THE BUILDING OF AGRO-BIOTECHNOLOGY CAPABILITIES IN SMALL COUNTRIES: THE CASES OF COSTA RICA, NEW ZEALAND AND URUGUAY

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Isabel Bortagaray

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THE BUILDING OF AGRO-BIOTECHNOLOGY CAPABILITIES IN SMALL COUNTRIES: THE CASES OF COSTA RICA, NEW ZEALAND AND URUGUAY

Approved by:

Dr. Susan E.Cozzens, Advisor
School of Public Policy
Georgia Institute of Technology

Dr. Philip Shapira
School of Public Policy
Georgia Institute of Technology

Dr. Hector Herrera
Consultant; (retired) Organization of American States (OAS)

Dr. Juan Rogers
School of Public Policy
Georgia Institute of Technology

Dr. Kirk Bowman
Sam Nunn School of International Affairs
Georgia Institute of Technology

Date Approved: July 05, 2007•

To my loving daughter, Manuela
To Felipe
To my parents

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LIST OF ABBREVIATIONS

Costa Rica

CATIE	Tropical Agronomic Centre of Research and Education (Centro Agronómico Tropical de Investigación y Enseñanza)
CENAT	High Technology National Centre (Centro Nacional de Alta Tecnología)
CIA (UCR)	Agronomic Research Center (Centro de Investigaciones Agropecuarias)
CIB (ITCR)	Biotechnology Research Center (Centro de Investigaciones en Biotecnología)
CIBCM - (UCR)1	Cellular and Molecular Biology Research Centre (Centro de Investigación en Biología Celular y Molecular), 1977
CIGRAS (UCR)	Research Center on Grains and Seeds (Centro de Investigaciones en Granos y Semillas)
CIPRONA (UCR)	Research Centre in Natural Products (Centro de Investigaciones en Productos Naturales)
CNTB (MAG)	National Technical Commission of Biosecurity (Comisión Nacional Técnica de Bioseguridad)
CTB - (MAG)	Technical Commission of Biosecurity (Comisión Técnica de Bioseguridad)
CONARE	National Council of Rectors (Consejo Nacional de Rectores)
CONICIT	National Council for Scientific and Technological Research (Consejo Nacional para Investigaciones Científicas y Tecnológicas, 1972)
CORBANA	National Banana Corporation (Corporación Bananera Nacional, Public non-governmental entity, created in 1971)
INBIO	National Biodiversity Institute (Instituto Nacional de Biodiversidad)
IICA	Interamerican Institute for Agriculture Cooperation (Instituto Interamericano de Cooperación para la Agricultura)
ITCR	Costa Rica Technological Institute (Instituto Tecnológico de Costa Rica)
MICIT	Science and Technology Ministry (Ministerio de Ciencia y Tecnología)
UCR	University of Costa Rica (Universidad de Costa Rica)
UNA	National University (Universidad Nacional)

New Zealand

CRIs (1992)	Crown Research Institutes

[1] Note that the name in parentheses indicates the hierarchical organization to which they belong.

DSIR - (MAF) +	Department of Scientific and Industrial Research
ERMA – (MFE)	Environmental Risk Management Authority
FRST	Foundation for Research, Science & Technology
LIC	Livestock Improvement Corporation Ltd.
MAF	Ministry of Agriculture and Forestry (former Ministry of Agriculture and Fisheries)
MFE	Ministry for the Environment
M&WNZ	Meat & Wool New Zealand
MoRST	Ministry of Research, Science and Technology
NZBio	NZ Industrial Association of Biotechnology
NZT&E (2003)	New Zealand Trade & Enterprise
RSNZ	Royal Society New Zealand
TEC	Tertiary Education Commission

Uruguay

AUDEBIO	Uruguayan Association of Biotechnology (Asociación Uruguaya de Biotecnología)
CERV	Commission of Risk Assessment of GMOs (Comisión de Evaluación de Riesgo de Vegetales Genéticamente Modificados)
CONICYT (MEC)	National Council of Innovation, Science and Technology (Consejo Nacional de Innovación, Ciencia y Tecnología)
CSIC (UR)	Scientific Research Council (Comisión Sectorial de Investigación Científica)
DGSA (MGAP)	General Directorate of Agricultural Sanitation (Dirección General de Sanidad Agrícola)
DGSG (MGAP)	General Directorate of Cattle Services (Dirección General de Servicios Ganaderos)
IIBCE (MEC)	Institute of Biological Research 'Clemente Estable' (Instituto de Investigaciones Biológicas 'Clemente Estable')
INASE	National Institute of Seeds (Instituto Nacional de Semillas)
INIA	National Institute of Agricultural Research (Instituto Nacional de Investigaciones Agropecuarias)
LATU	Technological Laboratory of Uruguay (Laboratorio Tecnológico del Uruguay)
LMSCI (MGAP)	Laboratory of soil microbiology and control of inoculants (Laboratorio de Microbiología de Suelos y Control de Inoculantes)
MEC	Ministry of Education and Culture (Ministerio de Educación y Cultura)
MGAP	Ministry of Livestock, Agriculture and Fisheries (Ministerio de Ganadería, Agricultura y Pesca)
PEDECIBA	Program for Basic Sciences Development (Programa de Desarrollo de las Ciencias Básicas)
PDT (MEC)	Program of Technological Development (Programa de Desarrollo Tecnológico)
UR or UdelaR	University of the Republic (Universidad de la República)

SUMMARY

This dissertation research focuses on the determining role of the institutional environment, including policies, institutions (rules of the game) and the web of related organizations (players of the game), on the building of agro-biotechnological capabilities in small countries. Furthermore, the main claim of this research is that the characteristics and dynamics (patterns of change) of the **institutional environment** critically affect the **building of capabilities by enabling/hindering the emergence of opportunities to move from being capable to innovative-based functioning,** and shape the specific trajectories of **agro-biotechnological capabilities** in small countries. Capabilities constitute a necessary condition, but the opportunities driven by the institutional environment are key to move from being capable to actually function and make them concrete and sustained achievements.

The key question is whether the institutional environments in Costa Rica, New Zealand and Uruguay have evolved in a way that has fostered or hindered the transition towards modern biotechnology at the level of firms and sector. Biotechnology provides a particularly interesting area of study because of the dramatic changes it has gone through since the 1970s and consequently, it allows to study the transition from 'second generation' to 'third generation' biotechnology. Differences in the institutional environments of the three countries studied here critically affect the emerging opportunities of encounter, collaboration and synergy within and between knowledge users and producers, and furthermore of developing a cumulative and sustained capabilities' trajectory.

For technological opportunities to emerge, the institutional environment requires some coherence to make accumulation possible; to be open, both related to the ability to include different actors and approaches, but also to be able to revise, and change based on the ongoing experience. Clear rules of the game are important, as it is the ability to enforce them. Fundamentally, institutional environment need to support and foster interaction among different kinds of actors and knowledge types.

From a broader perspective, I argue that the more rigid the institutional environment is, the more that firms are locked in traditional biotechnology. Failure to adapt and change the priorities and modes of operation, the patterns of collaboration, and the design of institutions, policies and the web of related organizations will constrain the building of modern biotechnological capabilities. I concentrate on two specific aspects: (i) the way in which institutional environment and technological capabilities have evolved over time, and whether this has fostered or hindered the building of more innovative capabilities; and (ii) the linkages and relationships between the constituent actors in the sectoral system, with a focus on the dynamics underlying these relationships. There are two reasons to focus on linkages and relationships: (i) because smallness and the consequent lack of resources makes transversal exchange vitally important to compensate for that scarcity; and (ii) because biotechnology requires some collaboration and exchange between different cognitive sources due to its interdisciplinary and multidisciplinary character.

The work presented here is anchored in the broader issue of change and adaptation, and concerned with the way in which institutional environments change, and whether these enhance or hinder the building of technological capabilities. The following paragraph from Nelson (1994a) succinctly illustrates the fundamental question that

orients this study, "A broader question, of course, is whether the larger set of institutions supporting the established technology and industry are able to adapt, or whether their conservatism makes it difficult for established firms to shift away from old practices, or for new firms to enter and take over” (Nelson 1994a).

This analysis is framed following the concept of the 'sectoral system of innovation and production' (Malerba 2002). It aims at contributing to the discussion about how technological change and institutional change are mutually inter-dependent. Finally, it focuses on small countries because country size matters for competitiveness and innovation. Size imposes a number of constraints on small countries including limited availability of resources, reduced market size and critical mass, higher reliance on exports and greater vulnerability to trade shocks. However, it is argued that rather than size, the key factors in competitiveness are flexibility, preparedness and the ability to adapt and respond to changes in economic conditions (Walsh 1988). Start typing the summary here.

CHAPTER 1.

INTRODUCTION

1.1. Introduction

In today's world every dimension of our concrete life has changed compared to few decades ago. Throughout many dimensions of our life, we concretely experience the widening and diversification of alternatives and resources. There is higher mobility of resources across the globe, and also the mechanisms to access those resources have changed. A firm from one corner of the world faces very different challenges today than few years go, and some of the resources on which it draws on have also changed. For instance, the speed and the mechanisms to access information have improved. That firm might be part of a global network for sharing information and experience on their use of resources, production, or commercialization practices. At the end of the day however, when things have to get done, those global patterns and widened alternatives become only one tiny part of the picture. Other part of the story might be that every week that same person with global connections, recognition and valuable experience, spend something like a part-time job going from one office to another to get reagents into the country to run a specific experiment, or going up and down stairs across public offices to obtain an approval or a certification to export a micro-propagated plant, or to get a permit to collect an organism from the woods in the search for new properties to combat an animal disease, or might have to spend half of the day making phone calls and looking for resources to know whether it is this ministry office or that other one who should put the stamp to go ahead with a certain productive process. And all these challenges and wasted resources are not because of the process or product is new and has never ever been conducted before, but it happens with routinely procedures that require the similar processes over and over again. And these issues might account exactly in the same way in the life of academic researchers.

So, how do these two sides of the story interact? How does the firm cope with these constraints? What of this environmental aspects matter for the firm to get things done? What mechanisms are used to build those capabilities? If they are capable, why still sometimes those capabilities do no translate into achievements? To what extent and in what ways those ‘environmental’ factors affect the firm/academic researcher? And how are these different across countries? Furthermore, how does this work in small countries, which are known to have some special features that overall make them more vulnerable, but which could benefit from smallness in terms of their flexibility, for instance?

To approach this research problem I have explored at the specific features and dynamics of the institutional environments and their role on the development of technological capabilities in the plant-based and animal-based biotechnology industries of three small countries: Costa Rica, New Zealand and Uruguay, and how have they changed over the last decade. I have concretely analyzed the set of organizations, their interactions, the institutions and policies existing in each case study. I also studied the mechanisms followed to build technological capabilities. And, I have looked at how both the environmental institutions and capabilities have changed over time.

This brief paragraphs point out the broad type of problem this dissertation attempts to articulate. It has aimed at responding the following questions: how has the institutional environment affected the building of agro-biotechnology capabilities in these three small countries? Through what processes and dynamics environments and capabilities interact in these contexts? Have their institutional environment been flexible? How have they changed and how capabilities have changed?

1.2. Research background

This dissertation stands in the intersection of three main themes. The first one is linked to the small size of the countries studied, and the empirical question about their flexibility. Country size matters as size imposes a number of constraints on small countries such as limited availability of resources, reduced market size and critical mass, higher reliance on exports and greater vulnerability to trade shocks. However, it is argued that rather than size, what is crucial for small countries' competitiveness is their flexibility, preparedness and the ability to adapt and respond to changes in economic conditions (Walsh 1988). It is argued that small countries are much more reliant on their ability to be flexible than larger ones (Johnson 1988).

The second theme relates to the area of study: agro-biotechnology; that is the application of biotechnology to agricultural products and/or processes. The three countries studied here are small countries, with less than 4.5 million people. These countries have been highly dependent on agriculture for their economy, as well as for the historical integration and structure of their societies. On the other hand, biotechnology, understood as the use of biological organisms with commercial purpose is a very old endeavor (i.e. fermentation), yet in the last decades it has undergone radical changes and discoveries in molecular biology, with major implications at various levels: from the widening of research problems and areas of study, to the need to combine cognitive and disciplinary fields to approach these new problems, to new products such as genetically modified seeds designed to enhance a certain attribute of the seed or plant, and processes such as cloning previously unimagined. Most recent innovation studies have tended to concentrate on these newer biotechnologies, dismissing the potential of older ones, which are still alive and hold their own potentiality. For agriculture, the latter are vastly utilized and probably will remain so for long time.

The third theme refers to technological capabilities and institutional environments. Mainstream innovation studies on these issues mainly emphasize economic aspects, yet a large part of them draw on Institutional Economics (i.e. choices and preferences are embedded in institutions) and/or Evolutionary Economics (i.e. choices and individuals evolve and change, and principles behind those evolutionary process need to be identified) which both consider the importance of social factors, bringing into sociological, and political dimensions, including policy aspects. Still they tend to concentrate on the economic processes and dimensions underlying technological capabilities. Nevertheless, this dissertation attempts to both: reflect some of the insights of these schools of thought, but also refract them to emphasize the sociological and policy aspects related to the processes of building technological capabilities.

Finally, this work is framed in the ‘sectoral system’ approach proposed by Malerba (2002) to analyze the innovation dynamics. This framework is useful both to organize the approach to the relationships, and to concretely map the structure and dynamics taking place in these case studies.

