relational measure	Knowledge dimension	
	R&D capabilities	**Scientific disciplines**
Similarity	Capability similarity $_{x,y}$: degree of similarity between R&D groups ***x*** and ***y*** regarding their **R&D capabilities**	Disciplinary similarity $_{x,y}$: degree of similarity between groups ***x*** and ***y*** regarding the **disciplines** of the members of the groups
Difference	Capability difference $_{x,y}$: measures the existence of distant non-overlapping **R&D capabilities** between groups ***x*** and ***y*** as a source of potential complementarities or synergies	Disciplinary difference $_{x,y}$: measures the existence of distant non-overlapping **disciplines** between groups ***x*** and ***y*** as a source of potential complementarities or synergies

Source: elaborated by the author

Beyond pairs of R&D groups, if we take the single collaborating actor as the unit of analysis, an aggregated measure of collaborative knowledge integration can be computed for each R&D group ***x*** by averaging all dyad-level measures of, say, *Capability similarity* between R&D group ***x*** (see Table 6.1) and all organisations ***y*** with which it has a working collaborative linkage. As an example, for R&D group ***i*** that has collaborative ties with two groups ***j*** and ***k***, the values of *Capability similarity **i-j*** and *Capability similarity i-k* are summed and then divided by two in order to arrive at the *Average capability similarity* for group ***i*** with all its collaborating partners. This aggregated metric hence provides an indicator of the ability of each research group to integrate distributed complementary capabilities through all its collaboration links. The aggregation algorithm for this example of *Average capability similarity* is described below.

$$Avg\ capability\ similarity\ _x = \frac{\sum_{y=1}^{n} Capability\ similarity\ _{xy}}{n}$$

<u>where:</u>

Capability similarity $_{x,y}$ = degree of similarity between R&D groups ***x*** and ***y*** regarding their R&D capabilities

n = total number of partners of group ***x***

Average capability similarity $_x$ = average for the Capability similarity between group ***x*** and all its *n* partners

The same computation procedure was applied for the aggregation of the remaining dyad-level similarity and difference measures described in Table 6.3. In this way, four aggregated group-level variables were computed. All resulting group-level variables are described in Table 6.4 below.

Table 6.4: Aggregation of dyad-level variables into average group level variables

Dyad-level relational variable	Single-group level aggregated variable
Capability similarity $_{x,y}$	Avg. capability similarity $_{x}$
Capability difference $_{x,y}$	Avg. capability difference $_{x}$
Disciplinary similarity $_{x,y}$	Avg. disciplinary similarity $_{x}$
Disciplinary difference $_{x,y}$	Avg. disciplinary difference $_{x}$

Source: elaborated by the author

It can be argued that our work, in adapting and developing these indicators to assess collaborative knowledge integration represents, in itself, an original methodological contribution. Up to this point of Section 6.2 (quantitative approach), we have focused on how indicators of collaborative knowledge integration were developed. As claimed before (Section 2.6.2), this was actually a central methodological challenge for our empirical study but we should now move on to our quantitative operationalisation of the remaining variables, namely those regarding the *factors shaping collaborative knowledge integration*. The quantitative approach to assessing these factors is presented in the next section.

6.2.7 Factors shaping collaborative knowledge integration: quantitative approximation

As proposed in our conceptual framework and introduced at the outset of this chapter (Section 6.1), we focus our attention on a reduced set of factors that substantially affect collaborative knowledge integration in our empirical context, namely: (i) absorptive and relational capabilities of the R&D group; (ii) system-level institutions and incentives – particularly public policies supporting interaction and knowledge integration among organisations and knowledge fields; and (iii) compliance of the R&D

group with scientific reward institutions. The second group of factors relates to public science and technology policies which we comprehensively addressed in chapter 5, with particular attention being paid to the influence exerted by the National Researchers' Assessment System (SNI). This is a system-level factor but since our unit of analysis for our quantitative examination is the individual R&D group, we will indirectly assess the likely influence of this system-level formal institution though a quantitative assessment of the third factor referred to above, namely the *compliance of R&D groups with these system-level incentive policies*. We describe the operationalisation of these indicators below, while the quantitative assessment of absorptive and relational capability is explained later.

For those R&D project coordinators that replied to the survey and identified collaborative relations, we subsequently asked for and obtained access to information from the database of the National Researchers' Assessment System (SNI is its acronym in Spanish). For each project leader we obtained data on two indicators: (i) total number of publications in peer-reviewed journals (the conventional indicator for assessments of knowledge production); and (ii) the actual position or rank of the project leader within the categorisation system established by the National Researchers' Assessment System (local indicator)[144]. For analytical purposes, we attribute these individual-scientist attributes to the R&D group to which the project leader is affiliated. With these indicators of compliance of the R&D with local formal incentive policies we intend to provide statistical support to the qualitative findings presented in chapter 5, on the relation between formal incentive institutions and the ability of R&D groups to collaboratively integrate complementary knowledge assets distributed throughout the system.

With regards to the structural attributes of the R&D group, we proposed to assess how *absorptive capacity* relates to the extent of knowledge integration. A number of variables were developed to characterise the *structure of each research group* in terms

[144] An ordinal variable that indicates the level of the project coordinator on a five-point scale: values 1 to 4 are derived from the categories established by the National Researchers' Assessment System, while we gave a value of zero (0) to those scientists (project leaders) that are outside or non-categorised by the system.

of its knowledge base. Giuliani and Arza (2009) assessed the influence of *absorptive capacity* in public-private collaborations by measuring the quantity, level of education and experience of researchers in each actor. Rothwell and Dodgson (1991) also assessed the ability to access and assimilate external know-how (absorptive capacity) through the number of qualified scientists and engineers. Following a similar approach, we built a rough proxy of *absorptive capacity* through a measure of the total number of highly trained scientists working in the group, namely those that have gained an MSc or PhD degree. As another dimension of the structure of an R&D group, in chapter 5 we showed revealing evidence of the role played by postgraduate students in facilitating the access to external sources of knowledge and skills. In order to statistically test this finding, we developed a variable that measures the absolute number of research students working in each R&D group.

Finally, a metric to appraise the *relational capability* of each R&D group was also developed. Previous studies have assessed relational capability through some measure of the alliance experience, in particular the total number of collaborations established by each organisation with other actors (Dyer & Singh, 1998; Gulati, 1995; Simonin, 1997). Following a similar approach, we built our indicator for *relational capability* by computing the sum of all collaborative links established by an R&D group with other local public research organisations or groups[145]. To sum up, we present in Table 6.5 a brief description of the whole set of variables developed in order to run our statistical analysis. The data required to construct most of the variables in the Table were collected through a survey that we describe in the next section.

[145] The links established during the implementation of collaborative R&D projects were identified through the survey questionnaire.

Table 6.5: Description of variables

Type of variable	Variable name	Description
Collaborative knowledge-integration measures	*. capability similarity* $_x$	Average degree of *R&D capabilities' similarity* between R&D group ***x*** and all the groups with which it has collaborative relations
	Avg. capability difference $_x$	Average degree of *R&D capabilities' difference* between R&D group ***x*** and all the groups with which it has collaborative relations
	Avg. disciplinary similarity $_x$	Average degree of *Disciplinary similarity* between R&D group ***x*** and all the groups with which it has collaborative relations
	Avg. disciplinary difference $_x$	Average degree of *Disciplinary difference* between R&D group ***x*** and all the groups with which it has collaborative relations
Group compliance with formal incentive institutions	*Peer reviewed papers*	Number of peer reviewed papers published by the coordinator of the project
	Researcher assessment degree	Position of the project coordinator in the National Researchers' Assessment System (SNI)
Group structural and relational attributes[146]	*Absorptive capacity*	Number of researchers with a masters or doctorate degree in the group
	Student number	Number of students that worked for the R&D group during the implementation of the project
	Relational capability	Total number of collaborative links established by the group with other national public R&D groups

Source: elaborated by the author

6.2.8 Design of the survey: the R&D project as the space for knowledge integration

In order to collect the primary data required to operationalise the quantitative indicators summarised in Table 6.5, a survey was designed to address *coordinators of local agri-biotechnology R&D projects*. This means that the *level of observation* where the actual collaboration between pairs of R&D groups and the interactive integration of knowledge assets take place was the *individual research project*. It is in the R&D project where both social interaction (between R&D groups) and cognitive integration (among the knowledge assets of these groups) can be observed and characterised (Wagner et al., 2011). Moreover, local collaborative projects of an exploratory nature are argued to be of particular importance in supporting the development and establishment of emergent technologies (Geels & Raven, 2006, p377).

Project leaders were asked to reply to an on-line survey questionnaire developed by the Qualtrics Research Suite (Qualtrics, Provo, UT, USA; www.qualtrics.com). Besides

[146] These attributes refer strictly to the group of people of the leading R&D group that were involved in the implementation of the project.

direct on-line replies, complementary phone calls to project coordinators were made in order to collect answers either for the whole questionnaire or for specific missing data from on-line completed questionnaires. The complete questionnaire delivered to project coordinators is presented in Appendix 8.5. The survey retrieved data for the following two analytical levels:

(i) The individual research group (or laboratory or department) to which the project coordinator belongs: Specific disciplinary knowledge and R&D capabilities existing in the groups were identified at this level (based on the knowledge-asset classifications presented in Tables 6.1 and 6.2), as well as data on *structural attributes* of the research group (number and qualification of researchers, and involvement of students in the group).

(ii) Collaborations with other R&D groups that took place during the implementation of the project: This allowed us to arrive at a comprehensive identification of the co-participation of research groups or organisations in collaborative research activities. So, when the project involved the participation of two or more actors, pairs of collaborating R&D groups (dyads) were identified, thereby generating *relational data* required for the subsequent analysis of collaborative knowledge integration.

In empirical terms, the delivery of the survey required first an exhaustive identification of agri-biotechnology R&D projects that have taken place in Uruguay during the period under study (1999-2010). A comprehensive database of R&D projects carried out in Uruguay between 1999 and 2010[147] was developed. The end-goal of this intermediate data-gathering stage was identifying the whole population of R&D activities over which we wanted to explore processes of collaborative knowledge integration. Faced with the lack of a single comprehensive national database, this process required exhaustive efforts for the collection, mining and integration of data from the main national research organisations and R&D funding agencies (or programmes) that respectively

[147] This period covers the most significant increases in research and application of modern biotechnologies on agriculture technology development (Bisang et al., 2009). Moreover, from an empirical viewpoint, the sources of information and databases available in Uruguay offered good quality information for this period, particularly regarding the identification of R&D projects.

carried out or funded most R&D activities during the period referred to above. Once the organisations, agencies and programmes listed in Table 6.6 had been identified as the main sources of projects' information, access to their databases was requested and subsequently granted. A subsequent tough process of integration and adaptation was carried out in order to achieve compatibility and homogeneity, finally building a consolidated database with 14,962 records of R&D activities.

Table 6.6: Sources of R&D projects' data[148]

Organisation or programme	Acronym	Number of R&D activities / projects
The National Agency for research and innovation (ANII)	ANII	138
Technological Development Programme from the National Direction of Science, Technology and Innovation (Ministry of Education).	PDT	184
Fund for the Promotion of Agricultural Technology (FPTA) and other competitive funds administered by the National Agricultural Research Institute (INIA)[149]	FPTA-INIA	336
Sectoral Commission of Scientific Research of the University of the Republic (UdelaR)	CSIC[150]	13.824[151]
The National Agricultural Research Institute R&D portfolio	INIA	480
Total records		14.962

Source: elaborated by the author

The set of information fields comprised by the consolidated database for each record is detailed in Table 6.7**.** To the best of my knowledge, this represents the only data source covering the bulk of R&D activities carried out by public research organisations and competitively funded by public agencies in Uruguay during the specified period. This provides a unique resource to characterise the patterns of collaboration among public R&D groups for agri-biotechnology research in Uruguay.

148 Databases accessed from public research organisations and funding agencies or programmes.
149 These are R&D projects competitively funded by INIA but carried out by other organisations.
150 The CSIC database covers the whole project portfolio of UdelaR (acronym for University of the Republic), which is the single public University in Uruguay.
151 The CSIC database not only included R&D projects but also other types of R&D activities such as funding of short training courses, participation in international conferences, visiting scholars, and local seminars. This explains the large number of activities in this database.

Table 6.7: Information fields comprised by the consolidated database of R&D activities

Database fields	
Project id	Project start date (year)
Funding Agency / Programme	Project end date (year)
Type of R&D activity / project	Partner organisations[152]
Project title	Research area (OECD / UNESCO)
Leading organisation	Research discipline
School, Department or Laboratory	Keywords
Project leader (name)	Abstract / goals
E-mail (project leader)	

Source: elaborated by the author based on the structure of the accessed databases

Once a single consolidated database of publicly funded R&D activities had been built, a number of data-cleaning procedures were required. Since R&D activities other than research projects were included in the database, a first filtering procedure was carried out, keeping only 2783 database records corresponding to actual R&D projects. In order to keep project selection within the boundaries of biotechnology research, a subsequent filtering procedure based on keyword identification was carried out (Gay & Dousset, 2005). On the basis of the keywords listed in Table 6.8 below, 848 biotechnology R&D projects were selected from the database. Finally, additional fine-grained work was required in order to narrow down the selection to the scope of this research, namely to R&D projects on *agriculture-related biotechnology*. This was performed with the aid of three local experts on agri-biotechnology research, generating a final selection of 329 agri-biotechnology R&D projects. A previous study of the impact of 430 R&D projects conducted by the University of the Republic (UdelaR) in Uruguay between 1996 and 2004 identified only eight (8) biotechnology R&D projects (Bianco et al., 2008). Consequently, we argue that our final projects database represents a reasonably exhaustive and robust identification of agri-biotechnology R&D projects undertaken by Uruguayan research organisations.

[152] Information on partners was rather poor and uneven among the different sources of data obtained for this study; therefore information on collaborating R&D groups and organisations for each project was subsequently collected through the survey questionnaire (Sections 3.5.5).

Table 6.8: Keywords for R&D projects' selection

Keywords	
biotechnology	bioremediation
DNA sequencing	biofiltration
DNA synthesis	phytoremediation
DNA amplification	gene vector
RNA sequencing	viral vectors
RNA synthesis	bioinformatics
RNA amplification	nanobiotechnology
genomics	transcriptomics
gene probes	subunit vaccine
genetic engineering	recombinant protein
gene expression profiling	recombinant antigen
antisense technology	metabolic engineering
peptide sequencing	siRNA
protein sequencing	PCR
peptide synthesis	RT-PCR
protein engineering	miRNA
Proteomics	microarray DNA
biodesulphurisation	microarray protein

Source: adapted by the author from Biotecsur (2008a) and OECD (2005) with the advice of three experts[153]

This final database became our primary data source for the identification of the coordinators or leaders of agri-biotechnology R&D projects to whom we delivered the survey questionnaire. The leaders of the 329 R&D projects selected became the target population for the survey that was subsequently carried out. Out of this set, 34 projects were discarded because of lack of contact information for the project leader. Project leaders that coordinated more than one R&D project recorded in our database were surveyed only once. On that basis, 71 projects were disregarded because of duplication of their coordinators. As a result, our final target for the survey comprised 224 individual researchers acting as coordinators of local agri-biotechnology R&D projects. Project leaders were asked to complete the survey questionnaire presented in Appendix 8.5. Most of the project leaders (215 out of the whole set of 224) work for

[153] The sources reviewed in order to build a first draft list of keywords to select the projects included Biotecsur (2008a) and OECD (2005 - see list-based definition of biotechnology). The draft list was subsequently tested and corrected with the help of three experts in the field.

the twelve main public research organisations we listed in Table 3.5 (Chapter 3, Section 3.4.3).

With regards to the results of the survey implementation, we obtained complete questionnaire answers from 148 R&D project coordinators. This represents a high response rate (66 %) if compared with the average response rate of 52.3% found by Anseel et al. in their analysis of 2037 survey-based studies in the organisational science field (Anseel et al., 2010, pp340-1). The affiliations stated by the 148 respondents encompassed 97 different agri-biotechnology R&D groups. As an additional filtering condition, R&D groups should internally have at least one R&D capability and one discipline from the knowledge assets' classification lists we employed in the survey questionnaire, in order to be considered as part of the agri-biotechnology system. Out of the 97 groups that replied to the survey, 12 groups did not meet this condition so they were discarded from further analysis, on the assumption that they are not directly related to the research and technology field under study. Hence, we kept data for *85 agri-biotechnology R&D groups*.

Our previous work in the identification of actors presented in Section 3.4.3 described a whole incumbent population comprising 132 agri-biotechnology R&D groups in the public sector. The survey showed that 12 out of these 132 groups do not actually belong to the agri-biotechnology system. Therefore, we can claim that our survey to incumbents in the agri-biotechnology system collected data from 70% of the entire population of R&D groups.

Finally, it should be recalled that we are exploring the integration of knowledge and R&D capabilities realised through research collaborations among *local public research organisations* or R&D groups. Consequently, research groups that actually developed local collaboration links with other public R&D groups (56) are the focus of our subsequent statistical analysis, while groups that did not build these sorts of local links (29) fall outside the scope of our study. Therefore, our subsequent statistical analysis encompasses 56 R&D groups that are actually active in collaboratively integrating local knowledge and skills from external sources in the public-sector research. In the following section, we describe the statistical model employed to assess how the extent of collaborative knowledge- integration achieved by R&D groups is shaped by the selected driving forces described in Section 6.2.7 and summarised in Table 6.5 above. Such analysis should allow us to reach a better understanding of the main determinants of collaborative knowledge integration in the context of emergent technologies in a developing country.