1.3. Research significance

The subject matter of this research, and the specific choice of sector and countries are of interest for at least four reasons. First, in spite of the vast library on innovation studies there is still need to better understand innovation dynamics in small countries, particularly those outside the set of small European countries. When it comes to innovation, smallness has both advantages and disadvantages. Within the former, smallness might be a source of competitive advantage as in some cases limited size is associated with flexibility and specialization, which are important characteristics of economic production and competitiveness. Still some of their disadvantages relate to structural constraints characteristic of smaller countries, including reduced market size, greater reliance on foreign trade, and the need to for firms to commercialize abroad to recoup their investments in R&D.

Secondly, innovation studies tend to prioritize on innovations related to knowledge frontiers, even though there are some scholars dedicated to better understand the dynamics of innovation in developing countries, and in 'less' innovative sectors[2]. But it is vital to improve our understanding of technological dynamics in organizations that might not be producing at the frontiers of knowledge, and are more oriented to technological acquisition and improvement, especially when these are located in countries with structural constraints (Lall 2000).

Third, innovation studies have focused on high-technology sectors as the main repositories of knowledge and learning. However, some scholars are claiming that traditional sectors that are often considered low-tech still play an important role in the learning economy as users of technology (Smith 2002).

[2] The Institute for New Technologies of the United Nations University (UNU/INTECH) has been one of these organizations. Another one is GLOBELICS, the Global Network for Economics of Learning, Innovation, and Competence Building Systems, which is dedicated to strengthen research and linkages between different contexts, regions, and research communities across the globe. International organizations have also studied similar issues, as well as individual scholars in very different parts of the world, and across the research spectrum.

The focus on the intersection between agricultural biotechnology in the specific context of small countries with an important agricultural sector intends to emphasize this sector's high knowledge-intensity character with the close connection to primary production in agriculture. The last reason is that most studies of innovation are economic studies, but this research attempts to bridge the study of public policy and related theories to innovation research by looking at science and technology from the perspective of the policy sciences.

1.4. Justification of the field and countries studied

Biotechnology provides a particularly interesting area of study because of the dramatic changes undergone since the 1970s. There are older and newer biotechnologies, and they vary in their costs, cognitive and disciplinary complexity, resources required, as well as in terms of the regulations and institutions involved. Thus, the question of how has the institutional environment in these three countries changed and whether it has adapted to enable this transition from older to newer biotechnologies becomes very relevant, and calls for empirical research. The focus on biotechnology applied to agriculture responds to the need to better understand how innovation dynamics operate in more mature sectors, which, as mentioned above, are oftentimes regarded as 'low tech'.

The choice of Costa Rica, New Zealand and Uruguay as small countries is due to the following reasons: (i) first, they are relatively similar in population terms, though this is changing as seen in the table above. By the year 2000 they had less than 4 million people; today only Uruguay remains in that category. Still these countries are small in populations terms, and less than 4.5 million people; (ii) second, Uruguay and New

Zealand have been traditionally compared as they both share an economic historic trajectory as part of the group of modern settler economies in temperate climate[3]; (iii) third, Costa Rica and Uruguay share an important cultural background, as well as their tradition in democratic values, advanced economic development, being paradigmatic cases of modern welfare states during the mid 20th century. Furthermore, they were both known as the ‘Switzerland of Central and South America, respectively; (iv) fourth, agriculture has been the fundamental sector for their development, accounted for societal structures, and even positions in the international markets. However there are some differences regarding their agricultural paths: Costa Rica relies less on exports of primary products as percentage of manufactured products than New Zealand and Uruguay, which show relative similar shares. There are also differences in terms of the type of agricultural products grown in each country, as well as in the productive dynamics. Costa Rica’s agriculture has been more crops-based, mainly banana and coffee, while in Uruguay and New Zealand cattle and sheep used to be their main agricultural products. At some point in time they both were perceived as Great Britain’s farms because of the importance of that country for their exports[4]; and, (v) fifth, the three of them show differences in terms of the composition of their agriculture and manufacturing exports as a percentage of total goods exports: most of Costa Rica’s exports in agriculture and manufacturing (as percentage of total goods exports) are high tech, while in New Zealand and Uruguay the least share is high tech (5 and 2 percent respectively). But while in New Zealand most are

[3] This perspective often compares the divergent patterns of countries which used to enjoy similar (or even more advantageous) points of departure and growth rates in the 19th century. In this perspective some of the countries often compared are New Zealand and Uruguay, as well as Argentina and Australia.
[4] See chapters 4,5 and 6 for the analysis of each country’s specific background.

medium-tech, in Uruguay are low-tech exports in agriculture and manufacturing (as percentage of total goods exports).

Furthermore, these countries differ in patterns of change also vary across these countries. As said earlier, the three of them are small in population terms: they have between 4.3 and 3.4 million people (Costa Rica and Uruguay respectively, 2004), with an area between 51 and 271 thousands square kilometers (Costa Rica and New Zealand respectively, while Uruguay has 175 thousand square kilometers). However, and in spite of their common smallness, the rate at which they are growing is different, and overall patterns of change drastically differ. Regarding population size, while by the year 2000 they all had less than 4 million people, today Uruguay is the only one that remains below that ceiling. By 2015, Uruguay will still have less than 4 million people, Costa Rica will be the one that has grown the most with 5 million, and New Zealand will have around 4.3 million population (UNDP 2005; UNDP 2006). Another commonality, already mentioned, is their historical reliance on agriculture and primary products for exports. But again with respect to this issue, differences arise. In Costa Rica agriculture has accounted for 70% of exports between 1970 and 1997, but since then that trend is shifting. While in 1990 agriculture represented 51% of total exports, a decade later it meant 24% of exports (Proyecto Estado de la Nación 2004).

Still the share of agricultural exports in GDP (2002) is relatively similar across the three countries: 9.46%, 11.51%, and 8.10% in Costa Rica, New Zealand and Uruguay, respectively (FAO 2005). However, their contribution to the world's agricultural exports (2002) are very different: Uruguay accounts for 0.22%, Costa Rica does so with 0.36% and New Zealand with 1.53%. Regarding these countries contribution with the world's agricultural GDP, Costa Rica and Uruguay have a relatively similar one (0.13%, and 0.12% respectively), while New Zealand's is more than two times higher (0.35%) (FAO 2005).

Thus, this dissertation attempts to analyze some of the hows and whys of the institutional environment patterns that play a role in the different trajectories. The comparative level contributes to the understanding of innovation dynamics beyond the challenges of comparative studies driven by uniqueness of these cases (see below the methodology section).

Table 1.1. Overview of Costa Rica, New Zealand and Uruguay

	Costa Rica	New Zealand	Uruguay
Population (2004)	4.3	4	3.4
Population (2000)	3.9	3.7	3.3
Population (estimated by 2015)	5	4.3	3.7
HDI rank, 2004	#48	#20	#43
HDI rank, 2001	#41	#19	#37
GDP per capita (PPP US$), 2004	9,481	23,413	9,421
R&D expenditures (as% of GDP), 2000-03	0.4	1.2	0.3
Public expenditure on education (as % government total expenditure), 2004	18.5	15.1	7.9
Current public expenditure on education by level (% of all levels)			
Pre-primary and Primary, 2002-2004	65.7	28.1	36.5 (1991)
Secondary, 2002-2004	34.3	41.7	29.3 (1991)
Tertiary, 2002-2004	36.1 (1991)	24.5	24.4 (1991)
Mean years of schooling (age 15 and above) 2000	6.1	11.7	7.6
Researchers in R&D (per million people), 1990-2003	368	3,405	366
Tertiary students in science, math and engineering (as % of all tertiary students) 1999-2004	23	19	24 (1994-97)
Total graduates in all programs. Tertiary	23,345	47,565	6,904
Enrolment in agriculture. Tertiary. Total	3,609	2,863	N/d
Telephone mainlines (per 1,000 people), 2004	316	443	291
Internet users (per 1,000 people), 2004	235	788	198
Patents granted to residents (per million people), 2004	9 (1998) (20 total)	-	3 (84 total)
Patents applications (residents, per million people)	N/d	70	N/d
Receipts of royalties and license fees (US$ per person), 2004	0.1	24.7	0.0
Imports of Goods and Services (as % of GDP) 2004	49	29	28
Exports of goods and services (as % of GDP) 2004	46	29	30
Primary exports (as % of merchandise exports) 2004	37	65	68
Manufactured exports (as % of merchandise exports) 2004	63	31	32
High-technology exports (as % of manufactured exports) 2004	37	14	2
Technology Achievement Index Rank	#36 (leader)	#15 (leader)	#38 (dynamic adopter)
Low-technology exports in agriculture and manufacturing (as % of total goods exports) 1999	13	8	24
Medium-technology exports in agriculture and manufacturing (as % of total goods exports) 1999	8	10	12
High-technology exports in agriculture and manufacturing (as % of total goods exports) 1999	44	5	2

Source: (UNDP 2001; RICYT 2006; UNDP 2006)

1.5. Research problem, research questions, and definitions

1.5.1. Research problem

This section outlines the main issues as discussed in the literature, yet they are analyzed in more detail in chapter three. There is relative agreement upon regarding the building of technological as a result of resources and strategies internal and external to the firm/organization. Technological capabilities relate to the complex of skills, experience and efforts that enable the firm (and/or sector) to efficiently buy, use, adapt, improve, and create technologies (Lall 2000), and they include capabilities in production, investment, innovation (Kim 1999) and linkages (Lall 1992).

On one hand the building of technological capabilities depends on internal resources such as the firm's strategies to acquire and absorb knowledge, and associational strategies oriented towards collaboration with external partners. On the other hand, the process of building capabilities is influenced by external factors, such as the presence and role of supportive organizations and institutions, the interactions and relationships through which experience and knowledge are exchanged, and collaborative efforts takes place. Capabilities are dynamic, and highly influenced by these external factors (Teece, Pisano et al. 2000). That is how and why the subject of institutional environment appears into the problem. And here too, there is relative consensus about the importance of the environment for technological change and innovation in general, and for the building of capabilities building in particular, though it is not so clear how and through what mechanisms the environment affects these processes. This is one of the (relative) blanks this dissertation tries to fill in.

In the innovation literature, institutions are seen as fundamental drivers of innovation and competitiveness. The role of institutions in innovation is of particular relevance because of the nature of innovation. Innovation is a social process, as it results from interactions among different and multiple actors, and it is based on the combination of 'learning' and 'searching' (Andersen and Lundvall, 1988; Johnson 1988). In the case of small countries, institutions are of particular relevance because of the need for small countries to be flexible, and prepared to successfully respond to changes in production dynamics. As it was mentioned above, flexibility is for small countries an important source of competitive advantage (Johnson 1988, Walsh 1988). Thus, an important question is about the characteristics of institutional change during the 1990s, and whether these countries' change has been oriented towards higher flexibility or rigidity.

This research attempts to determine the role and dynamics through which the institutional environment, including policies, institutions (rules of the game), and the web of related organizations (players of the game), affect the building of agro-biotechnological capabilities in small countries. Capabilities constitute a necessary condition, but are capabilities enough? I claim that the characteristics and dynamics (patterns of change) of the institutional environment critically affect the building of capabilities by enabling/hindering the emergence of opportunities for sectoral actors to move from being capable (holding capabilities) to actually achieving innovative-based functioning, and shape the specific trajectories of agro-biotechnological capabilities in small countries.

The environmental dynamics matter for the type of capabilities being built. The more rigid the institutional environment is, the more the firms are locked in tight and less innovative biotechnological capabilities. I concentrate on two specific aspects: (i) the way in which institutional environment and technological capabilities have evolved over time, and whether this has fostered or hindered the building of more innovative capabilities;

and (ii) the linkages and relationships between the actors in the sectoral system. There are two reasons to focus on linkages and relationships: (i) because smallness and the consequent lack of resources makes transversal exchange vitally important to compensate for that scarcity; and (ii) because biotechnology requires collaboration and exchange between different cognitive sources due to its interdisciplinary and multidisciplinary character.

On a broader level, this study attempts to contribute to the articulation of industrial, technological, and institutional dynamics. It is framed in the discussion about how technological change and institutional change are mutually inter-dependent. In this, it is claimed that "new technologies often are not well accommodated by prevailing institutional structures, and require institutional reform if they are to develop effectively" (Nelson 1994a) (p.58).

1.5.2. Research questions

Research questions are at two levels: the sectoral and the individual level of organizations, including both firms and research centers. Within the former level, research questions have to do with:

- What are the characteristics of the institutional environment across case studies?
- How coherent are they, and in what sense?
- How thick the institutional environments are?
- How cohesive these environments are?
- How have they changed over time?
- Have they been ruled by inertia and rigidity?

- What has been the extent of their change?
- How has changed been carried through?
- How stable and persistent have these environments been?
- How does the mapping of the sector currently looks like?
- What are the core, and boundaries?
- What types of organizations constitute them?
- What are the interaction and relational patterns at the sectoral level?
- How are the patterns in terms of connectedness, durability, institutionalization and symmetry of relationships?
- What types of relationships do the actors hold?
- Who is involved? For what purposes? With whom?
- What are the characteristics and dynamics of institutions and policies across case studies?

Within the latter, the research questions refer to:

- What are the types of technological capabilities hold by sectoral actors?
- What mechanisms do they implement to build them?
- What mechanisms? To do what? Who gets involved within the organization and outside? For how long, and in what loci are these mechanisms implemented?

1.5.3. Definitions

Now I turn into briefly defining the concepts on which this dissertation stands.

- *Technological capabilities*

Technological capabilities could be characterized as the set of existing and gained abilities both at the firm and/or sectoral levels, which require a wide range of skills and resources, and processes for their enhancement and development, along a scale of increasingly complex tasks (productive, and associational) demanding different orders of involvement, commitment, appropriation and mastering throughout various dimensions that are considered relevant for agro-biotechnology. This definition stresses the importance of time and loci. Thus, the temporal level of to what extent are capabilities sustained over time, and the features of the loci in which they take place.