6.2.9 Statistical model

The relational character of our quantitative data, particularly of our knowledge integration dependent variables, presented us with a tough challenge concerning the selection of a suitable statistical model. For statistical inference, common parametric tests and regression models (such the ordinary least squares) assume *independence of observations*, namely that the value that a variable takes in a specific unit is independent of the value for the same variable in all other units being analysed. This assumption is not met when the subject being examined involves social interactions such as in our study. As noted in Section 6.2.4 we consider the links between groups to be non-directed, which means that for a pair of collaborating groups X and Y our measures of collaborative knowledge integration, for example *Capability similarity* (Section 6.2.4) will be:

$$\textit{Capability similarity}_{x,y} = \textit{Capability similarity}_{y,x}$$

Subsequently, we compute our actor-level measure of *Capability similarity* $_{x}$, as the average of the degree of *Similarity* between actor X and all its partners (Section 6.2.6). As a result, the *Average capability similarity* for actor X will be interdependent with the value of the same variable observed in all its partners and vice-versa. Given this data structure, we drew on models developed to assess *social influence* (Leenders, 2002) or *spatial dependence* (Kelejian & Prucha, 1998; Drukker et al., 2013b; Elhorst, 2014) which allow and account for the existence of interactions among units of observation.

In fact, these two veins of research have a common methodological root in the field of *spatial econometrics*, particularly in the seminal contribution made by Luc Anselin (Anselin, 1988). When considering the use of *spatial models*, it has been claimed that

'...*space* is not restricted to geographic space, and many recent applications use these techniques in other situations of cross-unit interactions, such as social-interaction models and network models' (Drukker et al., 2013b, p221). Other scholars have claimed that despite '...[s]patial dependence … [being] ubiquitous in social relations and interactions..., there are surprisingly few social science studies accounting for spatial dependence' (Neumayer & Plumper, 2010, p585). Supporting this claim, well-known researchers from the field of inter-organisational collaboration and networks have criticised previous studies in this field since they predominantly rely on the independence assumption (Gulati et al., 2011, p210).

Consequently, drawing on Leenders (2002), Drukker et al. (2013b) and Elhorst (2014), we used a *spatial autocorrelation* or *spatial autoregressive* model formulated as follows:

$$Y = \alpha 1_N + \lambda WY + \beta X + \rho Wu + \varepsilon$$

Where:

Y is a (N x 1) vector of observations of the dependent variable for N units;

1_N is a (N x 1) vector of ones multiplying the constant parameter α to be estimated;

W is a (N x N) weight matrix (each element $w_{i,j}$ in the W matrix denotes the influence that actor j has on actor i (Leenders, 2002);

WY is a (N x 1) vector that denotes the endogenous interaction or spatial effect among the dependent variable, usually referred to as *spatial lag*[154], while λ is the *spatial autoregressive parameter* on the dependent variable to be estimated;

X is a (N x k) matrix of observations on k independent variables and β is the corresponding (k x 1) vector of parameters for each k independent variable;

[154] The spatial lag variable WY '…consists of the weighted values of the dependent variable in other units' as defined by the weight matrix (Neumayer & Plümper, 2010, p589).

Wu is a (N x 1) vector that denotes the interaction or spatial effect among the error terms of each unit, while ρ is the *spatial autoregressive parameter* on the error term to be estimated; and

ε is a (N x 1) vector of innovations (errors) for N units.

In spatial econometrics, the use of these models is usually intended to test the presence of autocorrelation, namely if the *spatial autoregressive parameter* (λ) is significant. Our empirical case is different: given the way our average indicators of *similarity* and *difference* were computed for each group, we know that there will be autocorrelation in the dependent variable, so we expect the λ coefficient to be significant. What we actually want from the spatial model is to control such autocorrelation and produce unbiased estimators of the β parameters for our independent variables (Leenders, 2002, p25).

A central element for the implementation of this model is reaching an adequate specification of the weight matrix *W* for our conceptual and empirical context. This matrix should represent the influence process present in our network of research collaborations among R&D groups (Leenders, 2002, p22). As we argued at the beginning of this section, we want the *W* matrix to account for the influence that an R&D group's partners have on the group value of the dependent variable. Hence, we used an adjacency or contiguity matrix which means that each element ($w_{i,j}$) of the matrix takes the value of 1 (one) if actors *i* and *j* have a collaborative link and 0 (zero) otherwise. Following Elhorst (2014) and Leenders (2002), this adjacency matrix was subsequently row-normalised so that all elements of each row sum to 1 (one). As claimed by Elhorst, '...the row elements of a spatial weights matrix display the impact on a particular unit by all other units. Consequently, row normalization has the effect that the impact on each unit by all other units is equalized' (Elhorst, 2014, p12). We used the 'spmat' command (Drukker et al., 2013a) of STATA in order to import this matrix from Excel into STATA and apply it in the autocorrelation model.

Another methodological issue when a spatial autocorrelation model is used regards the interpretation of the estimated coefficients for α (constant) and β (coefficient for each independent variable) from the model equation presented above. As clearly argued by LeSage and Pace, these coefficient estimates '...cannot be interpreted as if they reflect linear regression slope estimates... The econometrics literature interprets coefficients from these models using *marginal effects* that reflect partial derivatives indicating how changes in each explanatory variable impact (or effect) the expected y outcomes' (LeSage & Pace, 2014, p1542). Therefore, after estimating the model parameters (Section 6.3.2), we computed the corresponding *marginal effects* of changing each independent variable on the dependent variable (*y*) so as to produce meaningful results to address our research questions.

Throughout Section 6.2 we have provided a detailed description of the quantitative approach developed for our study. We claimed that our work in adapting and developing indicators to assess collaborative knowledge integration represents, in itself, an original methodological contribution. Moreover, studies reviewed in this last Section (6.2.9) suggest that only a minor portion of social-science studies account for cross-unit interdependence (Neumayer & Plumper, 2010) as we attempt to do with the use of the spatial autocorrelation model described above. Consequently, in the following section, we turn to present the results obtained from the empirical application of the quantitative methodology above.

6.3 Results from the statistical analysis

6.3.1 Descriptive statistics and correlations

Before turning to the results of the spatial autocorrelation model we present below the descriptive statistics (Table 6.9) and correlations (Table 6.10) for our dependent and independent variables summarised in Table 6.5. With regards to the measures of the ability of research groups to collaboratively integrate complementary knowledge assets, the metric for similarity of a group's R&D capabilities with its partners (*Avg. capability similarity*) shows a wide variation (from 0.206 to 0.968) with an average of

0.787. Likewise, the metric for similarity of disciplines of each group with its partners (*Avg. disciplinary similarity*) varied from 0.036 to 1.000 and averaged at 0.658. There is also a large range for the values of *difference* between a group and its partners, averaging 2.846 and 2.139 for *Avg. capability difference* and *Avg. disciplinary difference* respectively.

With respect to the independent variables, the number of researchers with a masters or PhD degree – which was regarded as a rough proxy of *absorptive capacity* – ranged from 0 to 9 and took the value of 2.839 researchers on average, while the *student number* ranged from 0 to 6 and averaged 0.93 students per group. Regarding our measures of compliance of the R&D group with formal incentive institutions, the absolute number of *peer reviewed papers* (published by the project coordinator) reached a maximum of 90 while the mean was 22.7 articles, and the rank of the surveyed researcher (the R&D project coordinator) in the National Researchers' Assessment System averaged 1.91. Finally, the number of collaborative links with other local public R&D groups – which we used as an indicator of the group's *Relational capability* – averaged 1.96 R&D collaborations per group. This broad variation observed for both dependent and independent variables, provides a fertile ground for our subsequent exploration of whether or not differences in the ability of research groups to integrate distant (or similar) knowledge assets through R&D collaborations, show a meaningful relation with the relevant driving factors on which we have focused our qualitative and quantitative analyses.

Table 6.9: Descriptive statistics

Variable		Obs. (N)	Mean	Std. Dev.	Minimum	Maximum
Dependent variables	*Avg. capability similarity*	56	0.787	0.156	0.206	0.968
	Avg. capability difference	56	2.846	3.523	0.559	17.951
	Avg. disciplinary similarity	56	0.658	0.190	0.036	1.000
	Avg. disciplinary difference	56	2.139	1.076	0.000	5.297
Independent variables	*Peer reviewed papers*	56	22.71	19.96	0	90
	Researcher assessment degree	56	1.911	1.116	0	4
	Absorptive capacity	56	2.839	1.523	0	9
	Student number	56	0.929	1.360	0	6
	Relational capability	56	1.964	1.144	1	6

Source: STATA output based on the author's own data

An overall look at the correlations among variables (Table 6.10) shows no straightforward association patterns between dependent and independent variables. Within the dependent variables, as expected, there are strong negative correlations between the *similarity* and *difference* measures for each knowledge dimension (-0.72 for *R&D capabilities* and -0.68 for *disciplines*). Despite being highly correlated, their distance from equivalence suggest that our approach to independently assess overlapping (similarity) and non-overlapping knowledge assets among groups (difference) may well provide a more comprehensive account of complementarity compared to most studies of inter-organisational complementarity that, as suggested in Section 6.2.5, base their analyses on a single indicator of complementarity[155]. Our measures of *difference* are particularly relevant in our empirical context, since the greater the degree of non-overlap (or unrelatedness) of the integrated capabilities, the greater the impact on local innovation expected in both individual organisations (Hage & Hollingsworth, 2000; Rosenkopf & Nerkar, 2001; Nooteboom et al., 2007) and the whole system (Carlsson & Stankiewicz, 1991; Lall, 1992; Cimoli et al., 2009)[156].

Table 6.10: Correlations

Variable	*Avg. capability similarity*	*Avg. capability difference*	*Avg. disciplinary similarity*	*Avg. disciplinary difference*	*Peer reviewed papers*	*Researcher assessment degree*	*Absorptive capacity*	*Student number*
Avg. capability similarity	1							
Avg. capability difference	-0.717	1						
Avg. disciplinary similarity	0.593	-0.439	1					
Avg. disciplinary difference	-0.285	-0.005	-0.678	1				
Peer reviewed papers	0.108	-0.112	0.161	-0.068	1			
Researcher assessment degree	0.254	-0.283	0.231	-0.044	0.699	1		
Absorptive capacity	0.115	-0.181	0.048	0.250	0.058	0.130	1	
Student number	-0.014	0.009	-0.029	0.247	-0.046	0.020	0.337	1
Relational capability	0.186	-0.201	0.009	0.227	0.136	0.211	0.143	0.045

Source: STATA output based on the author's own data

[155] E.g. Jaffe, 1986; Mowery et al, 1996; Mowery et al., 1998; Gulati, 1999; and Chung et al., 2000.
[156] This is a central assumption of our research. See Section 5.4 for a broader justification.

In addition, a strong but positive correlation was observed between the rank of the surveyed scientists (as representative of the R&D group) in the National Researchers' Assessment System and their record of publications in peer-reviewed journals (0.669). This finding is consistent with evidence from a previous study that showed how peer-reviewed publishing is by far the main determinant of the final categorisation of researchers in this formal incentive system, while a negligible influence is exerted by other criteria such as the production of *technical publications* (Bernheim et al., 2012, p12). Modest and positive correlations were observed between *researcher assessment degree* and both measures of *similarity* (0.254 for R&D capabilities and 0.231 for scientific disciplines), while the former variable has a moderate negative correlation with *Avg. capability difference* (-0.283). Finally, the number of students involved in a group shows a modest positive correlation (0.247) with the extent of non-overlapping disciplines accessed and integrated by the group through its research collaborations (*Avg. disciplinary difference*).

6.3.2 Spatial autocorrelation model

A number of methods have been developed for the estimation of spatial models (Elharst, 2014). We used the 'generalised spatial two-stage least squares procedure' (GS2SLS) developed by Kelejian and Prucha (1998, p99) and operationalised in the STATA command 'spreg' developed by Drukker et al. (2013b), since it does not rely on the normality assumption (Das et al., 2003) and has previously shown an efficient behaviour in small samples (Kelejian & Prucha, 2010). In Table 6.10 we showed that the variables *Peer reviewed papers* and *Researcher assessment degree* are highly correlated (0.699). Hence, from these two variables we included only *Researcher assessment degree* in the model in order to avoid problems of multicollinearity and taking into account that this indicator directly reflects the R&D groups' compliance with the most relevant formal incentive institution for the whole local scientific system.

We present four model estimations in Table 6.11, one for each indicator of *collaborative knowledge integration* as the dependent variable. The *spatial* *autoregressive parameters on y* (λ) are significant in all model estimations. As was argued in Section 6.2.9, we expected this coefficient to be significant, given the interdependence among observation resulting from the structure of research collaborations and the way our average measures of similarity and difference were operationalised. Hence, autocorrelation is controlled by the model, allowing an unbiased estimation of the regression parameters (*β*) for our independent variables.

The most salient finding from Table 6.11 is that the regression coefficient for the variable *researcher assessment degree* (β_1) is significant in all model estimations, so there is a clear association between this variable and our four indicators of collaborative knowledge integration. In other words, the compliance of research groups with the most salient formal institution establishing national-level incentives for scientists is significantly related to the ability of the group to collaboratively integrate knowledge-resources distributed throughout the system. As argued in Section 6.2.9, to interpret the actual relation between independent and dependent variables, we should look at the *predicted marginal effects* (PME) presented in Table 6.12. We argued in Section 6.2.2 for the relevance of assessing collaborative knowledge integration in two knowledge dimensions, namely *R&D capabilities* and *scientific disciplines*. The results suggest that our dependent variables have rather small marginal effects on the integration of *R&D capabilities* (PME on *capability similarity or difference* ranges from 0.04 to 2.17 %). Conversely, when we look at the *marginal effect* of our independent variables on the integration of *scientific disciplines*, the range of results is noticeably broader (PME on *disciplinary similarity or difference* ranges from -22.53 to 12.96%). Specifically a change in researcher assessment degree[157] resulted in a small marginal effect on *average disciplinary* similarity (2.78 %) and a large negative effect on *average disciplinary difference* (-22.53%). This provides statistical support to our qualitative findings (Section 5.4.2), namely that *the greater the compliance of R&D groups with formal scientific incentives mostly based on publishing in peer-reviewed journals, the weaker their ability to integrate*

[157] Following the approach suggested by Drukker et al. (2013b), the value of the corresponding dependent variable was increased by one unit (+1) for each observation (R&D group) and the consequent marginal effect on the dependent variable was then predicted using the *predict* post-estimation subcommand in STATA.

complementary knowledge and skills distributed throughout the public research system. The results in Table 6.12 show that this weaker *integration ability* is particularly evident when the integration of knowledge from complementary or non-overlapping core scientific disciplines is measured.

Table 6.11: Estimation of spatial autocorrelation models

Independent variable / parameter		Dependent variable (*y*)							
		Avg. capability similarity		*Avg. capability difference*		*Avg. disciplinary similarity*		*Avg. disciplinary difference*	
		Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
β_1	*Researcher assessment degree*	0.030**	0.012	-0.489**	0.201	0.037**	0.018	-0.204**	0.091
β_2	*Student number*	0.004	0.010	-0.177	0.169	0.011	0.015	0.091	0.071
β_3	*Absorptive capacity*	0.002	0.008	-0.153	0.147	0.033**	0.014	0.025	0.063
β_4	*Relational capability*	0.004	0.010	-0.029	0.188	-0.011	0.017	0.118*	0.064
α	*Constant*	-0.023	0.130	1.827**	0.764	-0.621***	0.222	0.202	0.228
λ	*Spatial autoregressive parameter on y*	0.928***	0.178	0.953***	0.106	1.709***	0.304	0.884***	0.145
ρ	*Spatial autoregressive parameter on the error*	-0.360	0.500	-0.117	0.509	-0.036	0.230	-0.727**	0.295

Source: results estimated by the author using STATA 12.0 (spreg command; Drukker et al., 2013b)
* Statistical significance at the 0.10 level;
** Statistical significance at the 0.05 level;
*** Statistical significance at the 0.01 level.

The coefficient for *absorptive capacity* (β_3) was significant in the model taking *disciplinary similarity* as the dependent variable ($p<0.05$), showing a small positive marginal effect (2.43%). Its marginal effect on *capability difference* was also small and positive (2.77%) but the regression coefficient is not significant. Overall, no clear association was observed between *absorptive capacity* and the extent of collaborative knowledge integration. In Chapter 2 (Section 2.7.2) we commented that scholarly research on inter-organisational collaboration has broadly assessed the relation between *absorptive capacity* and the establishment of collaborative R&D partnerships in absolute terms (Rothwell & Dodgson, 1991; Tsai, 2001; Fontana et al., 2006; Giuliani

& Arza, 2009)[158]. Conversely, we argued that these studies have left relatively unexplored how *absorptive capacity* influences the type of knowledge or technological capabilities accessed and integrated through the actor's collaborative linkages. We addressed this gap in our quantitative analysis and found that the *absorptive capacity* of an R&D group, measured through the number of highly trained scientists affiliated to the group (with a masters or PhD degree), is not clearly associated with the ability of public-sector research groups to collaboratively integrate complementary knowledge assets, and consequently neither with the exploitation of potential synergies throughout the agri-biotechnology research system.

Table 6.12: Predicted marginal effects

Change in independent variable		**Predicted Marginal Effects on each dependent variable (*y*)**							
		Avg. capability similarity (pred. mean = 0.791)		*Avg. capability difference (pred. mean = 2.799)*		*Avg. disciplinary similarity (pred. mean = 0.660)*		*Avg. disciplinary difference (pred. mean = 2.137)*	
		PME	PME (%)	PME	PME (%)	PME	PME (%)	PME	PME (%)
Researcher assessment degree	*+1*	0.0053	0.67%	0.061	2.17%	0.018	2.78%	-0.481	-22.53%
Student number	*+1*	0.0007	0.09%	0.022	0.79%	0.005	0.80%	0.214	9.99%
Absorptive capacity	*+1*	0.0003	0.04%	0.019	0.68%	0.016	2.43%	0.059	2.77%
Relational capability	*+1*	0.0006	0.08%	0.004	0.13%	-0.005	-0.83%	0.277	12.96%

Source: results estimated by the author using STATA 12.0 (predict option of spreg command).
PME = Predicted Marginal Effect on the dep. variable (DV) expressed in the same units of the respective DV.
PME(%) = Predicted Marginal Effect in the DV expressed in percentage of the mean predicted before changing the independent variable.

With regards to *relational capability* (β_4), its regression coefficient was significant ($p<0.10$) for the model of *average disciplinary difference* as dependent variable (Table 6.11). Specifically, our indicator of *relational capability* showed a relatively large and positive predicted marginal effect (12.96 %) on the ability of the R&D groups to collaboratively integrate knowledge from non-overlapping disciplinary fields (Table

[158] In these studies, absorptive capacity is usually measured through indicators of R&D intensity or by looking at the number of highly qualified employees in the organisation.

6.12). We presented in the literature review section[159] previous scholarly contributions illustrating that the *accumulation of relational capability* results in an increased likelihood of organisations to establish new collaborations; however, these studies have paid scant attention to the extent in which such an accumulation of partnering experience also results in an increased organisational ability to access and integrate distant complementary knowledge assets (Gulati, 1995; Gulati & Gargiulo, 1999; Lorenzoni & Lipparini, 1999). Our empirical findings suggest that this is actually the case within the public agri-biotechnology research sub-system in Uruguay. This is consistent with our qualitative findings presented in Section 5.4.3, particularly with interviewees' views of collaboration and knowledge integration as a difficult practice or technique that demands commitment and cumulative learning efforts during the implementation of collaborative research endeavours.

Finally, we turn our attention to the relation between the involvement of students in an R&D group and the extent of collaborative knowledge integration this achieves. Table 6.11 shows that the regression coefficients for *student number* (β_2) are not significant for all the knowledge integration dependent variables modelled. Nevertheless, the predicted marginal effects provide interesting insights. The average marginal effect of *student numbers* on our measure of *disciplinary difference* was 9.99 % (Table 6.12). Looking at this relationship in more detail, other things being equal, the marginal effect predicted for each unit (R&D group) ranged from -1.64 to +19.61%[160]. It is probably the case that the significance of the regression coefficient has been affected by the relatively small sample size of our study (56 R&D groups).

Taking a descriptive stance, despite not being statistically significant, the effect of having one student involved in an R&D group activities ranged from virtually nil up to almost 20% increase in the extent to which the group accesses and integrates non-overlapping knowledge from complementary scientific disciplines through its collaborative efforts. Our qualitative findings from the analysis of interviews provide strong empirical support to this observed effect of students' involvement. As shown by

[159] See Section 2.7.2 in Chapter 2.

[160] The data on minimum and maximum predicted marginal effects are not shown in Table 6.12 for simplification purposes.

evidence presented in Section 5.4.4, students contribute to more flexible and effective collaborative knowledge integration processes throughout the whole technological system. Dynamic interactions between research groups are frequently embodied in postgraduate students who act as intermediary or bridging agents, performing the actual inter-group transfer of information, knowledge and skills, and overcoming barriers for the realisation of potential local complementarities among the skills and research facilities of different organisations that were not previously being exploited.

6.4 Closing comments

During this chapter we have presented a rigorous and systematic description of the quantitative approach developed to assess collaborative knowledge integration within our empirical context. We then illustrated the results from the autocorrelation models estimated for each dependent variable operationalised to assess collaborative knowledge integration. From a preliminary interpretation, in general terms, these results showed consistency and provided statistical support for the qualitative findings presented in Chapter 5. We claim that the mixed qualitative and quantitative research methodology followed in our study has provided robust empirical evidence generating reasonable answers to our research questions. In the final Chapter, we present an aggregate discussion of the whole qualitative and quantitative findings presented in Chapters 5 and 6, drawing out the most important conclusions and contributions drawn from our study.

Chapter 7 - Discussion and conclusions

7.1 Introduction

This study has explored inter-organisational collaborations between public research organisations, and how their joint R&D activities integrate complementary sources of knowledge and skills distributed throughout the emergent agri-biotechnology innovation system in Uruguay. To be more specific, the driving question of the research has been: *How and why does the extent of scientific and technological complementarity exploited through R&D collaborations differ among collaborating actors of the agri-biotechnology innovation system in the context of developing countries?* Guided by this overarching question we focused our empirical approach on addressing two narrower sub-questions:

> *How do system-level institutions and incentives for public sector researchers shape the extent of integration of complementary knowledge assets achieved by R&D groups through collaborative research activities within a developing-country agri-biotechnology innovation system?*
>
> *How do organisational-level attributes shape the extent of integration of complementary knowledge assets achieved by R&D groups through collaborative research activities within a developing-country agri-biotechnology innovation system?*

The existence of complementary knowledge assets distributed throughout the system is indeed a precursor condition for their integration through inter-organisational collaborations. Therefore, we analysed the drivers and barriers for the actual exploitation of potential opportunities for complementarity among actors in the public research system. This should help us understand why some potential synergies may be realised by complementary actors or conversely why these opportunities may be left unexploited. Based on a review of previous scholarly studies and a preliminary analysis of our exploratory interviews, we decided to focus our research on a narrow selection of specific attributes understood as those playing the most relevant influence on the extent of collaborative knowledge integration achieved by R&D groups within the context of our empirical study. The various factors selected were aggregated into the conceptual framework (Section 2.7; Figure 2.4) developed in order to guide and bound the empirical work, analysis and discussion presented throughout this thesis. These factors encompass: (i) system-level institutions and incentives (informal institutions and public policies supporting the scientific community); (ii) structural and relational attributes of the R&D group (absorptive and relational capacities); and (iii) compliance of the R&D group with scientific reward institutions.

Evidence from the interviews confirmed, first of all, that complementarities do exist between public research groups throughout the system, and that different forms of collaborative research represent a valuable mechanism employed by R&D groups to exploit the potential offered by these complementarities. Agri-biotechnology R&D groups acknowledged a trend towards increased specialisation in particular research techniques and themes, which, as suggested by previous studies (Gibbons et al., 1994; Powell, 1998; Hessels & van Lente, 2008), leads to the development of a complex set of complementary capabilities distributed throughout the system, hence opening up broad opportunities for synergistic collaborations. Such complementarities, or potential synergies, should be realised through different types of formal and informal collaborative relations between organisations, if innovation and the exploitation of available knowledge resources are to be enhanced. Along these lines, most R&D groups also recognised that, in order to address the latest research challenges, they need to gain access to, and integrate diverse skills and knowledge resources available in external actors. These findings support the relevance of the research questions we defined and validated our empirical setting as a suitable context to address them.

Within this context of distributed complementary knowledge assets, R&D groups were observed to develop collaborative relations driven by one or more of the following rationales: (i) division of research activities among actors; (ii) acquiring new capabilities through learning and/or training; (iii) exchanging research materials; (iv) building scale and scope of R&D activities; (v) accessing other actors' ability of identifying technological needs of the productive sector; and (vi) jointly competing for public or private funds. Similar rationales have been identified by previous studies of research collaboration (Katz & Martin, 1997; Laudel, 2001; Rafols, 2007; Heinze & Kuhlmann, 2008).

We then analysed *how* collaboration and knowledge integration between public research groups is carried out, particularly focusing on local interactions. Most forms of collaborative knowledge integration identified ranged from close interactions in a collaborative project with jointly defined goals and division of research activities between groups, to less intense informal interactions where one group gains access to R&D capabilities which it does not have from another public research group (knowledge moving in a single-direction), but there are no jointly defined goals[161]. Evidence suggests that the latter form of knowledge integration is being under utilised, since most public R&D groups have a weak ability to grant easy access to their in-house research capabilities to external actors in need of accessing such complementary skills.

Regardless of the form of interaction, the collaborative integration of knowledge and skills required deliberate efforts by R&D groups to build *interaction interfaces* that enable effective knowledge-sharing among complementary groups. The evidence presented above suggests that developing such *interfaces* involved to a greater or lesser degree: (i) bridging different views, research routines, goals and motivations; (ii) defining compatible research protocols and knowledge-sharing procedures; (iii) becoming aware of other groups' needs; (iv) achieving external legitimacy of advanced research techniques mastered by the group; and (v) changing traditional work practices. Given this complex process, we observed that the actual collaborative integration of complementary knowledge fields and disciplines, either within a single organisation or across organisational boundaries, is not a straightforward task. Indeed, a number of researchers considered *collaborative knowledge integration* as a technique or practice in itself that demands a firm shared commitment and interactive learning by the collaborating actors.

This context highlights the relevance of identifying the most salient factors that are likely to affect the development of the *interaction interfaces* described above, the

[161] Rafols (2007) defined these forms of collaborative knowledge exchange as *deep collaboration* and *service collaboration* respectively.

required commitment of research groups, and consequently their ability to collaboratively integrate complementary knowledge assets distributed throughout the technological system. Assessing the factors shaping the extent of collaborative knowledge integration achieved by R&D groups is the central concern of our study. The *primary argument* underpinning our motivation to explore these factors is that research oriented to solving local production problems requires the integration of distant complementary knowledge (Van den Besselaar & Heimeriks, 2001) and hence that *the larger the extent of collaborative knowledge integration accomplished, the greater the innovation outcomes expected from both individual organisations* (Hage & Hollingsworth, 2000); Rosenkopf & Nerkar, 2001; Nooteboom et al., 2007) *and the technological system as a whole* are (Carlsson & Stankiewicz, 1991; Lall, 1992; Cimoli et al., 2009)[162].

7.2 Informal and formal institutions

With regards to *informal institutions*, we found that differences in scientists' perceptions and motivations and informal rules of different scientific communities, as well as the poor compatibility between R&D groups reluctant to change traditional research routines while focusing on disciplinary-bounded themes, are noticeably affecting their ability to collaboratively integrate complementary knowledge assets. Looking at their behaviour and attitudes, we observed that researchers may develop a sense of property and jealousy over particular research topics, resulting in an overly-competitive public-research environment. On the whole, we showed that these informal institutions are affecting the exploitation of potential local synergies within the technological system under study. In addition, supported by the qualitative evidence presented, we claimed that these *informal institutions* and their influence on R&D collaboration and knowledge integration are underpinned to a large extent by

[162] From another point of view, given our argument that we understand a low degree of collaborative knowledge integration as an indication that opportunities for complementarity between actors in the system are remaining unexploited, the barrier to innovation is defined by previous studies as a 'network failure' (Carlsson & Jacobsson, 1997 cited by Woolthuis et al., 2005, p614).

formal institutions, particularly science and technology policies and incentives to public-sector scientists, to which we later turn our attention.

We examined public science and technology policies as *formal institutions* playing a salient role in shaping the interactive dynamics within our empirical setting. We focused on public research assessment policies and incentive mechanisms, particularly the National Researchers' Assessment System (SNI) which, as suggested by a previous study (Bernheim et al., 2012, pp12 and 15), rewards almost only publishing in international peer-reviewed journals, while it seems to discourage the relevance of research outcomes to *solving local societal and technological problems*. Consequently, we found that publishing, in itself, ends up being the main goal of several R&D groups, particularly in the academic system, regardless of the actual research trajectory or its potential contribution to local innovation processes.

As clear evidence of the influence exerted by this formal incentive mechanism, we showed that one of the main criteria followed by academic groups to decide their priorities and research questions is the difficulty of particular thematic fields in publishing the research outcomes in well-known peer-reviewed journals. Hence, these groups direct their research efforts mainly towards priority themes preferred by global disciplinary research communities, even when those priorities omit research problems supported by other local incentives promoting impact-oriented research and innovation. Accordingly, opportunities to collaborate with complementary research groups are sometimes seen as a distraction from the main research orientation and agenda that may affect the publishability of results or the time taken to publish. From a local perspective, these academic institutions and science incentive policies seems to result in a *'systemic failure'* in terms of having local scientists and R&D capabilities highly committed to a global research agenda but leaving local technological needs poorly addressed. Moreover, it can be argued that such technological needs can hardly be sorted out through other pathways, given the weak R&D capabilities of private actors and also their limited ability to hire people with advanced R&D skills. The results from our statistical analysis support these qualitative findings. Specifically, *the significance of the regression coefficient for the variable researchers assessment degree in our four knowledge integration dependent variables and the predicted* *marginal effects substantiate the conclusion that the greater the compliance of R&D groups with the local scientific incentive system mostly based on publishing in peer-reviewed journals, the weaker their ability to integrate complementary knowledge and skills distributed throughout the public research system* (Section 6.3.2). This weaker *integration ability* was particularly evident through our measure of the degree of integration of complementary or non-overlapping core scientific disciplines (*Avg disciplinary difference*).

We also noticed that the National Researchers' Assessment System (SNI) as well as other *formal incentives* and rewards to researchers established at the organisational and academic-programme level, push many individual scientists – particularly in the academic sector – to take a rather self-interested research approach, narrowly focusing on very specific disciplinary themes while becoming somewhat isolated from other local R&D groups[163]. Conversely, we observed an almost complete absence of formal mechanisms explicitly promoting teamwork, collaboration or more integrative research approaches. Our results consequently showed that the formal incentive structure in place leads to the persistence of an overly competitive academic environment encompassing scattered research efforts and an excessively broad thematic diversity throughout the system. This provides evidence of an *institutional failure* that may be widening the distance between complementary research communities, thus hindering the mobilisation of local knowledge capabilities into actual innovation processes. Opportunities for *collaborative knowledge integration* between complementary R&D groups and disciplinary communities are being left unexploited while R&D efforts to address local production problems are probably being undermined.

Finally, we illustrated that, while formal incentives placed mainly by the National Researchers' Assessment System endow individual research groups with legitimating stimuli to retain a narrow disciplinary focus, in an opposite direction, other local support mechanisms try to foster innovation-oriented research and to focus

[163] Bortagaray (2007) also observed this isolation of research efforts and fragmentation of goals in the Uruguayan agri-biotechnology system.

(apparently rather unsuccessfully) such R&D efforts on a limited number of priority areas. Previous scholarly evidence suggests that scientists face conflicting forces from formal institutional incentives that might affect inter-organisational interactions and the integration of complementary knowledge fields (Hessels et al., 2011, p555; Hessels & van Lente, 2011, p216; Llerena & Meyer-Krahmer, 2003),. Nevertheless, the influence of such conflicting forces in specific knowledge-fields has received little attention in science and technology studies. These previous studies have analysed either specific collaborative initiatives (Llerena & Meyer-Krahmer, 2003) or specific research fields within a nation (Hessels et al., 2011, p555; Hessels & van Lente, 2011, p216), employing case studies and survey methodologies but developing neither an assessment of the knowledge assets being integrated nor indicators of the extent of collaborative knowledge integration accomplished.

Our findings suggest that within the agri-biotechnology research sub-system, on balance, formal incentives mostly based on publication records may often exert a stronger influence hindering knowledge integration and collaborative endeavours intended to address locally relevant problems. While these conflicting forces have been reported in the previous qualitative studies referred to above (Hessels et al., 2011, p555; Hessels & van Lente, 2011, p216; Llerena & Meyer-Krahmer, 2003), we took a step forward by providing statistical evidence on the relation between formal scientific incentives and collaborative knowledge integration in our empirical setting and by assessing its influence at the level of the whole system..

Finally, we should stress that we were able to assess the relation between system-level institutions and the extent of collaborative knowledge integration on the basis of our combined conceptual and empirical approach that pulled together theories on innovation systems, inter-organisational collaboration and (interdisciplinary) knowledge integration. We argue that such combined empirical perspective develops truly relational approach that, while encompassing the whole technological system, explores interactions and integration of capabilities among actors at lower levels of aggregation. This represents an empirical contribution to the structural approaches predominantly used by innovation systems' scholars (Carlsson & Stankiewicz, 1991, p94; Carlsson et al., 2002, p236; Markard & Truffer, 2008; Arocena & Sutz, 2002).

7.3 Absorptive and relational capabilities

Having examined system-level institutions and incentives, we turned our attention to actor-level attributes. With regards to *relational capability*, we showed that researchers actually perceive collaborative knowledge integration as a practice or technique that R&D groups should develop through interactive learning processes. Moreover, we noticed that *building relational capability* and *interaction interfaces* is influenced by institutions already analysed such as researchers' motivations and formal incentives to collaborate. In general, the picture that emerged was of weak flexibility among public R&D groups to adjust their research agenda and usual research practices so as to deal with demands from other actors, resulting in potential synergies being left unexploited. This is likely to affect the innovation capacity of the whole system. For the statistical analysis, we measured *relational capability* through an indicator of partnering experience (the number of links with public R&D groups). This indicator showed a relatively large and positive predicted marginal effect on the ability of the R&D groups to collaboratively integrate knowledge from non-overlapping disciplinary fields. In other words, the greater the experience of an R&D group in conducting collaborative research activities, the larger the degree of integration of complementary disciplinary knowledge it achieves through such collaborations, and hence the greater its contribution to knowledge spillovers throughout the whole technological research sub-system.