- *Institutional environment*

The concept of institutions is quite fuzzy, as in some cases it refers to the rules of the game as defined by (North 1990), while in others it is used in a broader sense, and covers organizations such as university departments or R&D laboratories (players of the game). In this work, the institutional environment refers to organizations and their interactions (players of the game), institutions (rules of the game), and policies.

- *Sectoral systems*

According to Malerba (2004) "A sector is a set of activities that are unified by some related product group for a given or emerging demand and that share some basic knowledge" (pp.9-10). They comprise three building blocks: knowledge and technology, actors and networks, and institutions.

- *Small countries*

Smallness in this research is in population terms. The three countries have less than 4.5 million people. Uruguay is the smallest country with 3.323 million, then New

Zealand with 4.180 million, and Costa Rica has 4.4 million people (2007). It is interesting to note that by the year 2000 the three countries had less than 4 million inhabitants.

- *Biotechnology*

Biotechnology is understood as "the application of biological organisms, systems, and processes to manufacturing or service industries" (ACARD 1980). Agro-biotechnology refers to those biotechnologies which have an impact on agriculture. Agriculture involves the use of the natural resource base to produce crops, livestock, fish and trees (Komen and Persley 1993), and agro-foods. Agro-biotechnologies then include animal-, and plant-based biotechnologies[5], as well as bioprocesses, which are used for agro-foods, and environmental management, among others. Biotechnology is classified in three generations depending on the age/novelty of the techniques. First generation biotechnology is mainly the one implemented since the New Stone Age, characterized by fermentation. Second generation biotechnology refers to the screening and categorization of organisms for their exploitation and useful application. Third or modern biotechnology belongs to the 1970s driven in part by the fundamental breakthroughs developed in genetic engineering, and molecular biology. The 1970s give birth to the third generation biotechnology with two breakthroughs in molecular biology: "…the discovery of a mechanism by which part of a foreign gene could be inserted into another and change its characteristics (recombinant DNA) and techniques for fusing and multiplying cells (hybridomas) –heralded the coming of genetic engineering" (Sharp and Senker 1999).

[5] This dissertation only focuses of these two areas of application of biotechnologies.

1.6. Methodology

This research draws upon a qualitative methodological approach, based on case study methodology to study the agro-biotechnological capabilities in small countries, and how do institutional environments affect the way firms and sectors build these capabilities. It also attempts to contribute to the theoretical discussion on institutional dynamics and their relation to processes of capabilities building.

The research is based on a multiple-case design, with embedded units of analysis, as it is focused on both the sector and the firm. The study of multiple cases is not aimed at representing small countries; or as Yin's (1994) frames it, multiple case studies are framed on replication logic rather than on a sampling logic, in which each case replicates a broader theoretical framework instead of representing a larger category of respondents. It rather intends to provide insights for developing a theoretical framework on capabilities and institutional environments. The case study technique is appropriate because of the complexity of the phenomenon studied as there are multiple layers involved including actors, their interactions and dynamics characterizing innovation, and the importance of context, and the historical dimension for the building of capabilities (Yin 2003).

Comparative research constitutes an important resource in innovation studies, but at the same time entails important methodological challenges given the uniqueness character of some events and processes. As pointed out by Heidenheimer, Heclo et al. (1990) “For comparisons to be possible, we must overlook a great many of the special features that make a country, policy, or decision unique. Every action is part of a particular context, but since every context is different, how can we make comparisons across time or national borders and be sure we are really comparing like with like, apples to apples instead of apples to oranges? […] comparative strategies, far from being stymied by the problem of uniqueness, can show a versatility depending on the analytic purpose at hand. We can compare apples and oranges, and there is no reason or need to decide in the abstract whether it is the similarities or differences that matter most. If our purpose is to establish better dietary guidelines, the difference between apples and oranges may not matter one bit as long as one of the two substitutes for junk food. If we are trying to make a pie or plant a fruit tree in a northern climate, the differences are all that matters" (Heidenheimer, Heclo et al. 1990).

1.6.1. Data collection

This study relies fundamentally on primary data provided by the in-depth interviews conducted personally, based on a semi-structured questionnaire. The interview took an hour average, and was designed to get some factual information about the individual's and organization's background and trajectory, and to make them elaborate on some of the processes and dynamics relevant for this study (See Appendix II). The interview protocol had slight variations, depending on whether the interview was directed to a firm, a research organization or a policy actor. Interviews to firms and research organizations included a separate section with a list of biotechnologies; in those cases interviewees were asked to mark which biotechnologies were utilized/produced by them, and for what purpose.

In each country interviewees were first approached by email, and invited to voluntarily collaborate in the study. After the first email, I contacted them either by phone or email again, to schedule the meeting. The interviews were digitally recorded to improve the accuracy, and stored in a computer. When available, I asked for additional information about the organization such as brochures, reports, etc.

The selection of interviewed organizations was based on (a) sectoral and outsider 'experts' opinions which I approached based on professional contacts and local 'entry points', (b) information from previous surveys and studies, and (c) a snowball approach in which interviewees were asked to suggest alternative individuals who were identified as part of the sector.[6]

I conducted a total of 72 in-depth interviews to researchers, firms' managers, intermediary and supportive organizations, and policy actors in the three countries. From the total interviews, 27 were done in Costa Rica in April 2005, 23 in New Zealand in May 2005, and 22 in Uruguay between May and July 2004. The following table indicates the total interviews in each country by category.

6 In Uruguay, there has been a study of the sector, but it is very superficial as it is mainly based on information from websites (INIA-MEC-DINACYT, 2001). In New Zealand, there has been a survey of biotechnology capabilities (including pharmaceutical and agricultural), which describes at an aggregated level, the strength of the sector in terms of # of patents, collaboration efforts, publications, human resources and presents some weaknesses such as financial tools. See Cooper, R. (2003). The New Zealand Biotechnology Industry Capability Survey. Wellington, BIOTENZ/New Zealand Trade and Enterprise/Biosphere.

Table 1.2. List of interviewees by category

	Costa Rica	**New Zealand**	**Uruguay**
Academic researchers	14	1	8
Hybrid research organizations	3(•)	4	1(*)
Firms	6	2	9
Intermediary-supportive organizations	1	6	1
Regional/Local innovation fostering (incubators)	-	2	-
University technology transfer offices	1	2	-
Corporative associations	(•) (levy-based org.)	1 (levy-based org.)	
Venture capital org.	-	1	-
Policy/regulatory agents	3	7	2
(sectoral outsiders) Social Analysts	-	3	1
Total	27	23	22

(•) One of these three hybrid organizations is a corporate association of producers. It plays two functions, the lobby and corporative one, and research as well. However, it is not double counted because the interviewed individual is a representative of the R&D department.
(*) Even though an important part of the funding of this organization is based on levies, it mainly acts as an agricultural research organization.

Secondary data such as archival data from newspapers, memos, and reports, among others also informed this research. Different resources were consulted to identify significant events both at the individual level of organizations, and at the sectoral one. The identification of historical events was necessary to trace the pattern of evolution of the institutional environment.

1.6.2. Data analysis

The analysis involves two levels, (i) the within-case based on the national level, and (ii) the cross-case level based on the comparison of the three case studies. Thus, each case study was first analyzed individually, to then pursue the second comparative stage. This comparative dimension is of utmost importance to the study as it provides more analytical and explanatory character. The analysis at all levels is strongly permeated by the historical dimension. The analysis of patterns is based on argumentative interpretation, finally supported by the data (Yin 2003). In both levels, the analysis followed a double process of articulating the data through the categories underlying the research questions, and through the broader theoretical categories. Secondly, these categories were analyzed between countries. Contextual aspects of the sectors and broad institutional environment were introduced based on secondary data. Responses were again looked taking these aspects into account.

1.6.3. Methodological limitations: Validity and Reliability

Empirical research, and case study research in particular requires consideration of reliability and validity issues throughout the research design[7]. As for validity, data must be plausible and credible. Yin (1994) proposes to test the quality of case studies through construct validity, internal validity, external validity, and reliability. The concern about construct validity is about how are the constructs or variables built (operationalized) in relation to the original concept. Construct validity refers to the task of variables operationalization, and data collection, and should be attempted by triangulating data, establishing a chain of evidence, and by consulting a third party (qualified informant) with a draft of the research report.

Regarding the concern with the internal validity, that is the causal relationship between independent and dependent variables, the analysis of the data has attempted to match results with specific patterns, and explanation-building (Yin 1994). 'Causality' is

[7] For a general discussion on validity and reliability see Cook, T. D. and D. T. Cambpell (1979). Quasi-Experimentation: Design and Analysis Issues for Field Settings. Boston, Houghton Mifflin Company.

not observed, but narrated based on the in-depth study of different contexts and organizations[8].

External validity refers to specifying the scope of the findings of the study, in the sense of discussing the degree to which results could be generalized. Case studies cannot be generalized to other contexts, but to theories. Studying three cases or one or ten is the same in terms of generalization. These cross-country cases do not account for small countries, but the study of this phenomenon in three different contexts helps to layout some of the complexities under the processes of building of capabilities and the role of institutional factors in such processes. The scope is then given by the connection between findings and theory. Finally the reliability of the study refers to the demonstration that the instruments used are stable so that if collection procedures are repeated, same results should be achieved.

1.7. Limitations

One of the most critical limitations of this work lies on the very nature of the field of agro-biotechnology. Biotechnology far from being a unified technology encompasses a wide range of technologies with varying degrees of complexity, and novelty. These biotechnologies characterize by their pervasiveness as they permeate various productive sectors and could be applied to very different purposes. Rather than a clearly demarcated sector, biotechnology is more of a platform technology enabler of different processes and products with multiple potential applications. This applies even when constrained to agriculture where biotechnology still could be applied to the agro-food sector, forestry,

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[8] Causal connections are always established from ‘outside’: they are inferred from the observed association among events. Singleton, R. A. and B. C. Straits (1999). Approaches to Social Research. New York, Oxford University Press.

and/or animal health. This feature of biotechnology has several implications for this study. One consequence of this fuzziness is that firms are in many cases unique in their area of application and exploitation of biotechnology.

This is aggravated by the small size of these countries and sectors, which encompass not too many firms and variation is not too large, even though there are some differences of density and diversity of firms within the sector between the three case studies. As a result, the cross-case study comparison is more challenging and difficult given that sectors are not strictly identical in the scope of their production. This is even aggravated because I have had to further constrain the areas of biotechnology application (animal- and plant-based biotechnology) for two reasons: one, to make it more coherent and approachable to comprehend the underlying sectoral institutional dynamics; and second, because of the limited resources I had to accomplish this research. For instance, fisheries and trees would have made comparability of these three countries even more difficult and exceed the subject matter analyzed here. That is why the emphases remained on crops and livestock, which have also been key to these countries agricultural trajectories.

A second limitation of this study is that the final users of biotechnology, which are farmers, were not included in the research. In this research the focus converged on the (agro-biotech) link between knowledge production and utilization, and their related actors, which are mainly universities, research centers and firms; apart from policy actors, and intermediary and supportive organizations.

A third important limitation of this work is the lack of precise data about firm's budgets, and particularly on their R&D investment. This is certainly the case for firms both in Costa Rica and Uruguay, where they could not answer the question about estimation of their R&D related budget. This difficulty only reveals part of the way these firms approach R&D, such as the informality involved, often with personnel not exclusively dedicated to these activities, and consequently it is difficult for them to calculate what goes in this category and what does not.

1.8. Structure of the dissertation

The structure of this dissertation is as follows: after this introductory chapter (Chapter One), I briefly describe the different biotechnologies that are applied to agriculture (Chapter Two). The third chapter goes into the theoretical and analytical core of the work. It sketches the rationale and the argument behind the analysis, and reviews previous empirical approaches to the matter of technological capabilities and institutional environments. This third chapter presents the analytical framework that guides the analysis of the next three chapters: Chapter Four on Costa Rica, Chapter Five on New Zealand, and Chapter Six on Uruguay. Then chapter seven presents a comparative overview of the three case studies. Finally, in chapter eight I present the conclusions of the dissertation at three levels, theoretical, empirical and at the policy level. Three appendices are included at the end of the dissertation. The first one presents the case study protocol that has guided this research. The second appendix presents the invitation letter and interview protocol applied to firms, university/research centers, and policy agents. The third appendix outlines the list of secondary data utilized for the dissertation.

CHAPTER 2.

A SNAPSHOT OF AGRO-BIOTECHNOLOGY

2.1. Introduction

This chapter introduces the specificities of biotechnology and its application to agriculture. The first section summarily introduces the main features on biotechnology and how has it changed over time, to then in the second section review some empirical studies applied to different contexts and countries, but with a biased focus in the Americas regions. The third section describes the different biotechnologies from microbial fermentation to rDNA; and the next one briefly refers to the agro-biotech applications to agriculture considered in this dissertation (animal and plant-based biotechnology). The fifth section refers to systemic approaches to biotechnology in the tradition of innovation studies, and the last one the focus is on the sectoral system approach to agro-biotech that frames this research project.

2.2. Meanings and implications of biotechnology

The singular use of the 'biotechnology' noun is a simplification to denote a group of tools involving biological processes with application in many areas. The singular noun is misleading not only because of the multiple biotechnologies, but also because it is often used to denote a set of more modern techniques like genetic engineering, dismissing a whole set of others extendedly applied. These various techniques co-exist within and across countries, yet with important variations in the level of novelty, complexity, costs, mastering and capacities required.

At a broader level, the term biotechnology integrates a set of technologies anchored to biological processes. Biotechnology as the use of biological organisms with commercial purpose is extremely old, yet in the last decades, key discoveries have lead to a new set of techniques developed in the early 1970s, which have revolutionized not only the research method, but also the production system as they entail a wide new range of possible applications. The so called modern or 'third generation' biotechnology refer to discoveries in molecular biology (rDNA, and hybridomas) and a whole new paradigm based on the incoming genetic engineering (GE), as they enable the transformation of the organisms' genetic structure by introducing new genes to carry out new functions (Sharp and Senker 1999).