Conversely, our statistical analysis of *absorptive capacity* (measured in terms of the number of scientists with a masters or PhD degree affiliated to the group), showed that this indicator is not clearly associated with the ability of *public-sector research groups* to collaboratively integrate complementary knowledge assets, and consequently neither with the exploitation of potential synergies throughout the agri-biotechnology research system. Scholarly research on inter-organisational collaboration has showed a positive relation between *absorptive capacity* and the establishment of collaborative R&D partnerships in absolute terms (Rothwell & Dodgson, 1991; Tsai, 2001; Fontana et al., 2006; Giuliani & Arza, 2009). Some authors suggest that the larger the absorptive capacity of an organisation, the more able it is to deal with the transactions costs involved in undertaking R&D partnerships (Colombo et al., 2006). Nevertheless, these studies have left unexplored how *absorptive capacity* influences the type of knowledge or technological capabilities accessed and integrated through the actor's collaborative linkages (Colombo et al., 2006). We have addressed this gap in our quantitative analysis. In our empirical setting, no clear relations between absorptive capacity and the extent of collaborative knowledge integration was found. Hence, while an R&D group with greater absorptive capacity may have greater ability to manage the transaction costs involved in collaborating with others, this attribute is not directly associated with: the type of partners selected by that group; the type of capabilities accessed from the partners; and as a result with the degree of complementarity and knowledge integration achieved through collaborations. As we discussed in Chapter 5 (section 5.4.2) and in section 7.2 above, system-level formal and informal institutions seem to be placing the strongest influence on how R&D groups select their partners and hence on their ability to access and complementary knowledge assets and capabilities. The relation between these two variables undoubtedly deserves a deeper understanding through further research efforts.

In sum, we explored how organisational-level attributes such as absorptive- and relational-capability shape the extent of knowledge integration accomplished by an actor through its collaborative R&D efforts. By doing this, we contribute to previous research on inter-organisational collaboration which has been focused mainly on whether these capabilities allow an organisation to form new collaborations but has left unexplored if they also foster an increased quality of those collaborations in terms of the extent to which the partners provide access to distant complementary knowledge assets (Gulati, 1995; Ahuja, 2000; Dyer & Singh, 1998). In addition, our assessment of the degree of complementarity among partners' knowledge assets and R&D capabilities goes beyond the well-established concept of complementary assets proposed by Teece (1986); the latter is based on highly aggregated categories of organisational assets (e.g. R&D vs. commercial assets) that have shown no explanatory power for exploratory R&D partnerships, the subject of our research (Colombo et al., 2006, p1167; Luo et al., 2009; Teece, 1986, p286).

7.4 The role of students

Closing our analysis of driving forces, evidence from the interviews revealed that the involvement of postgraduate students in R&D groups clearly fuels the dynamics of collaboration and knowledge integration that the groups achieve. We noticed that postgraduate research students actively pursue and gain access to capabilities and skills from external actors, hence often performing a valuable role as bridges or intermediaries between their host group and complementary knowledge assets existing in the system. While undergoing internships or periods of short training in external actors, they actually transfer, exchange and reproduce knowledge and skills across organisational boundaries. The evidence suggests that this student-embodied bridging mechanism is overcoming some of the barriers for the realisation of potential synergies among local actors that were not previously being exploited. Consequently, our quantitative work analysed the relation between the number of students involved in a research group's R&D activities and the extent of collaborative knowledge integration that the group achieves. Despite the fact that regression coefficients for the variable *student number* were not statistically significant (possibly due to our small sample size), taking a descriptive stance, the estimated effect of adding one student to an R&D group activity on the extent to which the group accesses and integrates non-overlapping complementary scientific disciplines through its collaborative efforts ranged from virtually nil up to almost a 20% increase. This is highly consistent with our qualitative findings. Hence, our aggregate qualitative and quantitative results provide a fairly solid foundation to the claim that the involvement of students in R&D groups confers a more flexible and effective ability to collaboratively integrate knowledge and skills from complementary scientific disciplines, thereby fostering greater cohesion and knowledge spillovers throughout the whole technological system under study.

7.5 Policy implications

Extant research reviewed in Chapter 2 made clear the central role that *public policies* should play in underpinning a country's ability to exploit the potential benefits offered by the knowledge-bases existing in the public research sub-system. Moreover, it was suggested that the integration of complementary knowledge through inter-organisational collaborations is a major determinant of the absorptive capacity of a developing-county's innovation system; namely its ability to absorb and exploit external technological opportunities, and to translate them into enhanced economic development. Consequently, our investigation of the most relevant factors shaping the collaborative integration of local sources of knowledge was expected to provide useful suggestions for policy-making efforts intended to raise the system-level absorptive capacity.

The overly-competitive public-research environment, the narrow focus of individual researchers on very specific disciplinary themes, their isolation from other local R&D groups, and the excessively broad thematic diversity observed throughout the system are particularly alarming in a country and technological system where more than 80 % of the R&D capabilities are located in the public-sector. We claimed that this scattered pattern of R&D activities is clearly rooted in the local structure of formal incentives for the scientific community. Indeed, we noticed an almost complete absence of formal mechanisms explicitly promoting teamwork, collaboration or more integrative research approaches. The innovation potential of the whole local agri-biotechnology system could be significantly enhanced if such institutional barriers to the mobilisation and inter-group integration of knowledge were overcome.

The solid statistical evidence revealing the negative association between the compliance of R&D groups with the national researchers assessment system (SNI) and the extent of collaborative knowledge integration they achieve, suggests that complementary formal incentives should be developed. These new scientific reward mechanisms should significantly change the incentive structure. It should be moved beyond the almost single focus on the absolute number of publications in peer-reviewed journals presently in force, into a multi-criteria system where research efforts that pursue more integrative approaches or that explicitly pursue the solution to local technological problems are also taken into account in the final reward granted to public-sector scientists. A new scientific reward system should transform collaboration among R&D groups or organisations and the integrations of complementary knowledge from diverse knowledge fields into a source of reputation and reward for the scientific community. For example, the National Researchers' Assessment System (SNI) could assess not only the absolute count of peer-reviewed papers, but also bibliometric indicators of knowledge integration and interdisciplinarity measured on research outcomes. This sort of indicators has been well developed by scholars that study interdisciplinary research process, as was presented in section 2.6. Competitive funding of R&D projects, such as those instruments described in section 4.3, could also be reformulated. The criteria of these instruments to assess R&D project proposals could explicitly grant higher merit to proposals presented by multiple R&D groups or organisations as well as to indicators of the degree of complementarity among the prospective partners that present the project proposal.

We claim that such a balanced incentive system would shift the choice of research agenda by scientists from the present excessive emphasis on topics more likely to be publishable in peer-reviewed journals, towards a broader set of motivations that, besides the publishability of the research outcomes, could also encompass: the expected contribution to the solution of local technological problems (local pertinence); the collaborative character of the research activity; and the extent to which diverse disciplinary backgrounds and/or complementary knowledge assets are integrated in a joint research activity or outcome.

Our statistical analysis showed that *absorptive capacity* is not clearly associated with the ability of public-sector research groups to collaboratively integrate complementary knowledge assets. This finding may lead us to presume that policies intended to provide greater investments in absorptive capacity in the public research sector would not ensure an extensive exploitation of the actual potential benefits from such investment throughout the whole agri-biotechnology research system. Policies to raise absorptive capacity would need to be accompanied with supplementary formal policies and incentives promoting the collaborative realisation of complementarities and synergies among actors if a greater exploitation of the potential benefits offered by such increased R&D capabilities is to be achieved.

Our qualitative findings showed that formal institutional support to inter-organisational collaboration, teamwork or more integrative research approaches are rather scarce at the level of both individual organisations and the whole research system. Conversely, informal and formal institutions tend to encourage scientists to pursue rather self-interested and isolated research activities weakly linked with other local scientists and R&D groups. We should contrast this with the statistical evidence that the accumulation of *relational capability* by R&D groups is significantly associated with achieving a broader integration of complementary disciplinary knowledge through the group's research collaborations. This finding suggests that formal incentives to scientists and research funding mechanisms should more clearly value and promote the collaborative character of research. Such incentives would enhance the collaborative experience of R&D groups, and consequently increase the collaborative integration of complementary disciplines and hence the level of knowledge-spillovers throughout the whole technological research sub-system.

Finally, sound empirical evidence suggests that the involvement of students in R&D groups brings with it a more flexible and effective ability to collaboratively integrate knowledge and skills from complementary scientific disciplines. Therefore, one policy-making implication is that specific *programmes supporting postgraduate training* should be foreseen, planned, implemented and evaluated not only as a human-capital building instrument but also as a mechanism supporting interactions between distributed national research capabilities, thereby fostering the overall cohesion and knowledge flows throughout the whole emergent technological innovation system. Scholarship programmes could explicitly promote the mobility of students among local public research groups and private actors hence fostering the positive influence of students on the establishment of synergistic collaborative linkages and the overall dynamics of collaborative knowledge integration found in our study.

7.6 Generalisation of results and limitations of the study

We have examined collaborative knowledge integration within an emergent technological field (biotechnology) since, in such contexts, the scientific knowledge base is complex and distributed among diverse actors, and hence inter-organisational collaboration is a prevalent way through which organisations access complementary sources of knowledge and research technologies. The dynamics of biotechnology R&D vary depending on the sector of application; therefore our study was bounded within the intersection of biotechnology innovation and the agriculture sector. We also set empirical boundaries around a single middle-income developing country, namely Uruguay, since the need to access knowledge across organisational boundaries is greater in developing than developed nations (Lundvall et al., 2002). Moreover, we narrowed our analysis to the public research sub-system since it is the location of most R&D investments in the context of developing countries[164].

Taking into account the boundaries of our empirical study, we might be tempted to suggest that our findings on the drivers and barriers of collaborative-knowledge integration could be generalised to other similar contexts, namely collaborations among public-sector organisations within emergent technological research sub-systems in small and middle-income developing countries, where most R&D activities and investments are to be found in the public sector. One limit to such a potential generalisation may be whether there are formal incentives for scientists and public research assessments that are mostly based on the record of publications in peer-reviewed journals. Nevertheless, evidence for previous studies indicates that we must be very cautious in pursuing the potential generalisability suggested above.

First, scholars that have studied innovation systems in developing countries have claimed that such studies should not pursue the development of general theories and that it is not acceptable to generalise results from a single system to other systems (Lundvall et al., 2009b). In addition, the dynamics of biotechnology innovation have been claimed to depend on the sector of application (Senker & Van Zwanenberg, 2001); Malerba, 2005); hence caution is needed when it comes to the generalisation of our results to biotechnology research systems other than those oriented to agricultural applications. Moreover, recent studies (Hessels & van Lente, 2011); Hessels et al., 2011) of institutional changes in public research have shown that the influence of formal institutional incentives on the research orientation and practices of scientists varies across research fields. This provides another note of caution against proposing a

[164] Public-sector share in the national R&D investments in Uruguay is 67 % (DICYT, 2010)

broad generalisation of our results obtained from agri-biotechnology to emergent systems based around other technological fields.

In addition to the above-mentioned limits to generalisation, which result from the country, sector and technological boundaries of the empirical study, other restrictions should be portrayed. The particular focus of the assessment of knowledge integration on the public research sub-system does not capture the integration and collaborative exploitation of complementary resources throughout the whole technological innovation system under study. This prevents achieving a more wide-ranging understanding of the patterns of inter-organisational collaboration and the realisation of potential synergies in the entire system.

Another limitation results from the central argument that underpinned this research, namely that the larger the extent of collaborative knowledge integration accomplished, the larger the technological and innovation outcomes expected from both individual organisations (Hage & Hollingsworth, 2000; Rosenkopf & Nerkar, 2001; Nooteboom et al., 2007) and the technological system as a whole (Carlsson & Stankiewicz, 1991; Lall, 1992; Cimoli et al., 2009). On that basis, the present study assessed the influence of a number of factors on the extent of collaborative knowledge integration achieved by public R&D groups, but has left unexplored the impact of the realisation of complementarities on the actual outcomes of individual organisations or the entire system in terms of technological, innovation and economic advancement.

The empirical methodology offers additional limitations. The quantitative approach to study collaboration, knowledge integration and its driving forces is cross-sectional. Cross-sectional studies do not allow identifying and assessing causality relations between the variables assessed. Therefore, the quantitative results presented in Chapter 6 are not statistical proof of the existence of causality relations. Nevertheless, previous research discussed in Chapter 2 and the qualitative findings presented in Chapter 5, provide well-grounded support to presume that the statistical results presented in Chapter 6 reflect an actual influence of the driving forces analysed and the extent of collaborative knowledge integration achieved by public R&D groups.

Finally, the indicators of collaborative knowledge integration, in particular, the measure of *difference* between collaborating R&D groups developed for this study (Section 6.2.5), implicitly assumes that all complementary, non-overlapping knowledge assets held by each partner are put into work during the collaborative effort, and hence that their synergistic potential is realised. Despite the study proposing this indicator as a fine-grained approximation to the actual extent of knowledge complementarity exploited, a more precise measure could be obtained through a data-gathering approach able to identify which complementary knowledge assets were contributed by each R&D group and actually used during the collaborative R&D project.

7.7 Opportunities for future research

This thesis bridged previous contributions from scholarly studies of innovation systems, inter-organisational collaboration and networks, and interdisciplinary knowledge integration into a conceptual and empirical approach to assess the forces affecting collaboration and knowledge integration in emergent technological systems. This approach, along with the novel indicators designed to measure the extent of knowledge integration between partners, represents a methodological contribution that has its own value and grants ample opportunities for future studies in other empirical contexts. Given the limitations for generalisation referred to in Section 7.6, the application of this approach in other countries, technological fields or sectors would provide a wider understanding of how and why the drivers and barriers of collaborative knowledge integration may vary across such differing contexts. As a result, more robust lessons for policy-making towards supporting the development of emergent technological innovation systems in diverse settings might be generated. For example, in contexts where the mobility of scientists is greater than those observed in Uruguay, the bridging role of postgraduate students and its impact on knowledge integration might be less significant than the influence observed in this study.

This study has also made empirical contributions of value for future research. In particular, the aggregated database of R&D projects publicly funded in Uruguay built for this study (Section 6.2.8) represents an original and valuable resource for further studies. It may well allow a comprehensive identification of R&D activities, the relevant involved actors and leading researchers, required to conduct similar studies for other technological fields and economic sectors in Uruguay.

While keeping a look at the whole agri-biotechnology innovation system, the assessment of the extent of complementarity between partners performed in this study was narrowed down to the public research sub-system. This relational approach was aimed at understanding the factors influencing the exploitation of local potential synergies and hence the collaborative building of system-level innovation capacity. To pursue this aim a step forward, future studies should encompass additional components of the technological system, particularly private actors involved in the production, commercialisation or use of agri-biotechnologies as well as intermediary or bridging organisations (see Figure 4.1, Section 4.3). The empirical implementation of this broader scope will require developing more complex wide-ranging assets' classification-systems which should be able to identify the skills and capabilities possessed by every actor to be assessed. In compliance with this broader scope, besides public scientific incentive policies, closer attention would need to be paid to other types of institutions supporting the exploitation of potential synergies such as research funding programmes, policies supporting the transfer of knowledge generated by the public research sector (Salter & Martin, 2001) and complementary inter-organisational interactions (Llerena & Meyer-Krahmer, 2003; Cimoli et al., 2009), and collaborative scholarship and training programmes (Lam, 2005).

7.8 Main findings and contributions

The central contributions from our study probably lie in our singular conceptual and empirical approach that merged three fields of scholarly research, namely studies of: (i) innovation systems; (ii) inter-organisational collaborations; and (iii) interdisciplinary research and knowledge integration. We discussed in Chapter 2 the criticism of *innovation system studies* for their continued static focus on structural attributes of the system and its components while the interactive processes resulting from relationships among actors and the quality of such linkages have usually been overlooked. The intended focus on the interactive dynamics and relational attributes of the innovation processes has been only partially explored by innovation systems' research, which is generally unable to capture the complexity of actors and linkages at lower levels of aggregation. Although we did not look at the whole innovation system[165], our research contributes to this body of scholarly research through the definition of a lower level of analysis (the public R&D group) while keeping the scope and boundaries of the whole *technological innovation system*, and by assessing how micro-level linkages between actors actually contribute to fuller exploitation of the knowledge base spread throughout the system.

Previous studies of the public research sub-system have already suggested that research evaluations based on bibliometric indicators and mechanisms supporting application-oriented research expose public-sector scientists to *conflicting institutional incentives* (Hessels et al., 2011, p555; Hessels & van Lente, 2011, p216; Llerena & Meyer-Krahmer, 2003). We found similar conflicting incentives confronting public-sector scientists and took a step forward with our systematic quantitative approach. We contribute to this scholarly research area with robust evidence of a clear negative relation between the compliance of R&D groups with the local scientists' assessment system and the extent to which the group collaboratively integrates complementary knowledge assets. These statistical results allow us to claim that formal incentives set up by the national researchers' assessment system (based mostly on academic-publishing records) clearly undermine the realisation of complementarities among public research groups, hence presumably affecting the overall system-level research and innovation capabilities.

We claimed in Chapter 2 that studies of inter-organisational collaboration have paid scant attention to the actual integration of knowledge assets between the collaborating actors. Previous studies have suggested the need for fine-grained methodological approaches for the identification of the knowledge assets and skills

[165] We focused on two key components of an innovation system: the public research sub-system and formal and informal institutions (Figure 4.1).

controlled by collaborating organisations (Colombo et al., 2006). We would contend that the methodological approach detailed in Chapter 6 has addressed this gap, and allowed a generation of reliable indicators to measure the extent of knowledge integration achieved by the collaborating R&D groups. From their side, studies of interdisciplinary research and knowledge integration have acknowledged that most studies assess knowledge integration at the level of *research outcomes* (scientific papers or patents), arguing the need for assessments at the level of the *research activity*, which is the actual 'space' where knowledge integration processes take place (Wagner et al., 2011). Scholars from this research vein also argued that further studies were needed on the drivers of knowledge integration during scientific research activities (Wagner et al., 2011). We address these gaps to some extent by providing a systematic empirical approach for the assessment of knowledge integration between research groups at the level of *collaborative R&D projects*, as well as through the illuminating empirical evidence presented in Chapters 5 and 6 on the most salient forces shaping the extent of collaborative knowledge integration achieved by public agri-biotechnology R&D groups.