Studies on biotechnology include various definitions depending on the context of analysis. Some are more restrictive, and focus on novel techniques, while others are more inclusive and consider older biotechnologies such as fermentation. According to the former, "[B]iotechnologies are an array of tools derived from research in cellular and molecular biology that could be applied in any industry that involves microorganisms, as well as animal and plant cells" (Johnston and Sasson 1986). It involves "…three main technologies, recombinant DNA, cell fusion and Bioprocessing" (Fransman 1991). This definition excludes older biotechnologies such as cell and tissue culture (second generation), and/or fermentation techniques (first generation). Older biotechnologies are still widely used and constitute an important toolkit with different applications, which would be missed based on this strict definition. Studies on developing countries often focus on the wider set of biotechnologies, as biotechnological developments would be missed in these countries if based on a strict definition of modern biotech. This is even more critical if research analyzes biotechnology applied to agriculture, where still older biotechnologies account for relevant developments. In most cases, inclusive definitions of biotechnology are found in studies of developing countries. For instance, Falconi's (1999) work of agricultural biotechnology in developing countries, defines it as including "cellular and molecular biology and new techniques coming from these disciplines for improving the genetic makeup and agronomic management of crops and animals [and T]issue culture applications, biofertilizer, and bioinsecticides" (Falconi 1999).

Thus, empirical studies on biotechnology tend to posit it as a ladder of technologies, but then the focus is on one set of steps and previous ones are neglected. Biotechnology refers to a continuum set of pervasive technologies, a platform, that could be applied into a wide range of activities and sectors, including pharmaceuticals, agriculture, chemicals, food and processing industry, and environmental management, among others. In this sense biotechnology resembles process technologies, as its outputs could be introduced into a diverse set of industries (Fransman 1994; Sahai 1999).

Modern biotechnology entails a discontinuity compared to its previous modalities, and that refers to two main changes: (i) the broadening of the knowledge basis required including not only biochemistry, microbiology, and cell-culture fermentation know how, but also molecular biology and genetics, immunology, virology, cell biology and tissue culture; and (ii) the procedures for searching and solving problems, and the heuristics are different as they engage ex ante programming and design of molecules with specific and desired properties, compared to the previous random and slow natural mutation(Orsenigo 1989).

Genetic engineering is seen as the trigger of a new paradigm. It occupies the leading role that previously had fermentation. This new technological platform could be applied into a wide range of activities and sectors, including pharmaceuticals, agriculture, chemicals, food and processing industry, environmental management, etc. However GE has not led to a total replacement of traditional biotechnologies nor incumbent's competencies were reduced as it was predicted by some. On the opposite, in the current scenario genetic manipulation of enzymes with new productive solutions is applied into traditional fermentation and biocatalysis, for instance (Nesta and Dibiaggio 2003). Or in Fransman's words (1991) "In terms of actual achievement, […], it is fair to conclude that at the present time the picture remains mixed. Not only are the new biotechnologies being introduced in limited areas, their rate of diffusion, upon which economic impact ultimately depends, is still very low. While there certainly are rumblings of change, by and large the forces of production of the old regime remain relatively firmly intact. The revolution may come, but most of those who are still, by choice or circumstance, locked into the old technology, or who refuse to be shaken by rumours of the coming winds of technical change, are not yet seriously threatened" (Fransman 1991).

One distinctive feature of biotechnology is its pervasiveness, as the set of techniques synthesized under the name of biotechnology could be utilized and have an impact on "…any current industrial biological process or any process in which a biological catalyst could replace a chemical one" (OTA 1984). Biology itself involves a wide range of knowledge bases or domains such as: cellular biology, molecular biology, physiology, histology, and biochemistry (Nesta and Dibiaggio 2003). Furthermore, biotechnology relies on distinctive disciplines, from chemistry to computing and programming, cell and molecular biology, microbiology, etc.

2.3. Previous research on biotechnology and agro-biotechnology

Most mainstream innovation studies of biotechnology focus on pharmaceutical biotechnology (Orsenigo 1989; McKelvey 1996; Henderson, Orsenigo et al. 1999; Sharp and Senker 1999; Christensen 2003; Coriat, Orsi et al. 2003; Nesta and Dibiaggio 2003), which entails a very different scenario in terms of the set of biotechnologies utilized (modern ones), the degree of their mastering, the science-technology linkages, and the sectoral dynamics including its structure, types of linkages, actors involved, the set of implemented policies, intellectual property rights and appropriability mechanisms, as well as international embeddedness. Thus, in general the majority of current studies on biotechnology are on modern technologies and their use in pharmaceuticals. Furthermore, research on biotechnology tends to concentrate in developed countries[9]. One of the highlighted characteristics of the sectors across those countries is the dynamics between large and small firms, and these with universities and their relationships and sometimes complementarity linkages (Arora and Gambardella 1990). Arora and Gambardella (1990)[10] suggest that the locus of biotechnology is network-based, as the process emerges from the complementary inter-organizational linkages.

Research on biotechnology applied to agriculture tends to concentrate on less developed countries, as in many cases it refers to the role of biotechnology on food security. CGIAR has a well-established trajectory in this field throughout its many studies of the relationship between biotechnology, food security and poverty either at the

[9] The focus tends to be in pharmaceuticals in US, Japan, and European countries.
[10] These authors' study looks at US, European, and Japanese firms. As they note, for US firms it is attractive to engage in linkages with US universities, as they are leaders in frontier biotech research.

general level, or applied to African, Asian and/or Latin American countries[11]. Bunders' (1990) research has focused on small farmers in developing countries, and how does biotechnology suits/is appropriate to their needs and socio-economic and institutional contexts. Few studies on agro-biotechnology have studied Latin American countries and/or assessed the potential of this technological platform at the regional level (Jaffe 1992; Herbert-Copley 1995; Gonsen 1998; Falconi 1999; Trigo 1999; Trigo, Traxler et al. 2000; Verástegui 2003; Orozco and Chaves 2004; Alarcón and Artundaga 2005)[12], or looked for appropriated indicators to study biotechnology in the region (Cozzens, Bortagaray et al. 2004; Orozco and Chaves 2004)

Finally this brief review of empirical analysis in this field should refer to one of the few studies of agro-related biotech in developed countries such as the work by (Lacy, Lacy et al. 1988; Senker, van Zwanenberg et al. 2001). And last, but not least, Fransman, Junne et al. (1995) have reunited a comprehensive collection of studies on biotechnology that includes from the broader aspects of this new (and not so new) technological 'revolution', to a description of the technologies, and empirical studies on their utilization in various fields and across different contexts.

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[11] To name a few see for example Komen, J. and G. Persley (1993). Agricultural Biotechnology in Developing Countries: A Cross-Country Review. ISNAR Research Report-Intermediary Biotechnology Service. The Hague, International Service for National Agricultural Research, James, C. (1996). Agricultural Research and Development: The need for Public-Private Sector Partnerships. Issues in Agriculture Washington, D.C., CGIAR-The World Bank, Braunschweig, T. (2000). Priority Setting in Agricultural Biotechnology Research: Supporting Public Decisions in Developing Countries with the Analytic Hierarchy Process, ISNAR, Serageldin, I. and G. J. Persley (2000). Promethean Science: Agricultural Biotechnology, the Environment, and the Poor. Washington, D.C., CGIAR - Consultative Group on International Agricultural Research**:** 48.

[12] As these studies indicate international organizations such as FAO, IADB, IDRC, IICA, and OAS have played an important role either by conducting research on agro-biotech at the regional and/or country levels, or by fostering strategies to improve technology transfer and linkages between firms, researchers and other actors in the Americas, and Intellectual Property Rights issues. See for instance, the SIMBIOSIS effort to enhance information exchange through Multinational System of Specialized Information on Biotechnology and Food Technology for Latin America and the Caribbean, fostered by OAS.

2.4. Types of agro-biotechnologies

This section shortly describes the different techniques encompassed in the term biotechnology, from cell and tissue culture to genetic modification, stressing their agro-related utilization. Agriculture broadly involves the use of the natural resource base to produce crops, livestock, fish and trees (Komen and Persley 1993). In this research the focus is more restricted, to only include crops and livestock[13]. The following diagram depicts the range of biotechnologies and their varying levels of complexity and costs (Persley 1990; Doyle and Persley 1996).

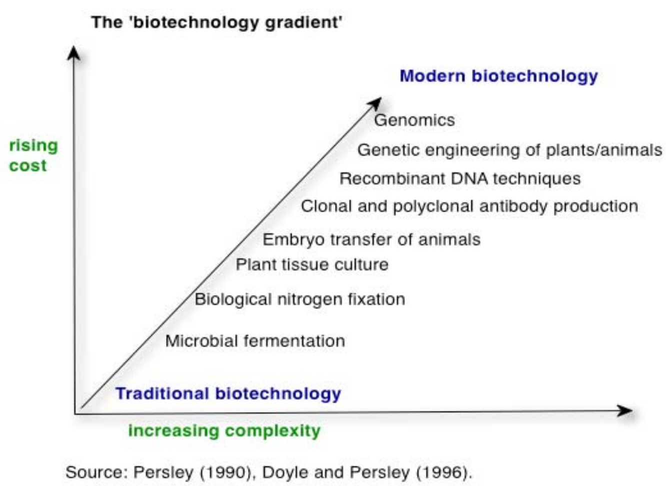

Figure 2.1. Types of biotechnologies

- Microbial fermentation

[13] See Chapter One Introduction for more details.

Fermentation is as old as the New Stone Age when men utilized fermentation techniques for beer, wine and dairy products. Fermentation processes applied to agricultural products has been largely used to increase their nutritive value and preserve them.

- Microbial inoculation of plants

This technique involves selecting and reproducing micro-organisms which are beneficiary for plants, for improving their nutrition (also known as biofertilizers), and for biologically improving pests, weeds and diseases control (known as biological control agents) (Bunders 1990). Biofertilizers are about the introduction of soil bacteria that fix nitrogen inside root nodules of legumes. This technique has been successfully utilized in several countries, with large productive impact. However they are marginal when compared to the markets of chemical fertilizers (Bunders 1990).

- Plant cell and tissue culture

Tissue culture refers to the regeneration of a whole plant from a single cell which will then be planted in the soil. The plant cell could be obtained from different sources (leaf, root, anther, protoplast, meristem or could be grown in sterile culture medium within a test tube). Plant cell culture in turn goes a step further than tissue culture and has been advanced based on fermentation or microbial techniques (Bunders 1990). These well-established techniques are widely used in plants, where cells and/or tissues are isolated and grown under controlled conditions (in vitro). They strongly vary in simplicity, time horizon, efficiency and costs. At the simplest extreme is vegetative propagation from cuttings, a rapid and cheap technique applicable to fruit, flowers and some vegetables. Then in vitro propagation includes meristem cultures, embryo production by somatic embryogenesis, and shoot production by organogenesis (Johnston and Sasson 1986).

In vitro culture is a special type of vegetative propagation but with some advantages compared to conventional methods, including controlling for sterilized conditions, shorter time of propagation, exclusion of pathogens, and potential of longer conservation. In vitro culture has several potential applications, including: micropropagation of pathogen free plants, development of new genotypes, conservation of germplasm banks, and culture in bio-reactors to extract secondary metabolites for industrial and/or medical purposes (Capdevielle and Castillo, INIA).

- Embryo-transfer

This technique consists of the transference of embryos into the female uterus. It is largely applied in cattle (Selk 2002). There are different levels of complexity associated to embryonic management. Transference as implantation is one alternative; but manipulation is more complex, and could be associated to cloning.

- Monoclonal antibody production (MAbs)

Antibodies are very valuable to combat, prevent or screen certain antigens, as they are extremely specific. One method of producing monoclonal antibodies is by cell fusion, and the resulting cell is known as an hybridoma (AE 1999; BIO n/d).

- Recombinant DNA (rDNA)

rDNA is about combining genes from different organisms to produce molecules that otherwise would not be produced by the recipient organism (Fransman 1991). rDNA technologies include DNA probes, micro-organisms transformation, rDNA vaccines, and plants and animal's transformation (Bunders 1990).

- Genetic engineering (GE)

The term GE refers to the scientific alteration, and therefore manipulation, of an organism's existing gene structure. It involves different processes from isolation to manipulation, transfer and reintroduction of DNA into cells or model organisms.

- Hybridoma

Cell fusion enables combining and multiplying cells into a fused cell or hybridoma (Fransman 1991; Sharp and Senker 1999).

- Genomics

Genomics is about studying the entire gene structure of a species. The study of single genes, a common endeavor in medical research for instance, is not genomics but molecular biology. Knowing full genomes has enabled functional genomics: the analysis of patterns of gene expression through varying conditions. Likewise, research on entire proteins in cells or tissues and their changes through varying conditions is known as proteomics. Bio-informatics is a critical tool for both, genomics and proteomics as it enables macro analysis of genomes.

- Bioprocessing/Enzyme technology

Bioprocessing entails the use of biological processes for large-scale industrial processes (Fransman 1991). Enzyme technology is utilized for industrial purposes in cosmetics, diagnostics, as well as in the food and feed processing, and chemicals, and for waste treatment for environmental management (Bunders 1990).

2.5. Agro-biotechnological applications

The technologies described above could be applied for different agriculture-related processes and/or products. Nonetheless, some of them are far less exploited and explored than others. For the purpose of this research project, those included are only plant-based and animal-based biotechnologies, while the agro-food and processing biotechnologies are excluded[14].