Finally, a valuable contribution relates to the role of individuals in fostering collaborative knowledge integration. Previous studies have shown that the mobility of skilled workers (Almeida & Kogut, 1999) and the role of individual linked-scientists (Lam, 2005) are major drivers of inter-organisational knowledge-transfer and the access to external R&D resources. Our empirical results showed that the number of highly trained researchers in an R&D group (our indicator of absorptive capacity) is not associated with the extent of collaborative knowledge integration achieved by the group. This may be the result of the poor mobility record of public-sector researchers in Uruguay that has been reported by previous studies. On the other hand, we found consistent qualitative and quantitative evidence that the involvement of students enhances the ability of R&D groups to access and integrate knowledge and skills from complementary disciplinary fields. Therefore, within the empirical boundaries of our study, students play a particularly relevant bridging role, fostering the overall cohesion and knowledge spillovers throughout the whole agri-biotechnology research sub-system.

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8 - Appendices

Appendix 8.1: Guidelinesfor exploratory interviews

(A) Protocol for scientists or other representatives of public research organisations (version in Spanish that was actually used)

Protocolo de Entrevistas

Nombre:

Fecha de entrevista:

Encuadramiento funcional:

Laboratorio:

Sección:

Departamento:

Institución:

Fecha de ingreso:

Cantidad de investigadores integrantes del grupo:

Nombres:

Introducción

i) ¿Me podés contar brevemente sobre tu formación superior y sobre cómo llegaste a la investigación y desarrollo en el área de biotecnología?

ii) ¿Cuáles son las principales áreas de investigación que lleva a cabo el [***GRUPO DE I+D***]?

iii) ¿Cuáles son las principales necesidades o limitantes que enfrenta la biotecnología en Uruguay para lograr progreso científico y cambio tecnológico?

iv) ¿Mirando en el mediano plazo, hacia qué grandes objetivos debe orientarse el ***[GRUPO DE I+D]***? … o sea, ¿en qué deberían concentrarse los recursos?

v) ¿Qué aspectos pueden afectar o han impedido el logro de esos objetivos? ¿y cuáles lo facilitan o promueven?

vi) ¿qué capacidades o técnicas de el ***[GRUPO DE I+D]*** podrían aplicarse o complementar acciones de investigación de otros grupos de investigación o empresas nacionales?

vii) ¿Qué objetivos persigue el ***Grupo*** cuando forma acuerdos de investigación colaborativa con terceros? -

Preguntas generales

viii) En tu actividad de investigación, ¿cuáles son los principales problemas científicos o técnicos que tenés que enfrentar?

¿Qué estrategias usas para solucionarlos?

¿Qué rol juega la cooperación inter-institucional en investigación & desarrollo en la solución de los problemas que identificaste?

ix) ¿mantienes contacto con ex-colegas de tus empleos previos?

Políticas y regulaciones pertinentes

x) ¿Qué lineamientos y mecanismos de evaluación y gestión operativa de tu institución incentivan al investigador a desarrollar arreglos inter-institucionales para investigación colaborativa?

xi) ¿y cuáles lo pueden desestimular de hacerlo?

xii) ¿Qué políticas nacionales de ciencia, tecnología e innovación pensás que han influido en el desarrollo de arreglos inter-institucionales para investigación y desarrollo colaborativo en biotecnología?

xiii) También con relación a las políticas de apoyo a la innovación: ¿cómo pensás que las normativas de propiedad intelectual influyen en el desarrollo de arreglos de colaboración en investigación?

xiv) ¿Cómo valoras la disponibilidad de fondos para financiar la investigación y el nivel de competencia por ellos?

xv) ¿Cómo interviene esta disponibilidad de recursos financieros a la hora de decidir entre llevar a cabo una investigación internamente en tu institución, o en colaboración con grupos externos?

Arreglos de investigación colaborativa

xvi) ¿De qué manera llevas a cabo la **búsqueda** e **identificación** de **capacidades complementarias,** o sea de **oportunidades** disponibles para el establecimiento de vínculos de investigación colaborativa?

xvii) ¿Cómo influyen las estancias de investigación por ***estudiantes de grado o postgrado***, en la formación de vínculos de colaboración con otras instituciones?

Actitudes hacia el intercambio de conocimientos y el cambio

xviii) Dejando de lado el ámbito organizacional; desde tu **punto de vista personal** como investigador:

a. ¿Qué dificultades implica el intercambio de conocimiento y trabajo con colegas de terceras instituciones o grupos?

b. En una investigación colaborativa: ¿percibís algún **riesgo** resultado del intercambio de conocimientos con otras organizaciones?

Ahora repasando antecedentes de colaboraciones interinstitucionales:

xix) Un ejemplo de investigación colaborativa que haya resultado bien:…

¿Por qué fue así?

xx) Un ejemplo que valores de forma negativa:…

¿Por qué lo fue?

xxi) En los últimos cinco años, ¿con qué organizaciones han realizado esfuerzos conjuntos de investigación? Te pido nombrar las cinco más importantes y en qué áreas fue dicha colaboración

Mirando ahora al ***Sistema de Innovación en Biotecnología***, o sea, al conjunto de actores en torno a la biotecnología nacional: ***Gobernanza institucional y mecanismos de 'ampliación de fronteras' organizacionales***

xxii) ¿Existen plataformas, programas u otros mecanismos de alcance nacional que faciliten y promuevan la interacción y comunicación entre instituciones o grupos?

xxiii) ¿Está tu ***grupo*** involucrado en alguno de estos mecanismos de gobernanza institucional que promueven el desarrollo de la colaboración?: *¿Cuáles?*]

xxiv) Estas plataformas y mecanismos de gobernanza: ¿hacen posible la **identificación** y el **acceso** a fuentes externas de conocimiento y capacidades o la identificación de demandas de investigación?

xxv) ¿Cómo podrían mejorarse estos mecanismos?

Capacidades de los actores *(capacidad de absorción y relacional)*

xxvi) Al acceder a conocimientos y capacidades brindadas por potenciales socios: ¿se enfrentan dificultades para ponerlos en uso en la institución?

xxvii) ¿Qué inconvenientes presenta la administración y gestión operativa de alianzas para investigación colaborativa?

(B) Protocol for scientists or other representatives of public research organisations
(Translation of the Spanish version into English)

Interview Guidelines (public R&D groups)

Name:

Date:

Group's position within the Organisations' structure:

Laboratory:

Section / Division:

Department:

Organisation:

Date when joined the Organisation:

Number of researchers working in the group:

Names:

Introduction

i) Could you tell me briefly about your studies and how you ended doing biotechnology research and development?

ii) Which are the main research lines conducted by the **[*GROUP*]**?

iii) Which are the main needs or limitations for scientific progress and technological change in biotechnology within Uruguay?

iv) With a mid-term view, on which central objectives should the **[*GROUP*]** focus its research efforts and resources?

v) What have affected or may affect in the future the achievement of such objectives? And what factors support their achievement?

vi) Which capabilities or research techniques available in the **[*GROUP*]** could complement or used in research activities of other national R&D groups or biotechnology firms?

vii) What are the goals of the **[*GROUP*]** when it establishes collaborative research partnerships with other parties?

General questions

viii) In your research activity; which are the main scientific or technical problems that you should cope with?

What strategies do you use to sort them out?

What is the role of inter-organisational R&D collaboration in sorting out the problems you identified?

ix) ¿Do you keep in touch with former colleagues from organisations you have worked for in the past?

Relevant policies and regulations

x) Which directions, assessment mechanisms, and operational management capabilities of your organisation may encourage researchers to establish inter-organisational R&D collaborations?

xi) And which may hinder them?

xii) Which national science, technology and innovation policies do you think that have influenced the development of inter-organisational collaborations for biotechnology R&D?

xiii) How do intellectual property regulations influence these collaborative efforts?

xiv) What do you think about the availability of R&D funds and the degree of competition for getting access to them?

xv) How does the availability of R&D funds influence your choice between conducting a research activity internally in your group and doing it in collaboration with external actors?

Collaborative R&D arrangements

xvi) How do you search for complementary capabilities and available opportunities for the establishment of R&D partnerships?

xvii) How does the involvement of graduate or postgraduate students in the **[*GROUP*]** influence the establishment of R&D collaborations?

Attitudes towards knowledge sharing and change

xviii) Now, beyond the organisational setting; from your personal point of view as a researcher:

a. What difficulties are faced during the collaborative work and knowledge exchange with colleagues from external R&D groups or organisations?

b. In a collaborative research activity: Do you envisage some sort of risk in sharing knowledge with other organisations?

Previous collaborations

xix) Could you tell me an example of successful collaborative research? Why did it succeed?

xx) And an example of failure? Why did it fail?

xxi) During the last five years: Which organizations the **[*GROUP*]** has collaborated with? Please mention the most important ones (5) and the respective themes of collaboration.

Institutional governance and boundary-spanning mechanisms within the biotechnology innovation system in Uruguay

xxii) Are there any institutional mechanisms or national platforms that you think facilitate the interaction and communication among groups or organisations?

xxiii) Is your group involved in any of these institutional governance structures that support the development of collaboration? If YES: Which ones?

xxiv) Do these mechanisms help your organisation in the identification and access to external sources of knowledge and capabilities or in the identification of research demands?

xxv) How these mechanisms could be improved?

Actors' capabilities *(absorptive and relational capability)*

xxvi) Does your organisation face any sort of difficulties in acquiring and putting into use the knowledge provided by potential partners?

xxvii) How does your organisation cope with the administrative and managerial issues involved in the implementation of collaborative R&D partnerships?

(C) Protocol for representatives of private organisations
(Version in Spanish that was actually used)

Protocolo de Entrevistas a Empresas

Nombre:

Fecha de entrevista:

Encuadramiento funcional:

Repartición Nivel 3:

Repartición Nivel 2:

Repartición Nivel 1:

Empresa:

Año de fundación de la empresa:

Socios integrantes:

Cambios relevantes en la estructura de socios o propiedad:

Nº de empleados:

Personal técnico / profesional (Nº):

Fecha de ingreso a la empresa:

Técnicos involucrados en investigación y desarrollo tecnológico - Nombres:

Introducción

i) ¿Cuáles son los principales rubros y **productos** de la empresa? ¿los **clientes**? ¿principales **insumos y proveedores**?

ii) ¿Me podés contar brevemente sobre tu carrera y cómo llegas a involucrarte en el desarrollo biotecnológico?

iii) ¿Desarrolla, la empresa **actividades de investigación** y desarrollo tecnológico? – ya sea internamente o en colaboración con terceros –.

En tal caso: ¿cuáles son las principales **áreas de investigación** y desarrollo tecnológico que lleva a cabo la ***empresa***?

iv) ¿En que otras áreas ha innovado la empresa? **[equipamiento, procesos, gestión, capacitación]**

v) ¿Cuáles crees que son las principales **necesidades o limitantes** que enfrenta el desarrollo biotecnológico en Uruguay?

vi) ¿Mirando en el mediano plazo, hacia qué **grandes objetivos** debe orientarse la ***empresa***? … o sea, ¿en qué deberían concentrarse los recursos?

vii) ¿Qué aspectos pueden afectar o han impedido el logro de esos objetivos? ¿y cuáles lo facilitan o promueven?

viii) ¿Qué motivación u **objetivos** persigue la ***empresa*** cuando establece acuerdos de **investigación colaborativa** con terceros?

ix) Si quisiera **clasificar** las capacidades de I+D que requiere la empresa; ¿de forma general cuáles están **disponibles internamente** y a cuales tiene que **acceder externamente** en otras organizaciones?

Preguntas generales

x) En las actividades de producción o de desarrollo de nuevos productos, ¿cuáles son los principales **problemas técnicos** que la empresa tiene que enfrentar?

¿Qué estrategias usan para solucionarlos?

xi) ¿A qué fuentes de información, conocimiento y capacidades recurren para la solución de estos problemas o para la identificación de oportunidades tecnológicas?

xii) ¿Qué rol juega la cooperación inter-organizacional en investigación & desarrollo en la solución de los problemas que identificaste?

Políticas y regulaciones pertinentes

xiii) ¿Qué políticas nacionales de ciencia, tecnología e innovación pensás que han promovido el desarrollo de arreglos inter-institucionales para investigación y desarrollo colaborativo en biotecnología?

xiv) ¿y cuáles pueden desestimular a la empresa de involucrarse en este tipo de arreglos de colaboración?

xv) ¿Disponen de información sobre incentivos fiscales a la inversión en investigación? ¿Han hecho uso de estos incentivos?

xvi) También con relación a las políticas de apoyo a la innovación: ¿cómo pensás que las normativas de propiedad intelectual influyen en el desarrollo de arreglos de colaboración en investigación?

xvii) ¿Cómo valoras la disponibilidad de fondos para financiar la investigación y el nivel de competencia por ellos? ¿Qué proporción representan de los gastos en investigación de la empresa?

Arreglos de investigación colaborativa

xviii) ¿De qué manera llevan a cabo la **búsqueda** e **identificación** de **capacidades complementarias,** o sea de **oportunidades** disponibles para el establecimiento de vínculos de investigación colaborativa?

xix) ¿Han tenido estancias de ***estudiantes de grado o postgrado*** en la empresa? ¿Cómo influyen en la formación de vínculos de colaboración con otras instituciones?

Actitudes hacia el intercambio de conocimientos y el cambio

xx) ¿De qué manera se lleva a cabo y qué **dificultades** implica el intercambio de conocimiento y trabajo con colegas de instituciones públicas o de otras empresas?

xxi) En una investigación colaborativa: ¿perciben algún **riesgo** resultado del intercambio de conocimientos con otras organizaciones?

Ahora repasando antecedentes de colaboraciones interinstitucionales:

xxii) Un ejemplo de investigación colaborativa que haya resultado bien:…
¿Por qué fue así?

xxiii) Un ejemplo que valores de forma negativa:…
¿Por qué lo fue?

xxiv) Un ejemplo de trabajo colaborativo que nunca se concretó:….
¿Por qué no se logró llevar a cabo?

xxv) En los últimos cinco años, ¿con qué organizaciones públicas o privadas han realizado esfuerzos conjuntos de investigación? Te pido nombrar las cinco más importantes y en qué áreas y con qué objetivos fue dicha colaboración

Mirando ahora al ***Sistema de Innovación en Biotecnología***, o sea, al conjunto de actores en torno a la biotecnología nacional: ***Gobernanza institucional y mecanismos de 'ampliación de fronteras' organizacionales***

xxvi) ¿Existen plataformas, programas u otros mecanismos de alcance nacional que faciliten y promuevan la interacción y comunicación entre instituciones o grupos?

xxvii) ¿Está tu ***empresa*** involucrada en alguno de estos mecanismos de gobernanza institucional que promueven el desarrollo de la colaboración?

[Si la respuesta es afirmativa: *¿Cuáles?*]

xxviii) Estas plataformas y mecanismos de gobernanza: ¿hacen posible la **identificación** y el **acceso** a fuentes externas de conocimiento y capacidades?

xxix) ¿Cómo podrían mejorarse estos mecanismos?

Capacidades de los actores *(capacidad de absorción y relacional)*

xxx) Al acceder a conocimientos y capacidades brindadas por potenciales socios: ¿se enfrentan dificultades para ponerlos en uso en la empresa?

xxxi) ¿Qué inconvenientes presenta la administración y gestión operativa de alianzas para investigación colaborativa?

(D) Protocol for representatives of private organisations
(Translation into English)

Interview Guidelines (biotech firms)

Name:

Date:

Interviewee's position within the firm's structure:

Level 3:

Level 2:

Level 1:

Firm:

When the firm was created (year)?

Owners:

Relevant changes in the firm's ownership or property:

No. of employees:

Personnel with bachelor degree (no.):

Date when joined the firm:

Personnel involved in research and development (names):

Introduction

i) Which are the main product lines of the firm? Who are the clients? Which are the main inputs and suppliers?

ii) Could you tell me briefly about your career and how you ended in the biotechnology sector?

iii) Does the firm conduct R&D activities? – either internally or in collaboration with third parties –.

If so: Which are the main areas of research and technology development conducted by ***the firm***?

iv) In which other areas has ***the firm*** innovated?

v) Which are the main needs or limitations for biotechnology development in Uruguay?

vi) With a mid-term view, on which central objectives should ***the firm*** be focused?

vii) What have affected or may affect in the future the achievement of such objectives? And what factors support their achievement?

viii) What are the goals of the firm when it establishes collaborative research partnerships with other parties?

ix) With regard to the R&D capabilities required by the firm: Which of them are internally available and which the firm should access from external actors?

General questions

x) For the production and new product development activities; which are the main technical problems that ***the firm*** should cope with?

What strategies does ***the firm*** use to sort them out?

xi) Which are the sources of information, knowledge and capabilities that the firm uses for the solution of the problems identified or for the identification of technological opportunities?

xii) What is the role of inter-organisational R&D collaboration in sorting out the problems you identified?

Relevant policies and regulations

xiii) Which national science, technology and innovation policies do you think that have influenced the development of inter-organisational collaborations for biotechnology R&D?

xiv) And which ones may hinder the firm from getting involved in this type of collaborative arrangements?

xv) Do you have information about tax benefits promoting private investment in research? Did the firm use or get access to such benefits?

xvi) How do intellectual property regulations influence the formation of collaborative R&D partnerships?

xvii) What do you think about the availability of public R&D funds and the degree of competition for getting access to them? How much these competitive funds contribute to the firm's R&D investments?

Collaborative R&D arrangements

xviii) How do you search for complementary capabilities and available opportunities for the establishment of R&D partnerships?

xix) Does the firm receive graduate or postgraduate students to perform research internships? How does the involvement of students in the firm influence the establishment of R&D collaborations?

Attitudes towards knowledge sharing and change

xx) How does the firm conduct collaborative work and knowledge exchange with colleagues from public R&D groups or other firms? And which difficulties the may firm face?

xxi) In a collaborative research activity: Do you envisage some sort of risk in sharing knowledge with other organisations?