Plant-based biotechnologies

Biotechnologies applied to plants could be grouped in two: plant and cell tissue culture and rDNA, that is second and third generation biotechnology, respectively. Plant and cell tissue culture techniques refer to isolating and growing cells, tissues and organs from plants in vitro or controlled conditions, and remains at the cell level, whereas genetic engineering refers to genes manipulation at the DNA level, involving genes isolation, recombination and expression in new forms and introduction into appropriate cells (Johnston and Sasson 1986). Plant and cell tissue culture are increasingly utilized for raising several disease-free plants, and crops (Sharp 1995). rDNA technologies applications to plants has happened slower than expected, and did not happen until the early 1980s. One of the most extended uses on genetic engineering on plants has been for herbicide resistance. Up to date this has been more successful in some species (dicotyledons like tomatoes or tobacco) than others (monocotyledons like rice or maize) (Sharp 1995).

Animal-based biotechnology

Biotechnologies also are key for animal husbandry, in areas like new reproductive technologies, new vaccines, and the production of hormones based on bacteria. Embryo technology has been an important area of experimenting in Asia and Latin America with

[14] For a short discussion of the reasons for this decision see Chapter 5 on the methodological issues.

interesting results applied to cows (Bunders 1990). In general research and development on these techniques are mainly oriented towards cows, swine and chickens, to tackle on issues such as increasing the number of elite cows (animal reproduction), production of new vaccines, and/or the development of hormones which impact the cow's milk productivity, for instance (Johnston and Sasson 1986).

rDNA applied to animals has been used to have valuable therapeutic proteins expressed in some animals, their organs or products (i.e., milk) (Sharp and Senker 1999). Biotechnology applied to animals includes several DNA-related studies. One is DNA parentage testing which enables farmers to trace parentage of horses, cattle, dogs, etc.. Gene discovery of those with potential impact on production is another application utilized in some cases. Within the countries studied here, this has been the case only in New Zealand where several genes with impact on milk production have been discovered by Livestock Improvement Corporation Ltd. Finally, trans-genesis of animals is another area of application, even though with slow development and lesser application because of public resistance (Sharp 1995).

2.6. Systemic approaches to agro-biotechnology

The analysis of biotechnology within the field of innovation studies entails different analytical frameworks, including technological systems, and sectoral systems. These differences in approaches depend on the specific focus of analysis, application, and context. *A priori* biotechnology could be approached through the frame of technological system or the sectoral system of innovation framework. In the next paragraphs a short description of each one is presented.

Biotechnology entails features of technological systems in which the system boundaries are technologically defined (Carlsson and Stankiewicz 1991). A technological system is defined as "…a network of agents interacting in a particular area of technology to generate, diffuse and utilize technology (Carlsson and Stankiewicz, 1991). The unit of analysis is the technology still at the systemic level, and goes beyond the sectoral and/or national loci.

Biotechnology could also be studied through the sectoral system framework (Malerba 2002). According to Malerba (2004) "A sector is a set of activities that are unified by some related product group for a given or emerging demand and that share some basic knowledge" (pp.9-10). They comprise three building blocks: knowledge and technology, actors and networks, and institutions.

This research is framed in the sectoral system approach, and particularly on its dynamics, and transformation, as well as on the interaction patterns of the sectoral actors in each country. The choice for the sectoral system of innovation (SSI) approach fundamentally responds to: (a) the actor- and relational-centered argument and rationale of this approach. The SSI puts the center of its analysis on the (wide range of) <u>actors</u> involved in and around innovation, and their <u>interactions</u> for different <u>functions</u>. This relational focus fits perfectly with the framing of the research problem analyzed in this dissertation, that is on interactions and linkages. The SSI enables tracing actors through their relationships, and the settings in which these take place, as well as the different functions that might bring them together. The sectoral approach centers on the "…agents carrying out market and non-market interactions", along the different functions of generating, adopting and using (new and established) technologies, as well as for the creation, production and use of (new and established) products of a sector (Malerba 1999) (p.4); and, (b) its consideration of institutions as one of the building blocks of sectors; and (c) because of evolving character of SSI in which the sectoral core and boundaries are conceived as dynamic, thus fitting this dissertation logic.

The next section reviews and discusses the constitutive elements of the innovation sectoral system framework.

2.7. Shape and structure of the agro-biotechnological sectoral system

The concept of ‘sectoral system of innovation’ provides a useful and attractive framework because sectors are seen as dynamic and multidimensional systems, and defined as “…a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of these products. [These sectors] have a knowledge base, technologies, inputs and demand [involving] individuals and organizations at various levels of aggregation with specific learning processes, competencies, organizational structure, beliefs, objectives and behaviors, [which interact] through processes of communication, exchange, co-operation, competition and command, and their interactions are shaped by institutions” (Malerba 2002). They comprise three building blocks: knowledge and technology, actors and networks, and institutions. The way they change, the motion laws, dynamics, their emergence and transformation are all factors of utmost importance in the study of sectoral systems of innovation (Malerba 2004).

The sectoral system framework is appropriate for analyzing the dynamics and change patterns of the sector. The features highlighted in this work are the following: (i) dynamics over time; actors, relationships and networks as explanatory factors for individual firm’s behavior; (iii) changing relationship and networks; and (iv) interactions between cognitive/technological elements, and institutional/country specific factors (McKelvey, Orsenigo et al. 2004). An overall description of the sectoral innovation includes the distinction between product and process innovation. Process innovation refers to those used inside the sector that produced them, while product innovations are those used outside the sector of production (Pavitt 1984).

The sectoral system of innovation (SSI) approach has been mostly utilized in the context of industrialized countries, and regarding biotechnology to study pharmaceutical biotechnology. In this context, the pharmaceutical biotech sector is characterized by the large firms, new biotechnology firms, universities and government research institutions (Fransman 1994). McKelvey, Orsenigo et al. (2004) study the evolution of the pharmaceutical sector in larger Western European countries (Germany, France and Italy) compared to US and UK.

These studies highlight the role of interaction patterns between large and small firms, and their linkages with universities. Biotechnology NBFs rely on knowledge capital as their main asset. “They have skills and know-how in applied laboratory research. The typical output of their activities is a new protein, obtained from genetically modified organisms.” (Arora and Gambardella 1990). They are in close relationships with other firms as next phases are not part of their assets, rather of large firms. Cooperation between them is necessary for the completion of the development and commercialization of the new biotech product/process. “Firms with a higher level of internal knowledge are better equipped to evaluate and to exploit new knowledge generated outside their organizational boundaries. The higher the level of internal knowledge, the higher the incentives to undertake strategies of external interactions” (Arora and Gambardella 1990, p.371).

The agro-biotechnology sector and the pharmaceutical are quite distinct sectors. Furthermore, as this dissertation elaborates, differences also arise between the agro-biotech sectors in the three countries studied, in terms of shape and structure, in the relational patterns and dynamics, and in the types of policies and institutions implemented. These two biotechnology sectors (agro and pharmaceuticals) have totally different mappings, structures (actors involved, core and boundaries), institutions, and differ in the combination of the cognitive aspects involved. Both sectors also involve different institutions, particularly with regard to regulatory requirements, and intellectual property rights. Only to name one difference, just think of the problems, terms of discussion and public acceptance of genetically modifying organisms for therapeutics or applied to seeds and ultimately foods.

2.8. Complexity of biotechnology: towards the articulation of knowledge and actors

Increasingly agro-biotechnology draws on and embodies different but interacting types of knowledge. First it entails the knowledge about the core content of the subject matter, which in agro-biotechnology involves the fundamentals of genetics, molecular biology, virology, cell biology, and others. This is a first type knowledge. A second type of knowledge relates to the instruments and techniques to either produce biotechnologies such as vaccines, GMOs, fermentations, for instance, or to use biotechnologies for further applications: to use a genetically modified organism to study its reaction against a pathogen, for instance.

There is a third type of knowledge, and has to do with the problem area towards which biotechnologies are applied. For example, the research interest could be to look for genes that are in charge of milk fat in dairy cattle, so research would be driven by the interest of changing milk composition. Or to identify genes that regulate particular traits like milk production. Thus the technologies underlying these areas are relatively common, but they are utilized and framed for different purposes, though closely intertwined in the broad industrial view of dairy production for instance. For instance a specific tool like QTL analysis (*Quantitative Trait Loci*) enables the identification of pieces of chromosome that hold the gene that regulates milk composition. Or it could be applied to analyze genes that do other things, like regulate the milk yield loss. Same technique could be used in the search of solutions for different problems, and that too might relate to different sets of disciplinary knowledge. So biotechnologies could be utilized for different problems, and they are crosscut by different knowledge disciplines, as seen in the following diagram:

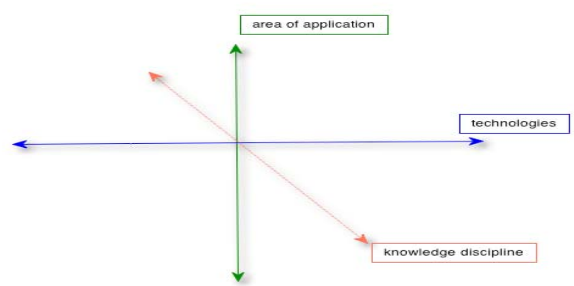

Figure 2.2. Dimensions of knowledge involved in agro-biotechnology

Thus these different types of knowledge are integrated when different but complementary, and maybe competing, actors interact. Agro-biotechnology draws on complementary skills, resources and processes. Tight organizational boundaries, or vertical (disciplinary) structures constrain the flow and exchange of biotechnology knowledge. Furthermore, tight boundaries and vertical arrangements reinforce encapsulation and weaken capabilities.

2.9. Summary

This chapter presented a short summary of biotechnology in general, and of its application to agriculture. Biotechnological innovations and applications have evolved and changed drastically in the last decades. Today there are several biotechnologies with varying levels of complexity and costs involved. Yet there are older biotechnologies that are still very much utilized for agriculture and should not be dismissed. This dissertation encompasses all these biotechnologies but the focus is restricted to agriculture. It is approached with the sectoral system of innovation framework elaborated by Malerba (1999, 2002, 2004) as it stresses the importance of actors (both market and non-market ones), their interactions, and institutions, which perfectly fit the dissertation's logic. This framework has already been utilized to analyze biotechnology applied to pharmaceuticals in which the dynamics and features are widely different from agro-biotechnology in each one of the categories mentioned before: actors, interactions, and institutions.

CHAPTER 3.

TECHNOLOGICAL CAPABILITIES AND INSTITUTIONAL ENVIRONMENTS: A CRITICAL REVIEW AND A ROADMAP

3.1. Introduction

This chapter presents and reviews the two streams of literature that nurture and frame this research, which are in turn, closely inter-connected. The chapter first places the theme of technological capabilities, and briefly presents a definition of the concept and its implications. After that, a summary of previous definitions and empirical approaches is presented; the types and dimensions of technological capabilities; the characteristics of agro-biotechnological capabilities; the mechanisms for their development; and their specific features in these small countries. Then, it situates the second stream of literature, which is that of institutions and institutional environment. The literature on these themes is also very extensive, and nurtured by different disciplines from Economics, to Sociology and Political Science. That section sketches the main features of the meso-level of the institutional environment, to then focus into each one of the three components: organizations, institutions and policies. In both cases, the discussion on technological capabilities and the institutional environment portray their characteristics and dynamics, and presented at the end of each section in a table or summary, as they will guide the analysis at the case study level.

3.2. Technological Capabilities

3.2.1. A note on the concept of technological capabilities

The analysis of capabilities constitutes an important area of research within the field of science, technology, and innovation studies. Capabilities' studies in this area tend to focus on the technological (Fransman 1984; Lall 1992) and organizational dimensions (Levinthal 2000; Teece, Pisano et al. 2000). Technological capabilities are related to the complex of skills, experience and effort that enables the firm (and/or sector) to efficiently buy, use, adapt, improve, and create technologies (Lall 2000), and they include capabilities in production, investment and innovation (Kim 1999), and linkages (Lall 1992). Capabilities in this context refer to the set of haves/assets across different dimensions, or functions. Based on Lall's (1992), and then on Bell and Pavitt (1993), the concept of technological capabilities often is related to certain functions such as production, and investment[15].

In the context of the innovation, and science and technology literature, capabilities also refer to the ability of bringing about an intended action. They are said to connect the intended action to the resulting outcome, an outcome that resembles the intended one (Dosi, Nelson et al. 2000). Within the area of innovation studies, technological capabilities refer to the firms and/or sectors ability of utilizing their skills, efforts and experiences to efficiently buy, use, adapt, improve and create technologies (Lall 2000). These definitions focus on the ability of firms/sectors to utilize their tangible and intangible assets to bring about an intended action. They consider the ability of absorb, learn and transform those into some concrete output. I posit that there is a missing link in between the identification/assessment/analysis of capabilities and their

[15] See for instance Figueiredo (2003).

transformation into achievements. This missing link lies on the dynamics of the institutional environment and its overall functioning, the loci where these processes take place, and the possibilities that those firms/sectors have of transforming their capabilities into sectoral achievements. The institutional environment must enable the process of matching capabilities with opportunities to become achievements. An important part of it is that the environment enables a locus of encounter where linkages are embedded and institutionalized reflecting the very social nature of the innovation process.

The emphasis on the relational dimension of learning and capabilities is almost a natural consequence of the very nature of the innovation process: its social character. The focus on this dimension is also stressed by regional studies of innovation and their attention to the locational dynamics underlying innovation processes (Malecki 1997; Cooke and Morgan 2000). Cooke and Morgan (2000) explicitly highlight the importance of the associational character of innovation. Learning, the root of innovation, is an interactive and socially embedded process, which cannot be understood outside its cultural and institutional context, [thus…] the wider environment of the firm –the social and political system in which it is embedded and with which it interacts-can play a vital role in facilitating (or frustrating) its learning capacity". That is how and why the institutional environment comes into scene[16].

The concept of capabilities is weakened if considered alone: capabilities might be more or less developed, advanced and complex, but they configure a duet with the opportunities that institutional environments might hinder or enhance. Between being able to achieve and actually achieving there is a gap; one that cannot and shall not be expected to be closed spontaneously. Being able to achieve and actually achieving are not

[16] The role of the institutional environment is discussed below.

necessarily coexistent, yet they are mutually reinforcing properties and the former is a necessary condition for the latter. But technological capabilities are not a unique compact thing, but a set of abilities on different dimensions. And there could be strong capabilities at some specific activity, for example at the research end but still not translating into achievements at the productive level. There are many factors that could explain such a gap, and certainly any socio-economic process is multi-causal by definition. Nevertheless, this research concentrates on one set of issues, and that is on the role of the institutional environment in the process of building those capabilities, and how and why is that strong capabilities in research do not translate into strengths at the productive level. Thus, I argue that the gap between being able to and actually achieving is bridged (or not) by the concept of *opportunities*: being capable, that is having the ability to do, does not necessarily mean to have the opportunity of utilizing/applying that capability in a way that leads to the expected/desired output. This link shall not be taken for granted, least in the context of developing countries where markets tend to be incomplete, the informal/formal balance might be disrupted, etc. (Katz 1984).

Opportunities are in turn, outcomes of the institutional environmental. The institutional environment may hinder the opportunities for capabilities to become achievements. Thus, broadly, institutional environments could be classified in a continuum between those which functioning and dynamics drive opportunities for capabilities, and those that hinder this duet. In an enabling environment, capabilities and opportunities are functionally intertwined, and the actual level of achievement depends on their interaction.

This distinction follows Sen’s leading contribution about the fundamentals of human freedom. The author distinguishes between achievements and freedom to achieve, or between *realized* functionings (actual ability to perform) and the *capability* set of alternatives (real opportunities) (Sen 2000). That is, the author claims that human freedom is not only about possessing a set of goods but more importantly about having alternative sets, i.e., being able to choose. A person is capable if she can choose how to live, or her functioning according to the author. In Sen's words, "[W]hile the combination of a person's functionings reflects her actual achievements, the capability set represents the freedom to achieve: the alternative functioning combinations from which this person can choose" (p.75). Sen (1987) defines functionings as achievements, and capabilities as the ability to achieve. Not only the final achievement counts, but also the existence of a set of alternatives from which to choose. Capabilities and functionings are intrinsically and mutually related. While for the author, functionings refer to living conditions, capabilities are notions of freedom, that is "…what real opportunities you have regarding the life you may lead"(Sen 1987).

Sen's analytical framework serves as a point of departure for this work: this research borrows the author's distinction but here it is applied in a different context. For Sen the main distinction is between being able to achieve on the base of freedom, i.e., choosing from different alternative sets (capabilities), and achieving (functioning). Throughout this dissertation, I argue that the concept of capabilities needs to be complemented by the one of opportunities, both are directly tied to the analysis of the characteristics and dynamics of institutional environments as institutional environments might enhance or hinder the emergence of opportunities.

For the study of technological capabilities, the concept of opportunities entails a relational dimension, a loci of encounter between multiple actors of diverse nature. The condition of achieving is preceded by these two required instances: being able/having the ability, and having the opportunity to materialize the ability. Thus, I posit that the process of building capabilities is anchored in institutional environments which depending on their characteristics and dynamics regarding coherence, connectedness within the sector and throughout the socio-economic settings, in which interaction and relational aspects between actors (multiple and diverse), and between problems and solutions, demanders and producers, capabilities and opportunities. I concentrate on these aspects of the institutional environment and the extent to which they facilitate (hinder) the emergence of opportunities enablers of capabilities. It is the specific shape and dynamics of the institutional environment what enables capabilities to encounter the opportunities of putting into practice those assets/haves and turn them into desired outputs[17].

The complementarity between the concept of capabilities and opportunities has been also stressed by Arocena and Sutz (2000, 2003). Learning, according to the authors, requires opportunities to learn: the concept of opportunities entails ‘interactive spaces of learning’. These spaces do not need to have a specific organizational shape, nor an a priori set of purposes (Arocena and Sutz 2000; Arocena and Sutz 2003). Opportunities are then drivers or enablers of capabilities, while also reinforcing and nurturing them. This research is tuned with that perspective, and attempts to go one step further by analyzing what are the characteristics and dynamics of these relational frame and through what mechanisms those influence and impact on technological capabilities at the sectoral level.

[17] At this point it might be necessary to restate the fact that this research is not claiming that those are the most important factors, nor the only ones in the firms/sectoral process of building agro-biotech capabilities in small countries. This research claims that they are very important and often overlooked because of the concentration on economic aspects of the processes underlying the building of capabilities. This element together with the policy context in which this work is framed lead to the focus on those dimensions.

Zahra and George (2002) stress a similar point concerning the distinction between potentiality and actual achievement, but constrained to the concept of capacity. Drawing on Cohen and Levinthal's (1990) concept of absorptive capacity, these authors distinguish between 'potential and realized capacity' (Zahra and George 2002). The firm's potential capacity is about making "… the firm receptive to acquiring and assimilating external knowledge [...while realized capacity…] is about transforming and exploiting the absorbed knowledge" (pp.190-191). These authors' distinction goes along the same line suggested here, between the ability to achieve and actual achievement.

3.2.2. Review of definitions and types of technological capabilities

Most reviewed studies on technological capabilities rest on a relatively common ground in terms of defining what capabilities are, the underlying activities, resources and processes, and their cumulative and path-dependent character (Dosi, Nelson et al. 2000), as technological development is (Price 1963, Pavitt 1992).

Fransman (1984) defines innovation capacity as the "capacity to perform formally organized innovation activities within the firm or the institutionalised search for more important innovations with the development of R&D facilities" (Fransman 1984) (Gonsen, p.18). (Gonsen 1998) defines technological capability "…as the capacity to select, assimilate, adapt and improve existing or improved technology, and/or create new technology." (p.7). (Bell and Pavitt 1993) define technological capabilities as those "resources needed to generate and manage technical change, including skills, knowledge and experience, and institutional structures and linkages" (p.163).

Technological capabilities comprise a range of activities that vary in depth and in the efforts required. The basic ones include (Fransman 1984): (1) searching for available technologies and the selection of the most appropriate technologies, (2) mastering the technology, (3) adapting the technology in order to suit specific production conditions, (4) further developing the technology as a result of minor innovations, (5) the institutionalized search for more important innovations through the development of R&D facilities, and (6) conducting basic research. The activities from (1) to (4) refer to 'know how' activities though they are not presented in a hierarchical order of complexity. The last two ones, items (5) and (6), on the other hand relate to more complex and costly activities, and are about 'knowing why'. To move from the first to the second set requires a qualitative leap, which in the long run might determine the progress of countries and firms (Fransman 1984).

Similarly Gonsen (1998) distinguishes between acquisition, design and project execution, assimilation, adaptation or modification, and innovation as firm level capabilities. Acquisition capability refers to activities such as searching, assessing, negotiating, procuring, and transferring technology. It is about identifying sources of technology (technology choices and costs), and, according to the author, coincides with (Lall 1987) investment capability, and (Dahlman 1990) acquisitive capability. It also coincides with the searching ability suggested by Fransman (1984). To acquire first it is necessary to know what to look for, and where to do it. Again, previous experience highly counts, but it does not suffice: anticipation to the future is also important, particularly considering the pace of change of technologies. Therefore, when after searching, a set of technological alternatives are found, they would have to be assessed against current local requirements and future forecasting in that specific context.

Lall (1992) suggests three major functional dimensions of technological capabilities: (i) production, (ii) investment, and (iii) linkages. Each one of these functions involves different activities with varying degree of complexity, from simpler to adaptive, or more innovative ones (Lall 1992). Linkage capabilities refer to the skills required to transmit and receive skills, knowledge and information from suppliers, subcontractors, consultants, service firms, and technology institutions. These capabilities are not only important to the firm as sources for its productive efficiency but also to the economy as carriers of technological diffusion through it, and to the sector as they the deepen the industrial structure (Lall 1992).

In a related way but from a very different approach and research context, Cooke and Morgan (2000) highlight the importance of the 'associational' dimension of current economic exchanges and actions. For the authors, it is not the shape of the organizational structure, or even the existence of some type of economic institutions *per se* what matters the most, "…but how well these forms operate given the nature of the product market, the scope for technological change, the presence of economies of scale (…). Allowing for these environmental factors the key issue is not economic form but the capacity to create and sustain a robust architecture for generating and using knowledge from a wide variety of sources, including employees, suppliers, customers and public bodies –which is what we mean by *associational* capacity" (Cooke and Morgan 2000)

Another distinctive feature of capabilities is their dynamic character. Teece, Pisano et al. (2000) and (Teece and Pisano 1994) refer to 'dynamic capabilities' as one key property to fit with dynamic environments and the importance of strategic management to appropriately adapt, integrate and reconfigure internal and external organizational skills, resources, and functional competences.

The next table presents a selective summary of previous empirical studies on technological capabilities.

Table 3.1. Brief review of some previous empirical studies

Source	Concept	Dimensions	Indicators	Approach	Unit of analysis
(Archibugi and Coco 2004)[18]	Technological capabilities	(I) Creation of technology	(Ii) Patents (Iii) Scientific publications	Quantitative index	National
		(II) Technological infrastructure	(IIi) Internet penetration, (IIii) Telephone penetration (IIiii) Electricity consumption		
		(III) Development of human skills	(IIIi) Tertiary science & eng. enrollment (IIIii) Mean years of schooling (IIIiii) Literacy rate		
(Desai 1984)	Indigenous technological capability/ technological competence	Types of ITC: (i) Required for production (ii) Technology transfer (iii) Innovation			National (India)
(Ekboir, Muñoz et al. 2006)	Innovative capabilities	(i) Abilities to search for new information	(i) Number of times a farmer was among the first seven adopters of a new particular technique	Quantitative (OLS, and system with 3 stages Least Squares)	Regional (Michoa cán, Mexico)
		(ii) To integrate components into an efficient package	(ii) Number of techniques a farmer used		
		(iii) To establish stable links with sources of commercial and technical information			
(Figueiredo 2003)	Technological capabilities	7 levels of capabilities (from basic to advanced) across 5 functions: investment (decision-making and control, and project preparation and implementation), process and production, product; and equipment.			Steel plants Brazil
(Fransman 1984)	Technological capabilities	1) Searching for available technologies and selecting most appropriate ones			Broad analysis, and applied to national level Hong Kong
		(2) Mastering the technology			
		(3) Adapting it to suit specific production conditions			
		(4) Further developing as a result of minor innovation			
		(5) Institutionalized search for more important innovations through the development of R&D facilities			
		(6) Conducting basic research			
(Gonsen 1998)	Technological capabilities	(I) Searching and selecting (acquisition capability)		Qualitative	Firm/ industrial branch Mexico
		(II) Adapting the technology (adaptive capability)			
		(III) Further development			
		(IV) Major innovation			

[18] Archibugi and Coco (2004) extensively review UN's technological indexes (UNDP 2001 and UNIDO 2002), and the World Economic Forum's Global Competitiveness Report for the construction of their own index.

Table 3.1. Continued

(Hall 1993)	Capabilities	(I) Functional (II) Cultural (III) Positional (IV) Regulatory	(I) and (II) are based on competencies or skills (intangible resources concerned with doing); (III) and (IV) relate to assets owned by the business (brand name or reputation) (concerned with having)		
Kim (1999)	Technological capability	National and firms' technological trajectory; Absorptive capacity		Qualitative	Firms and National - Korea
(Lall 1992)	Technological capabilities	(I) Investment capabilities	(Ii) Pre-investment (Iii) Project execution		Firm/national
		(II) Production capabilities	(IIi) Process engineering (IIii) Product engineering (IIiii) Industrial engineering		
		(III) Linkage capabilities	(IIIi) Linkages within economy		
(Langdon 1984)	Indigenous technological capability	(i) Sources of technological knowledge in the development of the enterprise			Firms in Kenya
		(ii) extent of present dependence on formal links w/ techno sources abroad			
		(iii) enterprise propensity to undertake process/product initiatives			
		(iv) sources of technological knowledge to take those initiatives			
		(v) enterprise emphasis on formal R&D facilities			
(Patel and Pavitt 2000)	Technological competencies (Firms' profiles of competencies (	(I) relative importance of each field in firm's total technological portfolio (II) firm's relative advantage in each field compared to other firms	(Ii) patent share of the firm's patenting in each one of 34 technical fields (IIi) firm's share of patenting in the field divided by the firm's aggregate share of patenting in all fields	Quantitative analysis (patent data-US)	Large firms
(UNDP 2001)	Technology Achievement Index (TAI)	(I) creation of technology	(Ii) patents by residents at national offices (Iii) receipts of royalty and license fees	Quantitative index	National
		(II) diffusion of newest technologies	(IIi) internet hosts (IIii) medium- and high-technology exports		
		(III) diffusion of oldest technologies	(IIIi) telephone mainlines (IIIii) electricity consumption		
		(IV) human skills	(IVi) years of schooling (IVii) tertiary science enrolment		

Table 3.1. Continued

(UNIDO 2002)	Industrial Performance Scoreboard	(I) technology effort	(Ii) patents granted by USPTO (Iii) enterprise financed R&D	Quantitative index	Country
		(II) competitive industrial performance	(IIi) manufactured value added (MVA) (IIii) medium and high technology share in MVA (IIiii) manufactured exports (IIiv) medium and high technology share in exports		
		(III) technology imports	(IIIi) FDI (IIIii) foreign royalty payments (IIIiii) capital goods		
		(IV) skills and infrastructure	(IVi) tertiary technical enrolment (IVii) telephone mainlines		
(Wagner, Brahmakulam et al. 2001; Wagner, Horlings et al. 2004)	science and technology capacity	(I) enabling factors	(Ii) GDP (Iii) tertiary science enrolment	Quantitative index	
		(II) resources	(IIi) R&D expenditure (IIii) number of institutions (IIiii) number of scientists and engineers		
		(III) embedded knowledge	(IIIi) patents (IIIii) S&T publications (IIIiii) Co-authored scientific and technical papers		
(WEF 2001)		(I) innovative capacity	(Ii) patents granted by USPTO (Iii) tertiary enrolment ration (Iiii) survey data	Quantitative index	
		(II) ICT diffusion	(IIi) internet hosts (IIii) telephone mainlines (IIiii) PC (IIiv) survey data		
		(III) technology transfer	(IIIi) non-primary exports (IIIii) survey data		

3.2.3. Mechanisms for building technological capabilities

Generating and managing technological capabilities requires a stock of resources, and the accumulation of these resources requires a conscious and deliberate learning process. One of the basic resources for building technological capabilities is the stock of knowledge, and its production, accumulation, diffusion, and use. The stock of knowledge does not translate into capabilities unless permeated by learning processes. The building of technological capabilities is based on learning, which makes accumulation possible, and the undertaking of new activities and the acquisition of new capabilities (Dutrenit

2000). It is also based on using knowledge in a proficient way so as to affect production, investment and innovation (Westphal, Kim and Dahlman 1985).