Previous collaborations

xxii) Could you tell me an example of successful collaborative research? Why did it succeed?

xxiii) And an example of failure? Why did it fail?

xxiv) An example of collaborative work that never materialises:.....
Why that collaboration could not be implemented?

xxv) During the last five years: Which public or private organizations the firm has collaborated with? Please mention the most important ones (5) and the respective themes and goals of the collaboration.

Institutional governance and boundary-spanning mechanisms within the biotechnology innovation system in Uruguay

xxvi) Are there any institutional mechanisms or national platforms that you think facilitate the interaction and communication among public R&D groups or organisations?

xxvii) Is your firm involved in any of these institutional governance structures that support the development of collaboration? If YES: Which ones?

xxviii) Do these mechanisms help your firm in the identification and access to external sources of knowledge and capabilities?

xxix) How these mechanisms could be improved?

Actors' capabilities *(absorptive and relational capability)*

xxx) Does your firm face any sort of difficulties in acquiring and putting into use the knowledge provided by potential partners?

xxxi) How does your firm cope with the administrative and managerial issues involved in the implementation of collaborative R&D partnerships?

Appendix 8.2: Complete record of public R&D groups identified within the biotechnology innovation system in Uruguay

Organisation (acronym)	Department / Division	R&D group or Lab
Agronomy School, UdelaR, UdelaR (FA)	Dpto. de Biología Vegetal	Botánica
	Dpto. de Biología Vegetal	Lab. de Bioquímica, GD de Bioquímica y Fisiología Vegetal
	Dpto. de Biología Vegetal	Lab. de Biotecnología, GD de Biotecnología y Microbiología
	Dpto. de Biología Vegetal	Lab. de Fitotecnia y Recursos Fitogenéticos, GD de Botánica y Recursos Fitogenéticos
	Dpto. de Biología Vegetal	Lab. de Genética, GD de Botánica y Recursos Fitogenéticos
	Dpto. de Biología Vegetal	Lab. de Microbiología, GD de Biotecnología y Microbiología
	Dpto. de Producción Animal y Pasturas	GD de Mejoramiento Genético
	Dpto. de Producción Animal y Pasturas	GD de Nutrición Animal
	Dpto. de Producción Animal y Pasturas	Lab. de Endocrinología y Biotecnología Animal, GD de Nutrición Animal
	Dpto. de Producción Animal y Pasturas	Laboratorio de Calidad de Carne (EEMAC)
	Dpto. de Producción Vegetal	GD de Mejoramiento Genético (EEMAC)
	Dpto. de Producción Vegetal	GD de Mejoramiento Genético: Hortalizas (CRS)
	Dpto. de Producción Vegetal	Unidad de Horticultura, GD de Poscosecha (CRS)
	Dpto. de Protección Vegetal	Unidad de Entomología (EEMAC)
	Dpto. de Protección Vegetal	Unidad de Fitopatología
	Unidad de Tecnología de los Alimentos	Área Lácteos
School of Natural Sciences, UdelaR (FC)	Centro de Investigaciones Nucleares	Lab. de Virología Molecular (Regional Norte)
	Centro de Investigaciones Nucleares	Laboratorio de Bioquímica y Biotecnología
	Centro de Investigaciones Nucleares	Laboratorio de Fisiología Vegetal
	Centro de Investigaciones Nucleares	Laboratorio de Virología Molecular
	Dpto. de Biología Animal, Instituto de Biología	Sección Etología
	Dpto. de Biología Animal, Instituto de Biología	Sección Evolución
	Dpto. de Biología Animal, Instituto de Biología	Sección Genética Evolutiva
	Dpto. de Biología Celular y Molecular, Instituto de Biología	Lab. de Biología Molecular Vegetal
	Dpto. de Biología Celular y Molecular, Instituto de Biología	Lab. de Biología Parasitaria
	Dpto. de Biología Celular y Molecular, Instituto de Biología	Lab. de Micología
	Dpto. de Biología Celular y Molecular, Instituto de Biología	Lab. de Trazabilidad Molecular Alimentaria (LaTraMa), Sección Bioquímica
	Dpto. de Biología Celular y Molecular, Instituto de Biología	Laboratorio de Organización y Evolución del genoma
	Dpto. de Biología Celular y Molecular, Instituto de Biología	Sección Biofísica
	Dpto. de Biología Celular y Molecular, Instituto de Biología	Sección Biología Celular
	Dpto. de Biología Celular y Molecular, Instituto de Biología	Sección Biomatemáticas
	Dpto. de Biología Celular y Molecular, Instituto de Biología	Sección Bioquímica
	Dpto. de Biología Celular y Molecular, Instituto de Biología	Sección Fisiología y Genética Bacterianas

Organisation (acronym)	Department / Division	R&D group or Lab
School of Natural Sciences, UdelaR (FC) (cont.)	Dpto. de Biología Celular y Molecular, Instituto de Biología	Unidad asociada: citogenética humana y microscopía cuantitativa
	Dpto. Ecología y Evolución, Instituto de Biología	Laboratorio de Ecología Terrestre
	Dpto. Ecología y Evolución, Instituto de Biología	Sección Evolución y Sistemática
	Instituto de Biología (DBCM) e Instituto de Química Biológica	Laboratorio de Interacciones Moleculares
	Instituto de Biología (DBCM) e Instituto de Química Biológica	Sección Virología
	Instituto de Ecología y Ciencias Ambientales	Lab. de Microbiología del Suelo
	Unidad Asociada de Química Biológica (FQ), Instituto de Química Biológica	Lab. de Microbiología
Engineering School, UdelaR (FI)	Instituto de Computación	
	Instituto de Ingeniería Química	Dpto. de Bioingeniería
	Instituto de Ingeniería Química	Grupo Biotecnología de Procesos para el Ambiente (BIOPROA), Dpto. de Ingeniería de Reactores
	Instituto de Ingeniería Química	Grupo de Ingeniería de Procesos Forestales
	Instituto de Ingeniería Química (IIQ)	Departamento de Ingeniería de Reactores
School of Medicine, UdelaR (FM)		Unidad de Reactivos y Biomodelos de Experimentación (URBE)
	Departamento Básico de Medicina (DBM)	Laboratorio de Citometría y Biología Molecular 'Roberto Caldeyro Barcia'
	Departamento de Biofísica	Laboratorio de Radiobiología
	Departamento de Genética	Laboratorio de Biología Molecular de Parásitos
	Departamento de Genética	Laboratorio de Oncología Básica y Biología Molecular
	Dpto. de Histología y Embriología, Área de Biología de la Reproducción	Dpto. de Histología y Embriología, Área de Biología de la Reproducción
	Dpto. de Inmunobiología	Dpto. de Inmunobiología
	Hospital de Clínicas	Centro de Medicina Nuclear
	Instituto Nacional de Donación y Transplante de células, tejidos y órganos (INDT) – Hospital de Clínicas	Laboratorio de Inmunogenética e Histocompatibilidad
School of Chemistry, UdelaR (FQ)	Dpto. "Estrella Campos"	Cátedra de Química Inorgánica
	Dpto. "Estrella Campos"	Cátedra de Radioquímica
	Dpto. de Biociencias	Cátedra de Bioquímica
	Dpto. de Biociencias	Cátedra de Inmunología
	Dpto. de Biociencias	Grupo de Biotecnología, Cátedra de Microbiología
	Dpto. de Biociencias	Grupo de Ecología Microbiana, Cátedra de Microbiología
	Dpto. de Biociencias	Grupo de Enzimas Hidrolíticas, Cátedra de Bioquímica
	Dpto. de Biociencias	Lab. de Microbiología Molecular, Cátedra de Microbiología
	Dpto. de Ciencia y Tecnología de Alimentos	Lab. de Grasas y Aceites
	Dpto. de Ciencia y Tecnología de Alimentos	Propiedades funcionales de alimentos
	Dpto. de Ciencia y Tecnología de Alimentos	Sección Enología
	Dpto. de Ciencia y Tecnología de Alimentos	Sección Evaluación Sensorial
	Dpto. de Ciencias Farmacéuticas	Lab. de Experimentación Animal

Organisation (acronym)	Department / Division	R&D group or Lab
School of Chemistry, UdelaR (FQ) (cont.)	Dpto. de Experimentación y Teoría de la Estructura de la Materia y sus Aplicaciones (DETEMA)	Lab. de Fisicoquímica de Superficies - LAFIDESU (gasificación catalítica de biomasa), Cátedra de Fisicoquímica
	Dpto. de Química Orgánica	Cátedra de Farmacognosia y Productos Naturales
	Dpto. de Química Orgánica	Lab. de Biocatalisis y Biotransformaciones
	Dpto. de Química Orgánica	Lab. de Ecología Química
	Dpto. de Química Orgánica	Lab. de Síntesis Orgánica, Cátedra de Química Orgánica
	Dpto. de Química Orgánica	Laboratorio de Glicoconjugados, Cátedra de Química Orgánica
	Polo Tecnológico de Pando	Química Bioanalítica
	Polo Tecnológico de Pando	Unidad de Biotecnología
School of Veterinary, UdelaR (FV)	Dpto. de Biología Molecular y Celular, Instituto de Biociencias	Área de Bioquímica
	Dpto. de Biología Molecular y Celular, Instituto de Biociencias	Biofísica
	Dpto. de Ciencia y Tecnología de la Leche, Instituto de Ciencia y Tecnología de los Alimentos de Origen Animal	Área Ciencia y Tecnología de la Leche
	Dpto. de Ciencias Microbiológicas, Instituto de Patobiología Veterinaria	Área Bacteriología
	Dpto. de Ciencias Microbiológicas, Instituto de Patobiología Veterinaria	Área de Inmunología
	Dpto. de Ciencias Microbiológicas, Instituto de Patobiología Veterinaria	Área de Virología
	Dpto. de Genética y Mejora Animal, Instituto de Producción Animal	Área de Genética
	Dpto. de Parasitología, Instituto de Patobiología Veterinaria	Lab. de Toxoplasmosis
	Instituto de Producción Animal	Clícicas, Rumiantes y Suinos
	Instituto de Producción Animal	Laboratorio de Técnicas Nucleares
	N/A	Dpto. de Salud Ambiental
	N/A	Laboratorio de Análisis Genético en Animales Domésticos
	N/A	Laboratorio de Endocrinología Molecular de la Reproducción Animal
	N/A	Laboratorio de Transferencia de Embriones y Biotecnología
National Seed Institute (INASE)	N/A	Laboratorios de: Calidad de Semillas; Diagnóstico Virológico; y Técnicas Moleculares
Pasteur Institute of Montevideo (IPM)	N/A	Lab. de Biología Celular de Membranas
	N/A	Unidad de Cristalografía de Proteínas
	N/A	Unidad de Animales Transgénicos y de Experimentación
	N/A	Unidad de Biofísica de Proteínas
	N/A	Unidad de Bioinformática
	N/A	Unidad de Biología Molecular
	N/A	Unidad de Bioquímica y Proteómica Analíticas

Organisation (acronym)	**Department / Division**	**R&D group or Lab**
Hygiene Institute, UdelaR (IH)	Depto.de Biología Celular y Molecula	Unidad de Biología Parasitaria
	Dpto. de Bacteriología y Virología	Lab. de Enteropatógenos Bacterianos y Zoonosis
	Dpto. de Desarrollo Biotecnológico	Lab. de Investigacion en Vacunas
Institute of Biological Research, *Clemente Estable* – (IIBCE)	Div. Ciencias Microbiológicas	Dpto. de Microbiología
	Div. Genética y Biología Molecular	Dpto. de Biología Molecular
	Div. Genética y Biología Molecular	Lab. de Epigenética e Inestabilidad Genómica
	Div. Genética y Biología Molecular	Servicio de Citometría de Flujo, Dpto. de Genética
	División Neurociencias	DEPARTAMENTO DE BIOQUÍMICA Y PROTEÓMICA ANALÍTICAS
	División Neurociencias	DEPARTAMENTO DE NEUROFISIOLOGÍA CELULAR Y MOLECULAR
	División Neurociencias	DEPTO. DE PROTEÍNAS Y ACIDOS NUCLÉICOS
	Dpto. de Bioquímica y Genómica Microbianas, Div. Ciencias Microbiológicas	Lab. Bioquimica y Genómica Microbianas (BIOGEM)
	Dpto. de Bioquímica y Genómica Microbianas, Div. Ciencias Microbiológicas	Lab. de Ecología Microbiana
	Dpto. de Bioquímica y Genómica Microbianas, Div. Ciencias Microbiológicas	Lab. de Microbiología Molecular
National Agricultural Research Institute (INIA)	Est. Exp. Las Brujas	Lab. De Fitoquímica
	Est. Exp. Las Brujas	Lab. de Protección Vegetal / Lab. de Bioproducción
	Estación Experimental: La Estanzuela	Laboratorio Calidad de Leche INIA
	Estación Experimental: Las Brujas	Programa Nacional de Horticultura
	INIA Treinta y Tres	Programa Nacional de Producción de Arroz
	Programa Nacional de Carne y Lana, Est. Exp. Las Brujas	Mejoramiento Genético Animal
	Programa Nacional de Cultivos de Secano, Est. Exp. La Estanzuela	Lab. Proteccion Vegetal
	Programa Nacional de Cultivos de Secano, Est. Exp. La Estanzuela	Laboratorio de Calidad de Granos
	Programa Nacional de Producción Forestal, Est. Exp. Tacuarembó	Mejoramiento Genético Forestal
	Unidad de Biotecnología, Est. Exp. Las Brujas	Lab. Cultivo de Tejidos
	Unidad de Biotecnología, Est. Exp. Las Brujas	Lab. de Proteínas
	Unidad de Biotecnología, Est. Exp. Las Brujas	Lab. Marcadores tolerancia estrés
Uruguayan Technological Laboratory (LATU)	Dpto. de Gestión y Transferencia Tecnológica pata el Desarrollo Local	Gerencia de Proyectos Alimentarios
	Gerencia de Análisis, Ensayos y Metrología	Dpto. de Microbiología (Unidad Fray Bentos)
	Gerencia de Análisis, Ensayos y Metrología	Investigación ambiental
Ministry of Husbandry, Agriculture and Fisheries (MGAP)	Dirección General de Servicios Agrícolas (DGSA)	Laboratorios Biológicos, División Análisis y Diagnóstico
	Dirección Nacional de Recursos Acuáticos (DINARA)	Lab. de Bioquímica, Lab. de Análisis de Pescado
	División de Laboratorios Veterinarios (DILAVE), Dirección General de Servicios Ganaderos (DGSG)	Depto. de Patobiología: Sección Anatomía Patológica
	División Sanidad Animal - DGSG	Dpto. de Programas Sanitarios
Ministry of Public Health (MSP)	N/A	Departamento de Laboratorios de Salud Pública
Uruguayan Wool Secretariat (SUL)	N/A	Area de Investigación en Producción Ovina
Catholic University of Uruguay (UCUDAL)	N/A	Facultad de Ingeniería y Tecnologías

Source: Elaborated by the author based on the sources described in Section 3.4.3

Appendix 8.3: Record of private organisations identified within the biotechnology innovation system in Uruguay

Ref. No.	Organisation name
1	Acichan
2	Adiamar SA
3	Agroplant
4	Atgen
5	Biogen
6	Biologistica
7	Biomega S.A.
8	Bio-Systems
9	Bodegas Carrau
10	Calister
11	Camara de Semillas
12	Celsius
13	Cgmed
14	Colaveco
15	Enzur S.A.
16	Identitas
17	Infodynamics / Bio High Tec
18	Laboratorio Fourneau
19	Laboratorio Genia
20	Laboratorios Clausen
21	Laboratorios Microsules
22	Laboratorios Santa Elena
23	Lage y Cía.
24	Merial
25	Nanosil
26	Perales del Sur SA
27	Phyto Uruguay
28	Prondil
29	Semillas Santa Rosa
30	Tepyve SA
31	Urodelia/ Polo Tecnológico de Pando
32	Uruwagyu
33	Villa Lima

Source: elaborated by the author based on MIEM (2011)

Appendix 8.4: Letter to members of R&D groups and representatives of firms

Montevideo, ………… 2011

[Nombre]
[Cargo]
[Division / Departament0]
[Organización]

Estimado(a) [Nombre],

Quien le escribe, Ing. Agr. Nicolás Gutiérrez (MSc), está llevando a cabo un proyecto de investigación sobre los procesos de formación de arreglos inter-organizacionales para investigación y desarrollo de forma colaborativa en el área biotecnológica en Uruguay. Dicho proyecto se enmarca en mis estudios de postgrado en el Departamento de Investigación en Políticas de Ciencia y Tecnología (SPRU) de la Universidad de Sussex, Reino Unido.

Como componente del trabajo de campo de este proyecto actualmente estoy realizando una ronda de entrevistas con investigadores vinculados a grupos de investigación, laboratorios, cátedras, institutos y empresas que han estado involucrados en la aplicación y desarrollo de biotecnologías en Uruguay. El objetivo de estas entrevistas es conocer las actividades de investigación biotecnológica de estos grupos, sus experiencias de colaboración inter-institucional, así como su opinión sobre los principales aspectos o mecanismos que pueden promover o inhibir el inicio e implementación de acciones colaborativas de I+D en este campo de conocimiento.

El envío de esta nota es de carácter informativo, para brindarle antecedentes generales sobre la referida investigación en curso. En los próximos días me pondré en contacto telefónico con Ud. para explorar la posibilidad de coordinar una entrevista en un día y hora de su conveniencia, o si lo prefiere, puede hacerme llegar sus preferencias vía e-mail a n.gutierrez@sussex.ac.uk .

Agradeciendo su disponibilidad y colaboración con esta iniciativa, le saluda muy atentamente,

____

Ing. Agr. Nicolás Gutiérrez (MSc)
MPhil Candidate
Science & Technology Policy Research (SPRU)
University of Sussex
n.gutierrez@sussex.ac.uk
094 404 403

Appendix 8.5: **Survey questionnaire to R&D project coordinators**
(i) Version in Spanish that was actually used.