These learning processes are complex and specialized, and are nurtured by sources and channels external to the firm as well as by mechanisms and dynamics within the firm. Internally, the firm might implement explicit strategies to enhance learning processes, apart from learning by doing or learning by trial and error. Internal personnel mobility could also contribute to strengthen learning within the firm.

Mobility between firms and between different organizations is also an important mechanism for technological accumulation. In Korea, the mobility of skilled personnel contributed to changing the industrial structure of the country. One source of mobility was between firms inside Korea, and another was the mobility of experienced workers returning to Korea from abroad. The mobility of personnel plays a vital role in basic process and production technology[19] (Bell and Pavitt 1993).

Learning involves the acquisition and manipulation of different kinds of knowledge, embedded in different loci and through different mechanisms. There are a number of classifications and typologies of knowledge. Faulkner and Senker (1995), based on Gibbons and Johnston (1974), distinguish between knowledge of particular fields, technical information, skills, and knowledge related to artifacts. Lundvall (1996) distinguishes between know-what (knowledge about facts, which is codifiable into information pieces), know-why (knowledge about principles and laws of motion in nature, the human mind, and society), know-how (skills, the capability to do something is typically developed and kept within the confines of an individual firm or research team), and know-who (who knows what, who knows how to do what, which involves the social

[19] See Westphal et al., 1981.

capability to establish relationships). The channels for knowing-what and knowing-why are reading books and articles, attending conferences, and accessing databases (which are easier to transfer and codify); while for knowing-how (learned in apprenticeships) and knowing-who, the channels relate to practical experience and social interaction. To some extent, knowing-who is learned in specialized educational environments.

Lundvall (1994) stresses the importance of alternative sources and mechanisms for learning other than science and R&D efforts. The author highlights the importance of connecting the internal learning practices and external sources of learning. Learning occurs at different levels and in different loci, and through different routines and practices. Workers, production engineers, sales representatives in their everyday experience influence the agenda and thus the direction of innovative efforts, and their knowledge produced inputs the process of innovation. Every source and mechanism of learning contributes in the shaping of innovation (Lundvall 1994).

Searching for alternative and new technologies, information and knowledge is a fundamental activity for building capabilities. The question of how do actors search for these alternatives is not irrelevant. (Levinthal 2000) points out the importance of parallelism within an organization. Parallel efforts enhance the speed of adaptation while also contributes to preserve variety of initiatives and perspectives (Levinthal 2000, p.364).

Access to new knowledge is of the utmost importance in the development of a firm’s ‘absorptive capacity’. The firm’s ability to evaluate and use outside knowledge depends on 1) prior knowledge, which confers the ability to recognize the value of new information, assimilate it and apply it to commercial ends, and 2) intensity of effort, which is related to internal organization mechanisms to develop an effective absorptive capacity (Cohen and Levinthal 1990). Absorptive capacity relies heavily on in-house R&D. In-house capacity is essential to be able to absorb knowledge from outside the firm. As (Dosi 1988) succinctly puts it, “One needs to have substantial in-house capacity in order to recognize, evaluate, negotiate, and finally adapt the technology potentially available from others” (p.1132).

Zahra and George’s (2002) distinction between potential and realized capacity leads to some important issues regarding internal processes and strategies for firms to transit from potential to realized capacity. Knowledge acquisition, and assimilation shape potential capacity, while knowledge transformation, and exploitation define realized capacity. Knowledge acquisition’s components are prior investment and prior knowledge, intensity, speed and direction, and matter for the scope of search, and the perceptual schema, for the speed and quality of learning and to establish new connections. The transit from knowledge acquisition to assimilation requires certain processes that ensure the understanding and interpretation of such knowledge. It is not obvious nor spontaneous that acquired knowledge gets assimilated. Understanding the knowledge acquired is what enables interpreting and comprehending it. Further in the scale of capacity is knowledge transformation. This requires internalizing and converting it. Finally knowledge exploitation is about using and implementing it (p.189).

Now the transit from having the potential to realize that capacity lies on a major qualitative jump, which is connected to the discussion on opportunities. Not only certain internal heuristics should be created and utilized for the firm to jump and get hands on functioning realized capabilities, but there has to be an enabling environment that makes that jump possible, and even might stimulate firms to engage in those processes.

3.2.4. Defining the types and characteristics of agro-biotechnology capabilities

Overall it could be said that agro-biotech capabilities involve two main dimensions: one related to the productive level (including not only specific knowledge about the area of production, but also about the context of application, investment, and operation) and the consequent ability to go through different levels of complexity with increasing levels of appropriation, involvement and internalization of knowledge (different types and formats of knowledge), and higher commitments to exploring and exploiting that knowledge and innovation. This first level has to do with the various activities and tasks mentioned in the literature such as scanning, searching, absorbing, acquiring, mastering, adapting, transforming, developing, and innovating.

Related to capabilities at the production level, Gonsen (1998) distinguishes between three sets of biotechnological capabilities (i) core scientific capabilities, (ii) bio-processing capabilities, and (iii) complementary capabilities (Gonsen 1998). Core scientific capabilities have to do with the manipulation, modification and transference of genetic materials. They are a necessary condition to be innovative in biotechnology; they are not only necessary to develop biotechnology, but also to adopt it. Bioprocessing capabilities have to do with industrial scale processing, and include putting into practice and scaling the biotechnology-related processes within the set of available biotechnologies[20]. Finally complementary capabilities include those related to commercialization, marketing, and complying with regulatory requirements in biotechnology (Gonsen 1998).

A second broad dimension relates to the ability of the firm of being part of a larger collective, connected and linked with different actors within and outside the

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[20] See Chapter Two for a description of the biotechnologies.

boundaries of the sector. Building associational capabilities is fundamental for innovation in general but for capabilities in agro-biotech in particular because of many reasons. I would highlight two of these in this research context: (a) because of the cognitive nature of biotechnology which heavily draws on integrated knowledge bases, and requires complementarities and synergies, and (b) because of one distinctive feature of innovation in less developed countries and that is the encapsulation of innovation practices, which are anecdotal and lack institutionalization throughout the socio-economic fabrics. Innovation takes place on a very punctual basis, and lies on isolated efforts in actors that are often tightly bounded; where the institutionalization of innovation and learning is in the best of the cases, weak, or just missing.

For the purpose of this research, technological capabilities are characterized as the set of existing and gained abilities both at the firm and/or sectoral levels, which require a wide range of skills and resources, and processes for their enhancement and development, along a scale of increasingly complex tasks (productive, and associational) demanding different orders of involvement, commitment, appropriation and mastering throughout various dimensions that are considered relevant for agro-biotechnology. This definition stresses the importance of time and loci. Thus, the temporal level of to what extent are capabilities sustained over time, and the features of the loci in which they take place.

Decomposing the concept of capabilities into skills, processes and resources involves the following indicators. At the organizational level, skills are characterized by: (Sa) educational and experience backgrounds, and trajectories; and, (Sb) areas of application, actors involved and knowledge structures. Processes refer to (Pa) the mechanisms and strategies implemented to access and absorb knowledge. For resources, I focus on: (Ra) infrastructure in terms of buildings, equipment, and access to databases, particularly of publications; (Rb) R&D investment and funding; and (Rc) future regard: research and productive agendas. In the case of investment efforts, the discussion centers on the general orientation of those investments: what items are being prioritized at the time of investing. The reason to constrain the discussion to only these aspects is because I could not get detailed data from the interviews or secondary sources of data to support a more thorough analysis[21]. The issue of the research/productive agenda centers on the identification of research and/or productive agenda and future orientation. The point here alludes to the question of whether there is an agenda or not, could be tentative or certain, but most importantly whether there is a regard into the future[22].

Technological capabilities are reinforced by the associational character of these actors, and the extent to which they get involved with external actors, both in the sector, and across sectors, and internationally. Thus, this dimension underlies the chapter by referring to associational patterns of these actors. Associational capabilities bridge these different categories, and depending on how strong they are, they could serve as a glue for reinforcing productive capabilities, and embed them in a deeper structural level moving through more porous and dynamic sectoral boundaries, with higher levels of international involvement. In other words, associational capabilities are strong when at the sectoral level serve they bridge subsectors (like plant-based with animal-based biotechnologies); various and multiple actors get engaged in sectoral interactions with other actors, and

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[21] See chapter 1 for more details about this methodological issue.

[22] Even though this issue of the research agenda and the future regard are included as part of resources, they are also connected to the theme of strategies, as future plans and agendas might lead to establishing certain strategies, which are more related to processes, according to the distinction made here. The borders between skills, resources and processes are not fixed, nor clearly demarcated. In reality these three are not totally separate things, but for analytical purposes it helps to distinguish them, particularly given the comparative base of this study. The decision to consider them part of resources rather than processes is first, because there might not be an agenda or a future regards; and second because even if these issues are part of the resources of the organization, there might not be processes related to those resources.

fundamentally rely on a wide variety of them for generating and using knowledge (Cooke and Morgan 2000); and take place in porous settings that enable the dynamic re-arrangement of strengths and capabilities, and transforming them into environmental opportunities. Thus opportunities are attributes of the institutional environment: when institutional environments drive opportunities then capabilities could be enacted and become actual achievements.

The following table illustrates these categories and indicators defining the concept of technological capabilities.

Table 3.2. Categories of technological capabilities

Categories		
Productive		**Associational**
Skills	(Sa) educational and experience backgrounds and trajectories (Sb) Areas of application, actors involved and knowledge structure	A C T O R S /Sectoral/ Cross-sectoral /international
Processes	(Pa) Mechanisms and strategies to access and absorb knowledge	
Resources	(Ra) infrastructure (Rb) R&D investment and funding (Rc) research and productive agendas and regard of future	

3.3. Institutionalism and institutional environments

The importance and role of institutions and institutional environments/arrangements/settings on different socio-economic actions and/or individual/collective behaviors has been largely analyzed throughout current and past studies in economics[23], sociology[24] and political sciences[25].

Institutionalism and the introduction of the institutional environment into the analysis of social action has been a fundamental contribution to a better understanding of the whys and hows of social action (in general including political and economic types of action and behavior). Institutionalism has provided a more thorough and realistic

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[23] Some classical studies on New Institutional Economics are compiled in Ménard, C. and M. M. Shirley, Eds. (2005). Handbook of New Institutional Economics. New York, Springer.

[24] For an overview of Institutionalism in Sociology, see Brinton, M. C. and V. Nee, Eds. (1998). The New Institutionalism in Sociology. New York, Russell Sage Foundation.

[25] For a summary of Institutionalism in Political Science, see Guy Peters, B. (2005). Institutional Theory in Political Science: The 'New Institutionalism'. New York, Contiuum.

analytical framework to understand socio-economic action, as an alternative to the neoclassical view that individuals' and organizational' choices and decisions are the output of independent rational decision processes based on a utility function with consistent ordering of decisions, and the chosen alternative is assumed to be the one with highest utility. But organizations rarely count on the resources needed to accomplish a rational decision, neither they have homogeneous goals (Lindblom 1959; Cyert and March 1963; Simon 1976). Organizational decisions and strategies are shaped through culture and social processes and, furthermore they are socially constructed (Wildavsky 1987).

Disciplinary approaches to institutions and institutionalism are increasingly intertwined[26], and share a common fundamental ground: actors' behaviors are bounded by institutions and institutional settings or environments. Individuals and/or organizations when making choices are constrained by resources, and their choices are a function of time and place. Institutional environments are not external environments but interact with actors and their decisions and capabilities. The interaction could be positive or negative, could hinder or enhance, but in all cases actors have bounded rationality as at best they can only be rational with what they are aware of (Simon 1945, 1985; Lindblom 1959). Human behavior is therefore, adaptive rather than optimal (Simon 1965).