Caracterización de actividades de investigación en Ciencias de la Vida en Uruguay: capacidades científicas o tecnológicas, y colaboración inter-organizacional en marco de proyectos de I+D

Información del estudio y consentimiento

Introducción

Este cuestionario pretende recoger información sobre actividades de investigación científica y/o desarrollo tecnológico en el área de 'ciencias de la vida' en Uruguay. Se intenta prestar especial atención a las capacidades de investigación disponibles en grupos, laboratorios, cátedras o institutos públicos de investigación vinculados a esta área en Uruguay. Asimismo, se busca relevar las actividades de colaboración inter-organizacional llevadas a cabo en el marco de proyectos de investigación y/o desarrollo financiados con fondos públicos en Uruguay.

Este estudio es conducido por el Ing. Agr. Nicolás Gutiérrez (MSc) en marco de su investigación de postgrado en el Departamento de Investigación en Políticas de Ciencia y Tecnología (SPRU) de la Universidad de Sussex, Reino Unido.

Alcance

La encuesta ha sido remitida a responsables, coordinadores y/o participantes de proyectos de investigación en el área de ciencias de la vida, iniciados entre los años 2000 y 2011 en Uruguay, con financiamiento de diversas organizaciones y programas nacionales (PDT, CSIC-UdelaR, FPTA-INIA, y ANII).

Participación y procedimientos

La participación en este estudio es totalmente voluntaria. Si lo desea, usted puede abandonar la encuesta en cualquier momento, cerrando su explorador de internet. El cuestionario incluye 7 preguntas y su respuesta le tomará entre 30 y 40 minutos.

Importancia de su participación y beneficios

El presente estudio pretende identificar las actividades de investigación y mapear de forma general las capacidades científicas o tecnológicas del conjunto de actores y grupos nacionales en el área de ciencias de la vida. Este tipo de información es de gran relevancia para el desarrollo de políticas y mecanismos de apoyo a las actividades de investigación científica, desarrollo tecnológico e innovación en esta área.

Su aporte a esta encuesta representa una valiosa contribución al referido relevamiento. Además de agradecer sinceramente el tiempo dedicado a responder este cuestionario, los resultados del estudio serán presentados a los participantes de la encuesta, ya sea en forma escrita o convocándolos a una actividad de difusión y discusión.

Confidencialidad

Toda la información recabada de los participantes en la encuesta será mantenida en estricta confidencialidad. Únicamente el responsable de este estudio y un asistente del proyecto tendrán acceso a la información recabada. Toda utilización o divulgación de esta información será únicamente en forma de resultados agregados, evitando cualquier alusión identificable con encuestados específicos y sus respuestas.

Consultas acerca de la investigación

Si tiene consultas con relación a este estudio puede contactar a su responsable, Ing. Agr. Nicolás Gutiérrez (n.gutierrez@sussex.ac.uk; Tel.: 29020550, 094 404 403) o a Wanda Iriarte (2902 05 50, int. 1140).

Muchas gracias por su atenta disposición.

(A) Información general del cuestionario

El cuestionario a continuación se presenta a usted en su rol de responsable y/o participante del proyecto de investigación cuya información descriptiva (título, año de inicio, y programa financiador) se detalló en la nota enviada solicitando su participación.

Las preguntas conciernen a las actividades de investigación científica y/o desarrollo tecnológico llevadas a cabo específicamente durante el referido proyecto y al grupo de investigación que lideró. Por favor, refiera sus respuestas específicamente a dicho proyecto de investigación, salvo cuando la pregunta indique un alcance diferente.

El primer bloque de preguntas refiere a información general del proyecto, el coordinador y el grupo de investigadores y/o técnicos de su organización involucrado(s) en la implementación.

(1)
Indique el número de referencia del proyecto de investigación que le fue provisto en la nota o e-mail solicitando su participación en la encuesta

(2)
Por favor, completar la siguiente información personal de quien responde a la encuesta:

Nombre	
Apellido	
Cargo	
Laboratorio o grupo de investigación	
División y/o Departamento	
Organización	

(3) Grupo Principal responsable de la ejecución del Proyecto

Por favor, indique aproximadamente cuántos integrantes de su grupo participaron en el proyecto:

(Información sobre participantes de **organizaciones externas** es solicitada en la pregunta **6**)

	Total de miembros involucrados del grupo principal

(4.1)
Del total de involucrados que indicó arriba (Preg. 3), indique la cantidad correspondiente a cada nivel de formación.

Cantidad	Nivel de formación
	Post-doctorado
	Doctorado
	Maestría
	Grado
	Bachiller
	Otro

(4.2)
Del total de miembros involucrados que indicó en (3), indique la cantidad correspondiente a cada tipo de vinculación con la organización (cargo).

Cargo o tipo de vinculación con la organización:

Cantidad	Relación con la organización
	Investigadores o técnicos permanentes
	Investigadores o técnicos contratados a término
	Estudiantes temporarios
	Otro

(5.1)

Formación y experiencia: seleccione las disciplinas y especialidades representadas por los miembros de su grupo involucrados en el proyecto.

Disciplinas y especialidades (marque con una 'x' las opciones que correspondan)					
	Bacteriology		Entomology		Animal breeding
	Biophysics		Enzymology		Metabolomics
	Bioinformatics		Epidemiology		Mycology
	Biostatistics		Evolution sciences		Microbiology
	Biomathematics		Pharmacology		Neurosciences
	Cell and membrane biology		Physical-chemistry		Parasitology
	Botany		Plant physiology		Animal pathology
	Molecular biology		Genetics		Plant pathology
	Biochemistry		Structural genomics		Proteomics
	Biotechnology		Functional genomics		Radiology
	Environment sciences		Comparative genomics		Animal Reproduction
	Food science and technology		Histology		Animal health
	Cytogenetics		Bioprocess engineering		Toxicology
	Cell and tissue culture		Reactors engineering		Transcriptomics
	Ecology		Immunology		Virology
	Embryology		Plant breeding		Other

(B) Participación de organizaciones y/o grupos colaboradores

El siguiente bloque de preguntas refiere a la participación de organizaciones o grupos colaboradores* en el proyecto y su identificación

(6)

Indique si el desarrollo del proyecto involucró la participación de integrantes de organizaciones o grupos de investigación colaboradores*, ya sea de manera formal o informal**

Si	❒
No	❒

En caso de que la respuesta sea **NO**, pasar a la pregunta **7**.

***Organizaciones o grupos colaboradores: investigadores o técnicos que contribuyeron al proyecto pero no pertenecen al grupo principal responsable de la ejecución del proyecto. Cada 'grupo colaborador' puede ser integrado por una o más personas.**

Se incluye aquí también a organizaciones proveedoras de servicios de análisis u otros servicios científicos relevantes

(6.1)

Identifique las organizaciones y/o grupos de investigación colaboradores que contribuyeron formal o informalmente a la implementación del proyecto (máx. 7 grupos). Incluya aquí también organizaciones proveedoras de servicios de análisis u otros servicios científicos relevantes

	Persona de Contacto: Contraparte científica o técnica del grupo	Nombre de la organización a la que pertenece el grupo	Origen de la Organización: Nacional (N) Extranjera (E)
Grupo 1			
Grupo 2			
Grupo 3			
Grupo 4			
Grupo 5			
Grupo 6			
Grupo 7			

(6.2)

Para cada grupo y organización identificados, indique Disciplina y Repartición de la Contraparte científica o técnica

	Especialidad de la Contraparte científica o técnica	Repartición a la que pertenece la Contraparte dentro de su Organización	
		Laboratorio o grupo de investigación	División, Departamento y/o Facultad
Grupo 1			
Grupo 2			
Grupo 3			
Grupo 4			
Grupo 5			
Grupo 6			
Grupo 7			

(C) *Capacidades científicas y tecnológicas*

El siguiente bloque de preguntas refiere a las capacidades científicas y/o tecnológicas de su grupo de investigación / organización que lideró el proyecto.

(7)

Por favor, en la tabla debajo seleccione los **campos científicos o tecnológicos** para los que su grupo dispone internamente de capacidades para conducir actividades de investigación.

	Su grupo (coordinador) tiene capacidades de investigación en este campo (marque con una '**x**' las opciones que correspondan)
(7.1) Técnicas de análisis molecular de ADN y/o ARN (y su asociación con el fenotipo)	❒
(7.2) Cultivo de células o tejidos	❒
(7.3) Estudio de proteínas y péptidos	❒
(7.4) Microorganismos y procesos microbiológicos o enzimáticos	❒
(7.5) Inmuno-ensayos y vacunas	❒

Definición:

Capacidades de investigación científica o tecnológica: conjunto de conocimientos, técnicas, infraestructura e instrumentos disponibles en el grupo, requeridos para la implementación del proyecto.

NOTA: vaya al punto que seleccionó en la pregunta 7. Por ejemplo si seleccionó la 7.2, vaya a la pregunta 7.2 y no complete la 7.1, 7.3, 7.4 y 7.5

(7.1) Estudio del ADN y/o ARN:

En la lista debajo, indique cuál es el grado de desarrollo en su grupo de cada técnica de investigación o área de conocimiento.

Grado de desarrollo de la capacidad dentro de su grupo: indique la disponibilidad y grado de desarrollo de cada capacidad en su grupo .

Capacidad científica o tecnológica	Grado de desarrollo de la capacidad dentro de su grupo (marque con una 'x' las opciones que correspondan)				
	No desarrollada 1	Desarrollo Bajo 2	Desarroll o Medio 3	Desarrollo Alto 4	Desarrollo Muy Alto 5
Técnicas de hibridación (southern, northern) – sondas frías	❒	❒	❒	❒	❒
Técnicas de hibridación – sondas radioactivas	❒	❒	❒	❒	❒
Técnicas de ADN recombinante	❒	❒	❒	❒	❒
Vectores de expresión de ADN	❒	❒	❒	❒	❒
Técnicas de mutación de ADN	❒	❒	❒	❒	❒
Marcadores moleculares de alta densidad: SNPs	❒	❒	❒	❒	❒
Marcadores moleculares de media o baja densidad: RFLP, AFLP, SSR, RAPDs, etc	❒	❒	❒	❒	❒
Secuenciación capilar de ADN/ARN (método Sanger)	❒	❒	❒	❒	❒
Secuenciación masiva de ADN y ARN (next generation sequencing-NGS)	❒	❒	❒	❒	❒
Perfil de expresión génica (Microarrays, Real-Time PCR, ESTs, SSH, etc)	❒	❒	❒	❒	❒
Silenciamiento génico (knock-out, ARN interferencia, etc.)	❒	❒	❒	❒	❒

Capacidad científica o tecnológica	**Grado de desarrollo de la capacidad dentro de su grupo** (marque con una 'x' las opciones que correspondan)				
	No desarrollada 1	**Desarrollo Bajo 2**	**Desarroll o Medio 3**	**Desarrollo Alto 4**	**Desarrollo Muy Alto 5**
Transferencia de ADN (transformación, transducción, conjugación, etc)	❒	❒	❒	❒	❒
Transgénesis vegetal	❒	❒	❒	❒	❒
Transgénesis animal	❒	❒	❒	❒	❒
Bibliotecas genómicas	❒	❒	❒	❒	❒
Bibliotecas de cDNA	❒	❒	❒	❒	❒
Bibliotecas para Next Generation Sequencing	❒	❒	❒	❒	❒
Bioinformática	❒	❒	❒	❒	❒
Técnicas moleculares de identificación y caracterización de organismos	❒	❒	❒	❒	❒
Técnicas de diagnóstico molecular de patógenos y enfermedades	❒	❒	❒	❒	❒

(7.2) Cultivo de células o tejidos

En la lista debajo, indique cuál es el grado de desarrollo en su grupo de cada técnica de investigación o área de conocimiento .

Grado de desarrollo de la capacidad dentro de su grupo: indique la disponibilidad y grado de desarrollo de cada capacidad en su grupo .

Capacidad científica o tecnológica	Grado de desarrollo de la capacidad dentro de su grupo (marque con una 'x' las opciones que correspondan)				
	No desarrollada 1	Desarrollo Bajo 2	Desarroll o Medio 3	Desarrollo Alto 4	Desarrollo Muy Alto 5
Cultivo e ingeniería de células animales	❒	❒	❒	❒	❒
Cultivo e ingeniería de tejidos animales	❒	❒	❒	❒	❒
Cultivo e ingeniería de células vegetales (fusión de protoplastos, etc)	❒	❒	❒	❒	❒
Cultivo e ingeniería de tejidos vegetales (micro-propagación, rescate de embriones, etc)	❒	❒	❒	❒	❒
Cultivo de microorganismos	❒	❒	❒	❒	❒
Fecundación in-vitro y manipulación de embriones	❒	❒	❒	❒	❒

(7.3) Estudio de Proteínas, péptidos y otras biomoléculas

En la lista debajo, indique cuál es el grado de desarrollo en su grupo de cada técnica de investigación o área de conocimiento .

Grado de desarrollo de la capacidad dentro de su grupo: indique la disponibilidad y grado de desarrollo de cada capacidad en su grupo .

Capacidad científica o tecnológica	Grado de desarrollo de la capacidad dentro de su grupo (marque con una 'x' las opciones que correspondan)				
	No desarrollada 1	Desarrollo Bajo 2	Desarroll o Medio 3	Desarrollo Alto 4	Desarrollo Muy Alto 5
Expresión de Proteínas recombinantes	❒	❒	❒	❒	❒
Secuenciación y/o síntesis de proteínas y/o péptidos	❒	❒	❒	❒	❒
Cuantificación de proteínas: ELISA o radio-inmunoensayos	❒	❒	❒	❒	❒
Identificación de proteínas: (inmunoblot, inmuno-histoquímica, etc.)	❒	❒	❒	❒	❒
Aislamiento y purificación de proteínas y/o péptidos	❒	❒	❒	❒	❒
Determinación de estructura y plegamiento de proteínas	❒	❒	❒	❒	❒
Ingeniería de procesos enzimáticos (cinética enzimática)	❒	❒	❒	❒	❒
Identificación y cuantificación de metabolitos y hormonas	❒	❒	❒	❒	❒
Análisis de composición química de alimentos	❒	❒	❒	❒	❒

(7.4) Microorganismos y procesos microbiológicos o enzimáticos

En la lista debajo, indique cuál es el grado de desarrollo en su grupo de cada técnica de investigación o área de conocimiento .

Grado de desarrollo de la capacidad dentro de su grupo: indique la disponibilidad y grado de desarrollo de cada capacidad en su grupo .

Capacidad científica o tecnológica	Grado de desarrollo de la capacidad dentro de su grupo (marque con una 'x' las opciones que correspondan)				
	No desarrollada 1	Desarrollo Bajo 2	Desarroll o Medio 3	Desarrollo Alto 4	Desarrollo Muy Alto 5
Promotores de crecimiento vegetal	❒	❒	❒	❒	❒
Agentes de control biológico de organismos patógenos	❒	❒	❒	❒	❒
Producción de moléculas bioactivas	❒	❒	❒	❒	❒
Biocombustibles y bio-refinación	❒	❒	❒	❒	❒
Ingeniería de procesos microbiológicos y bio-reactores	❒	❒	❒	❒	❒
Escalado de procesos biológicos (piloto o industrial)	❒	❒	❒	❒	❒
Recuperación y purificación de bio-productos	❒	❒	❒	❒	❒
Formulación de productos biológicos	❒	❒	❒	❒	❒
Fermentación en sustrato sólido y/o líquido	❒	❒	❒	❒	❒
Bio-procesamiento de madera y bio-blanqueado de celulosa	❒	❒	❒	❒	❒
Bio-remediación, bio-filtrado, o biodegradación	❒	❒	❒	❒	❒
Producción de enzimas u otros metabolitos	❒	❒	❒	❒	❒
Inocuidad de alimentos y otros productos de consumo humano	❒	❒	❒	❒	❒

(7.5) Inmuno-ensayos y vacunas:

En la lista debajo, indique cuál es el grado de desarrollo en su grupo de cada técnica de investigación o área de conocimiento .

Grado de desarrollo de la capacidad dentro de su grupo: indique la disponibilidad y grado de desarrollo de cada capacidad en su grupo .

Capacidad científica o tecnológica	Grado de desarrollo de la capacidad dentro de su grupo (marque con una 'x' las opciones que correspondan)				
	No desarrollada 1	Desarrollo Bajo 2	Desarroll o Medio 3	Desarrollo Alto 4	Desarrollo Muy Alto 5
Vacunas virales (virus atenuado o inactivo)	❐	❐	❐	❐	❐
Vacunas bacterianas	❐	❐	❐	❐	❐
Vacunas recombinantes sub-unitarias	❐	❐	❐	❐	❐
Inmuno-diagnóstico (técnicas inmunológicas)	❐	❐	❐	❐	❐
Inmuno-diagnóstico (técnicas moleculares)	❐	❐	❐	❐	❐
Inmuno-ensayos *in-vitro*	❐	❐	❐	❐	❐
Inmuno-ensayos *in-vivo*	❐	❐	❐	❐	❐
Ingeniería de anticuerpos	❐	❐	❐	❐	❐
Receptores celulares, citocinas y comunicación celular	❐	❐	❐	❐	❐

(7.6) Instrumental de análisis en laboratorio y técnicas de evaluación de productos:

En la lista debajo, indique cuál es el grado de desarrollo en su grupo de cada técnica de investigación .

Grado de desarrollo de la capacidad dentro de su grupo: indique la disponibilidad y grado de desarrollo de cada capacidad en su grupo .

Capacidad científica o tecnológica	Grado de desarrollo de la capacidad dentro de su grupo (marque con una 'x' las opciones que correspondan)				
	No desarrollada 1	Desarrollo Bajo 2	Desarroll o Medio 3	Desarrollo Alto 4	Desarrollo Muy Alto 5
Citometría de flujo	❒	❒	❒	❒	❒
Microscopía de fluorescencia (epifluorescencia, confocal, etc.)	❒	❒	❒	❒	❒
Cristalografía por rayos-X	❒	❒	❒	❒	❒
Espectrometría de masas	❒	❒	❒	❒	❒
Radioinmunoanálisis	❒	❒	❒	❒	❒
Espectroscopia de resonancia magnética nuclear (RMN)	❒	❒	❒	❒	❒
Cromatografía (HPLC, cromatografía de gases, etc.)	❒	❒	❒	❒	❒
Termociclador para Real Time PCR	❒	❒	❒	❒	❒
Bio-sensores: técnicas de detección de bio-moléculas y patógenos	❒	❒	❒	❒	❒
Bio-ensayos: evaluación y validación de biotecnologías	❒	❒	❒	❒	❒

Si desea que algún comentario adicional sea considerado en este estudio, por favor escríbalo en la casilla de texto debajo

Muchas gracias por su atenta disposición para participar de esta encuesta!

Appendix 8.5: **Survey questionnaire to R&D project coordinators**
(ii) Translation of the Spanish version into English.

Characterisation of Life-Sciences research activities in Uruguay: scientific or technological capabilities and inter-organisational collaboration in the context of R&D projects

Information about the study and consent

Introduction

This questionnaire is intended to collect information about scientific-research and/or technological-development activities within the field of `Life-Sciences' in Uruguay. Particular attention is paid to the research capabilities available in R&D groups, laboratories, university schools or public research institutes involved in this area in Uruguay. In addition, the questionnaire is aimed to survey inter-organisational collaboration activities carried out in the context of publicly funded R&D projects.

This study is being conducted by Nicolás Gutiérrez (MSc) as part of his postgraduate research projects Department of Science Policy Research (SPRU) of the University of Sussex, United Kingdom.

Scope

This questionnaire has been delivered to scientific leaders of publicly funded R&D Projects in the area of Life-sciences that started between years 2000 and 2011 in Uruguay and were funded by diverse Uruguayan organizations and programmes (PDT, CSIC-UdelaR, FPTA-INIA, and ANII)

Participation and procedures

The participation in this study is absolutely voluntary. If you wish, you can leave the survey at any time simply by closing your internet browser. The questionnaire includes seven questions; answering them would take between 30 and 40 minutes.

Importance of your answer and benefits

The present study tries to identify the R&D activities and to map the scientific and technological capabilities of all actors and national R&D groups involved in the area of life sciences. This type of information is highly relevant for the development of public policies and support mechanisms for scientific research, technological development and innovation activities in this field.

Your answer to this survey represents a valuable contribution the study referred to above. The results of the study will be presented to the participants of the survey, either in written form or through an open seminar. Thank you very much for the time dedicated to respond this questionnaire.

Confidentiality

All the information provided by the participants in this survey will be preserved in strict confidentiality. Only the person in charge of this study and a project assistant will have access to this information. Every use or dissemination of this information will be exclusively as aggregate results, avoiding any identifiable reference to the respondents to this survey.

Queries

If you have questions about this study, please contact Nicolas Gutiérrez (n.gutierrez@sussex.ac.uk; Ph.: 29020550, 094 404 403) or Wanda Iriarte (2902 05 50, ext. 1140).

Thank you very much for your kind attention.

(A) General information about the questionnaire

The following questionnaire is delivered to you as the scientific leader (or participant) in the R&D project described in the letter that you received asking for your participation (title, start year and financial program).

The questions regard to the scientific research and/or technological development activities carried out during the implementation of the project referred to above as well as to the R&D group that it led the project.

The first section of the questionnaire refers to general information about the project, the coordinator and the group of researchers of your organisations that were involved in the project's implementation.

(1)
Introduce the project reference number that was provided in the letter and/or e-mail that your received asking for your participation in the survey

(2)
Please, complete the following personal information about the respondent:

First Name	
Last name	
Position	
Laboratory or R&D group	
Division and/or Department	
Organisation	

(3) Main R&D group in charge of the R&D project's implementation

Please, indicate how many members of your group were involved in the Project:

(information about participants from external **organisations is** asked for in question **6**)

(4.1)
From the total members specified above (3), indicate the corresponding number for each education level listed below.

No.	Education level
	Post-doctorate
	PhD
	Master
	Graduate
	Under-graduate
	Other

(4.2)
From the total members specified above (3), indicate the corresponding number for each category of employment-relationship with your organisation (position).

Position or relationship with your organisation:

No.	Relationship with your organisation
	Permanent researchers
	Short-term contract researchers
	Temporary students
	Other

(5.1)

Training and research experience: select the disciplines and specific research subjects encompassed by the members of your group that were involved in the Project.

Disciplines and areas of expertise (mark with an '**x**' the corresponding options)					
	Bacteriology		Entomology		Animal breeding
	Biophysics		Enzymology		Metabolomics
	Bioinformatics		Epidemiology		Mycology
	Biostatistics		Evolution sciences		Microbiology
	Biomathematics		Pharmacology		Neurosciences
	Cell and membrane biology		Physical-chemistry		Parasitology
	Botany		Plant physiology		Animal pathology
	Molecular biology		Genetics		Plant pathology
	Biochemistry		Structural genomics		Proteomics
	Biotechnology		Functional genomics		Radiology
	Environment sciences		Comparative genomics		Animal Reproduction
	Food science and technology		Histology		Animal health
	Cytogenetics		Bioprocess engineering		Toxicology
	Cell and tissue culture		Reactors engineering		Transcriptomics
	Ecology		Immunology		Virology
	Embryology		Plant breeding		Other

(B) Involvement of collaborating R&D groups or organisations in the Project

The following section concerns the involvement of collaborating R&D groups* or organisations and their identification.

(6)
Indicate if the implementation of the R&D project involved the participation, either formal or informal, of collaborating research groups or organisations.

Yes	❐
No	❐

If your answer was NO, continue in question **7**.

*** Collaborating organisations or groups: researchers who contributed to the project but do not belong to the main group in charge of the implementation of the project. Each `collaborating group' can be integrated by one or more individuals.**

Lab-analysis service organisations or other relevant scientific services are also included here

(6.1)

Please list the collaborating organisations, laboratories or research groups that were involved in the implementation of the project.

	Contact person: group's scientific counterpart	Name of the organisation to which the group belongs	Organisation's nationality: National (N) Foreign (E)
Group 1			
Group 2			
Group 3			
Group 4			
Group 5			
Group 6			
Group 7			

(6.2)

For each R&D group / organisation identified in (6.1), indicate discipline and organisational unit or lab of the scientific counterpart

	Discipline of the scientific counterpart	Organisational unit to which the counterpart belongs	
		Laboratory or R&D group	Division, Department or School
Group 1			
Group 2			
Group 3			
Group 4			
Group 5			
Group 6			
Group 7			

(C) Scientific and technological capabilities

The following section of the questionnaire concerns the scientific and/or technological capabilities of your R&D group which led the project.

(7)

Please, in the table below, select the scientific or technological fields on which your R&D group has internally-available capabilities to conduct research activities.

	Your group (project leader) has research capabilities in the respective fields (mark with an '**x**' the corresponding options)
(7.1) DNA and/or RNA molecular-analysis techniques	❒
(7.2) Cell and tissue culture	❒
(7.3) Study of proteins, peptides and other bio-molecules	❒
(7.4) Microorganisms and microbiological or enzymatic processes	❒
(7.5) Immunoassays and vaccines	❒

Definition:

Scientific or technological R&D capabilities: set of knowledge, techniques, facilities and instrumentation available within the research group to carry out the project R&D activities.

Note: turn to the corresponding item(s) selected in question 7. For example, if you selected 7.2, turn now to question 7.2 but do not complete questions 7.1, 7.3, 7.4 and 7.5

(7.1) DNA and/or RNA molecular-analysis techniques:

From the list below, indicate the degree of development of each **R&D capability** within your R&D group.

Scientific or technological R&D capability	**Degree of development of each R&D capability within your R&D group** (mark with an '**x**' the corresponding options)				
	Not Developed 1	**Low Development 2**	**Medium Development 3**	**High Development 4**	**Very high Development 5**
Hybridization techniques (southern and northern blotting; cold probes)	❒	❒	❒	❒	❒
Hybridization techniques - radioactive probes	❒	❒	❒	❒	❒
Recombinant DNA techniques	❒	❒	❒	❒	❒
DNA expression vectors	❒	❒	❒	❒	❒
DNA mutation techniques	❒	❒	❒	❒	❒
High density molecular markers: SNPs	❒	❒	❒	❒	❒
Medium or low density molecular markers: RFLP, AFLP, SSR, RAPDs, etc.	❒	❒	❒	❒	❒
DNA/RNA capillary sequencing (Sanger method)	❒	❒	❒	❒	❒
Massive DNA/RNA sequencing (next generation sequencing-NGS)	❒	❒	❒	❒	❒
Gene expression profiling (Microarrays, Real-Time PCR, ESTs, SSH, etc)	❒	❒	❒	❒	❒
Silenciamiento génico (knock-out, ARN interferencia, etc.)	❒	❒	❒	❒	❒
DNA transfer (transformation, transduction, conjugation, etc.)	❒	❒	❒	❒	❒

Scientific or technological R&D capability	Degree of development of each R&D capability within your R&D group (mark with an '**x**' the corresponding options)				
	Not Developed 1	**Low Development 2**	**Medium Development 3**	**High Development 4**	**Very high Development 5**
Plant transgenesis	❒	❒	❒	❒	❒
Animal transgenesis	❒	❒	❒	❒	❒
Genomic libraries	❒	❒	❒	❒	❒
cDNA libraries	❒	❒	❒	❒	❒
Libraries for Next Generation Sequencing	❒	❒	❒	❒	❒
Bioinformatics	❒	❒	❒	❒	❒
Molecular techniques for identification and characterisation of organisms	❒	❒	❒	❒	❒
Molecular techniques for pathogen and disease diagnosis	❒	❒	❒	❒	❒

(7.2) Cell and tissue culture

From the list below, indicate the degree of development of each **R&D capability** within your R&D group.

Scientific or technological R&D capability	**Degree of development of each R&D capability within your R&D group** (mark with an '**x**' the corresponding options)				
	Not Developed 1	**Low Development 2**	**Medium Development 3**	**High Development 4**	**Very high Development 5**
Animal cell culture and engineering	❐	❐	❐	❐	❐
Animal tissue culture and engineering	❐	❐	❐	❐	❐
Plant cell culture and engineering (protoplast fusion, etc)	❐	❐	❐	❐	❐
Plant tissue culture and engineering (micro-propagation, embryo rescue, etc)	❐	❐	❐	❐	❐
Microbial culture	❐	❐	❐	❐	❐
In-vitro fecundation and embryo manipulation	❐	❐	❐	❐	❐

(7.3) Study of proteins, peptides and other bio-molecules

From the list below, indicate the degree of development of each **R&D capability** within your R&D group.

Scientific or technological R&D capability	**Degree of development of each R&D capability within your R&D group** (mark with an '**x**' the corresponding options)				
	Not Developed 1	**Low Development 2**	**Medium Development 3**	**High Development 4**	**Very high Development 5**
Recombinant protein expression	❒	❒	❒	❒	❒
Protein / peptide sequencing or synthesis	❒	❒	❒	❒	❒
Protein quantification (ELISA or radioimmunoassay)	❒	❒	❒	❒	❒
Protein identification (immunoblot, immunohistochemistry, etc.)	❒	❒	❒	❒	❒
Protein / peptide isolation and purification	❒	❒	❒	❒	❒
Protein structure and conformation analysis	❒	❒	❒	❒	❒
Enzymatic process engineering (enzyme kinetics)	❒	❒	❒	❒	❒
Identification and quantification of metabolites and hormones	❒	❒	❒	❒	❒
Analysis of food chemical composition	❒	❒	❒	❒	❒

(7.4) Microorganisms and microbiological or enzymatic processes

From the list below, indicate the degree of development of each **R&D capability** within your R&D group.

Scientific or technological R&D capability	Degree of development of each R&D capability within your R&D group (mark with an '**x**' the corresponding options)				
	Not Developed 1	Low Development 2	Medium Development 3	High Development 4	Very high Development 5
Plant growth promoters	❒	❒	❒	❒	❒
Agents for biological control of pests	❒	❒	❒	❒	❒
Bioactive compounds production	❒	❒	❒	❒	❒
Bio-fuels and y bio-refining	❒	❒	❒	❒	❒
Microbial processes engineering and bio-reactors	❒	❒	❒	❒	❒
Biological process scale up (pilot or industrial)	❒	❒	❒	❒	❒
Recovery and purification of bio-products	❒	❒	❒	❒	❒
Biological products formulation	❒	❒	❒	❒	❒
Fermentation on solid or liquid substrates	❒	❒	❒	❒	❒
Wood bio-processing and y bio-bleaching	❒	❒	❒	❒	❒
Bio-remediation, bio-filtration, or biodegradation	❒	❒	❒	❒	❒
Enzyme and other metabolites production	❒	❒	❒	❒	❒
Food safety	❒	❒	❒	❒	❒

(7.5) Immunoassays and vaccines

From the list below, indicate the degree of development of each **R&D capability** within your R&D group.

Scientific or technological R&D capability	**Degree of development of each R&D capability within your R&D group** (mark with an '**x**' the corresponding options)				
	Not Developed 1	**Low Development 2**	**Medium Development 3**	**High Development 4**	**Very high Development 5**
Viral vaccines (attenuated or inactive virus)	❒	❒	❒	❒	❒
Bacterial vaccines	❒	❒	❒	❒	❒
Recombinant sub-unit vaccines	❒	❒	❒	❒	❒
Immunodiagnostics (immunological techniques)	❒	❒	❒	❒	❒
Immunodiagnostics (molecular techniques)	❒	❒	❒	❒	❒
In-vitro immunoassays	❒	❒	❒	❒	❒
In-vivo immunoassays	❒	❒	❒	❒	❒
Antibody engineering	❒	❒	❒	❒	❒
Cell receptors, cytokines and cell communication	❒	❒	❒	❒	❒

(7.6) Laboratory-analysis techniques and instruments, products assessment methods:

From the list below, indicate the degree of development of each **R&D capability** within your R&D group.

Scientific or technological R&D capability	Degree of development of each R&D capability within your R&D group (mark with an '**x**' the corresponding options)				
	Not Developed 1	Low Development 2	Medium Development 3	High Development 4	Very high Development 5
Flow cytometry	❐	❐	❐	❐	❐
Fluorescence microscopy (epifluorescence, confocal, etc.)	❐	❐	❐	❐	❐
X-rays Crystallography	❐	❐	❐	❐	❐
Mass spectrometry	❐	❐	❐	❐	❐
Radioimmunoassay	❐	❐	❐	❐	❐
Nuclear magnetic resonance spectroscopy (NMR)	❐	❐	❐	❐	❐
Chromatography (HPLC, gas chromatography, etc.)	❐	❐	❐	❐	❐
Thermocycler for Real Time PCR	❐	❐	❐	❐	❐
Bio-sensors: bio-molecule y pathogen detection techniques	❐	❐	❐	❐	❐
Bio-assays: evaluation and validation of biotechnologies	❐	❐	❐	❐	❐

If you want to leave any additional comment, please write it down in the box below

Thank you very much for your kind participation in this survey!

Appendix 8.6: List of interviewees (CONFIDENTIAL)

Note: Names and organisational affiliation of interviewees are deliberately omitted for confidentiality purposes.

Reference code	Interviewee name	Organisation	Date of interview
Interviewee A	CONFIDENTIAL	CONFIDENTIAL	18/3/2011
Interviewee B	CONFIDENTIAL	CONFIDENTIAL	8/11 and 9/12, 2010
Interviewee C	CONFIDENTIAL	CONFIDENTIAL	18/3/2011
Interviewee D	CONFIDENTIAL	CONFIDENTIAL	2010
Interviewee E	CONFIDENTIAL	CONFIDENTIAL	2011
Interviewee F	CONFIDENTIAL	CONFIDENTIAL	2011
Interviewee G	CONFIDENTIAL	CONFIDENTIAL	2011
Interviewee H	CONFIDENTIAL	CONFIDENTIAL	22/7/2011
Interviewee I	CONFIDENTIAL	CONFIDENTIAL	23/11/2010
Interviewee J	CONFIDENTIAL	CONFIDENTIAL	25/3/2011
Interviewee K	CONFIDENTIAL	CONFIDENTIAL	15/8/2011
Interviewee L	CONFIDENTIAL	CONFIDENTIAL	23/3/2011
Interviewee M	CONFIDENTIAL	CONFIDENTIAL	21/3/2011
Interviewee N	CONFIDENTIAL	CONFIDENTIAL	1/4/2011
Interviewee O	CONFIDENTIAL	CONFIDENTIAL	25/3/2011
Interviewee P	CONFIDENTIAL	CONFIDENTIAL	27/7/2011
Interviewee Q	CONFIDENTIAL	CONFIDENTIAL	31/3/2011
Interviewee R	CONFIDENTIAL	CONFIDENTIAL	25/3/2011
Interviewee S	CONFIDENTIAL	CONFIDENTIAL	21/3/2011
Interviewee T	CONFIDENTIAL	CONFIDENTIAL	30/3/2011
Interviewee U	CONFIDENTIAL	CONFIDENTIAL	28/7/2011
Interviewee V	CONFIDENTIAL	CONFIDENTIAL	26/7/2011
Interviewee W	CONFIDENTIAL	CONFIDENTIAL	16/8/2011
Interviewee X	CONFIDENTIAL	CONFIDENTIAL	25/7/2011
Interviewee Y	CONFIDENTIAL	CONFIDENTIAL	31/8/2011