Different versions of institutionalism differ in their definitions of institutions: what is and what is not part of the concept, and on the actors they focus on. On the latter, economic institutionalism focuses on firms while sociological institutionalism does so on public actors, and political institutionalism emphasize political structures such as the state

[26] See for instance Powell, W. W. and P. J. DiMaggio, Eds. (1991). The New Institutionalim in Organizational Analysis. Chicago, The University of Chicago Press, Ostrom, E., Ed. (2005). Understanding Institutional Diversity. Princeton, Princeton University Press.

and their role on political outcomes (DiMaggio and Powell 1991; Parsons 1995). On the former, definitions on institutions vary mainly with respect to what counts as institutions and what does not. In some cases institutions strictly refer to the rules of the game as defined by North (1990), while other scholars define institutions in a broader sense, and include organizations such as university departments or R&D laboratories (players of the game) (Coriat and Weinstein 2004).

3.3.1. Institutional environments and innovation processes

Systemic approaches to innovation have highlighted the key role that institutional environment plays in the innovation process. The National Innovation System (NIS) approach in particular concentrates on the role in innovation of the national institutional environment, and specifically on those organizations, policies and institutions related to the production and diffusion of scientific and technical knowledge (Lundvall 1992a; Nelson 1993; Edquist 1997). Institutions are considered key in other variations of the innovation systems approach as well, such as the regional systems and the sectoral systems of innovation, which focus on the regional and the sectoral dimensions of the institutional environment, respectively[27]. In these systemic approaches to innovation, firms, which are the loci of the innovation process, operate embedded in institutional environments. They are dependent on them because firms' choices and strategies are critically permeated by the institutional context they are in (Metcalfe 1994, (Orsenigo 1989). But it is not a one-way relationship; rather firms might also contribute to altering and transforming that context, and they combine with it to shape a process of co-

[27] See Cooke, P., M. G. Urange, et al. (1997). "Regional innovation systems: institutional and organizational dimensions." Research Policy **4**(5): 475-493, Malerba, F. (2002). "Sectoral systems of innovation and production." Research Policy **31**: 247-264.

evolution of industries, technologies and institutions through learning and the development of organizational and technological capabilities (Nelson and Winter 1982; Nelson 1994a; Nelson 1994b; Coriat and Dosi 1998; Murmann 2003).

So, how does the institutional environment shape innovation, and agro-biotechnology capabilities in particular? The role of the institutional environment in innovation is of particular importance because of the nature of innovation itself. Innovation understood as the search for, discovery, experimentation, development, imitation, and adoption of new products, production processes and organizational set-ups (Dosi 1988) is rooted in a social process: it results from interactions between multiple and diverse actors, and it lies on a combination of different processes including 'learning' and 'searching' processes. These learning and searching processes are largely determined by the peculiarities of the institutional environment, including public and private organizations and public policies (Nelson and Winter 1982; Andersen and Lundvall 1988; Johnson 1988), which determine the emergence of specific national trajectories of innovation (Coriat and Weinstein 2002). Firms do not search independently or in isolation, but by looking at and interacting with their competitors, suppliers and customers (Nelson and Winter 1982; Andersen and Lundvall 1988; Johnson 1988), and by collaborating with them. In some contexts, firms might enjoy comparative institutional advantages, that is "[F]irms can perform some type of activities, which allow them to produce some kinds of goods, more efficiently than others because of the institutional support they receive for those activities in the political economy, and the institutions relevant to these activities are not distributed evenly across nations" (Hall and Soskice 2001).

Firms' searching and learning processes are bounded by their institutional environment. Their decisions and strategies respond, to a large extent, to their perceptions and sensing of that environment. This ability to make sense does not only have to do with information on markets, business and technological trends, but also relates to the ability of identifying and absorbing the relevant external technology, and this constitutes the absorptive capacity of the firm (Teece 2000). In other words, there are institutional limits to what firms can and cannot do and to the type of capabilities they build, because institutions affect the directions and the ways in which firms search (Johnson 1988). As stated by North (1990) "The kinds of knowledge, skills, and learning that the members of an organization will acquire will reflect the payoff –the incentives- imbedded in the institutional constraints" [or enablers] (p.74). Even though for some time the discussion on institutions has been restricted to their constraining role (North 1990), lately the focus has expanded to include not only their constraining power, but also their (potentially) enhancing role (Coriat and Weinstein 2004).

A firm's external sensing ability has to do with its alertness and responses to the opportunities and signals perceived. It is not only about perceiving opportunities and calibrating how they can be appropriated, given the particular features of the firm, but also about implementing changes oriented to take advantage of those opportunities. This ability totally depends on the environment, on how connected the firm is to the environment, and on the 'quality' of those connections given that what matters here is not only perceiving signals but more importantly about perceiving the 'right' signals. Communication and information are fundamental inputs for firms' quality-based sensing. To sense the right signals, firms need information and communication about them. Apart from the flow of information and communication, firms also need some level of *clarity*, *certainty* and *stability* in the rules of the game to decide in what direction to move. If rules are volatile depending on issues like who are subject to rules application, or who is enforcing them (or if they are not enforced at all), or if they change all the time because loose interpretation, then firms' strategies for building capabilities are importantly harmed and could be very disrupted. Innovation inheres uncertainty, but requires stable commitment and effort from firms. In those environmental conditions the time frame for building capabilities is largely constrained, and incentives are negative for longer-term efforts. The firm's ability to draw on previous experience and knowledge is harmed. And previous experience is a key resource for innovation and capabilities given the path dependent character of what firms can and cannot do. Thus the *sustained* character of capabilities is important for firms to cumulate and learn. This also applies at the sectoral level regarding the trajectories of capabilities.

In many cases small countries' institutional environments lack resources, from critical mass to financial assets in most cases. *Variety* and *complementarity* of the components of the institutional environment becomes crucial to substitute for the lack of resources. Complementary combined with variation in types of organizations constitute fundamental inputs and resources for individual firms to rely on, and complement for the lack of resources. That is, for a firm in a small country, it is fundamental to count on a thick institutional environment that could provide for the variety of resources it needs and internally lacks to build novel capabilities. A single agro-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.

For firms to engage in acquiring and building new agro-biotechnology capabilities in small countries, they need to interact with complementary as well as varying organizations so as to search in different directions and preview novel building paths. Complementarity and cross-fertilization of capabilities at the sectoral level expands the boundaries of resources available as well as the opportunities to engage in new types of capabilities. This is particularly the case when subsectors interact between them and boundaries are intertwined, for instance between plant-based and animal-based agro-biotechnology. The combination and interaction of their knowledge bases, and resources push the boundaries towards alternative paths, and contributes to the emergence of common strategic purposes that encompass more than the single sector. For example, agro-biotechnology involves different types of knowledge, from core scientific knowledge (molecular biology, cell and tissue biology, etc.), to knowledge on the specific techniques (micropropagation, genetic engineering, etc.), and knowledge of the area of application (animal health, plants, agrifood, etc.). Thus, the building of capabilities in this sector requires the articulation of these different types of knowledge, and the related heuristics to build them, and of different types of actors. These actors must bring into and couple these different types of knowledge. It is not only thickness, cohesiveness, and consistency what matters, but also the functions and roles played by those actors: thickness with actors that facilitate the *articulation* of those varying organizations, and contribute to frame and guide the sector towards a next direction of biotechnology.

3.3.2. Institutionalism and alternative explanations

Multiple answers respond the question about the factors shaping technological capabilities. Dependence theory for instance would highlight the center-periphery relationship and the relational position of these three small countries in the world economy. Costa Rica, New Zealand and Uruguay have been part of the periphery, though they have had different relationships with core economies. New Zealand has been tightly related to the British Empire, and part of the Commonwealth. Uruguay has also been tightly related to Britain but only on an economic basis. Uruguay had its splendor epoch at the beginning of the 20th century when Britain was importing Uruguay's commodities (wool, and meat mainly) and heavily investing on infrastructure (railroads, freezing houses, banks). For long years, New Zealand has also heavily relied on that country's market. However for a long time now New Zealand has loosen its relationship with Britain and opened up its markets towards Asia, Europe and US. Furthermore, Uruguay and New Zealand had coupling economic situations in the early 20th century; but for the last half a century they have had very divergent paths (Bértola, Calicchio et al. 1998; Alvarez Scanniello and Porcile 2006). Something alike has taken place between Scandinavian and Latin American countries when a century ago the former was very similar to many countries in Latin America (Blomstrom and Meller 1991). Peripheral countries have changed and international relationships and market positions have shown some level of dynamics. Internal environmental aspects play an important role in the direction towards which these countries and sectors orient to.

It could also be claimed that the presence of foreign direct investment and multinational corporations is what makes the difference. Costa Rica has had a strategy of capturing FDI, but not so much in agricultural related businesses. Nor New Zealand or Uruguay has done so. Still, variations in the characteristics and directions of agro-biotechnology capabilities permeate these three case studies. Alternative and complementary explanations could still be claimed, and this research does not attempt a comprehensive, one shot response. On the opposite it attempts to contribute to a better understanding of the dynamics between institutional environments and capabilities. It focuses on one broad dimension, and does not claim that it is the only or most important response. Rather it seeks to understand the way this dimension operates and how does it affect the process of building technological capabilities.

3.3.3. Analyzing the institutional environment

This work introduces the meso-level of the dynamics of the institutional environment, and the organizations/actors and their interactions and relationships; the institutions; and the set of relevant policies. The reference to the institutional environment does not intend to present it as a supra-entelechy with its own life beyond the socioeconomic actors and their relationships. This research neither intends to benchmark each case against institutional blueprints, assuming that there is ‘one best way’ or in Evans terms, falling into ‘institutional monocropping’ (Evans 2004). It rather aims at understanding the underlying dynamics and interactions of organizational actors, institutions and policies, and how these shape the capabilities at both, levels firms and sectoral. Furthermore, this research attempts to avoid uni-dimensional approaches to social phenomena, either-or type of analysis in which is either innovation processes are outcomes of structural factors or of atomized social actors whose actions explain one or another types of capabilities paths. Classic social science has been distinguished based on the primacy given to one of these two analytical extremes. But these oversimplified lenses have been subsumed to more integrative approaches stressing the double character of social change. It is neither based on standing-alone structures, conceived as supra entities nor on actors standing in the vacuum. Social change entails the interaction of structures and actors embedded in those structures, constrained by them while shaping and reproducing them. It is, in Giddens terms, the duality of social structure which are "both the medium and the outcome of the practices they recursively organize" (Giddens 1984, p.25). This research attempts to articulate structural aspects with those referring to social action; thus, the institutional environment, and its components are analyzed through the lens of interaction between structure and action. This entails a dynamic approach and thus, both the diachronic- and synchronic levels are referred to along the analysis.

In this work, the concept of 'institutional environment' involves two complementary (analytical) levels: (a) a synthetic layer referring to the overall environment with some broad characteristics of its change dynamics; and, (b) the institutional environment as a compound of three main components: organizations and their interactions, institutions and policies. I will first describe (a), then establish the main features regarding its change mechanisms, and then analyze each one of the components of (b).

In the dissertation I concentrate on both a set of institutions affecting technological capabilities, i.e. intellectual property rights, and the web of related organizations. The term institutional environment includes institutions, policies and organizations. This characterization of the aspects of institutional environments is in agreement with other authors' approaches. For instance, Coriat and Dosi (1998) refer to institutions as including: a) formal organizations, b) collectively-shared patterns of behaviors, and c) negative norms and constraints. In this research however, institutions are not confined to their negative constraining role only, as they could also be enablers of certain behavior patterns. This research also distinguishes between institutions and the web of organizations, though they are encompassed under the concept of institutional environment.

3.3.4. Constitutive aspects of the institutional environment

The institutional environment includes three sets of intervening factors: institutions, organizations and policies. This categorization of the institutional environment matches other classifications within the innovation literature. For instance, Dosi, Pavitt et al. (1990) define the institutional set-up, based on three components: “(i) the forms of organization of the interactions between agents (…); (ii) the fundamental rules of behavior that agents embody towards their competitors, customers, suppliers, employees, government officials, etc.; and (iii) the forms and degrees of the direct exercise of discretionary power by non-market actors who contribute to the organization of the patterns of allocation, the rules of behavior and the performance of market processes (clearly policies come under this heading)" (Dosi , Pavitt et al. 1990). These also fit the perspective of institutionalization through specific institutional carriers: organizations, regimes and institutional (Jepperson 1991).

Policies, institutions and organizations are not independent, or sharply demarcated in reality. This distinction is analytical as it helps to study the patterns of evolution and their characteristics. History crosscuts each one and all of these elements and processes. This work strongly relies on the historical dimension, necessary to understand the specific paths of evolution and change of the institutional environment in each country, the critical events that have contributed to reinforce and/or prevent their reproduction and change, how and why they may be functioning and serving different roles compared to the intended original ones, and whether they are constraints or resources for actors to engage in their respective functions and goals. The analysis is framed in a path-dependent logic in the sense that the forces leading to institutional change cannot be predicted ex ante, are strongly linked to the initial conditions, are not driven by efficiency arguments, and do rely on a certain degree of inertia, yet contingency could take place (Thelen 2003). The following paragraphs briefly identify each constitutive element.

3.3.4.1.Institutions

The concept of institutions is largely utilized in the analysis of social processes, including the economic, political, and sociological dimensions. In this study, institutions are defined as "…sets of routines, rules, norms, and laws, which by reducing the amount of information necessary for individual and [collective] action make society, and reproduction of society, possible" (Johnson 1988). They provide stability and incentives, reduce uncertainty, and mediate conflicts, and they are essential devices for social and economic change. They are social patterns reflecting or revealing specific social processes reproduction (Jepperson 1991). Institutions as guide-posts reducing the uncertainty typical of innovation enable survival of economic systems and action of economic agents (Lundvall 1994).

In spite of the different definitions of institutions, strict ones share the view of institutions as practices and rules, and as webs of inter-related formal and informal norms that govern social relationships (Nee and Ingram 1998). March and Olsen (1998) define them as "…a relatively stable collection of practices and rules defining appropriate behavior [which] are embedded in structures of meaning and schemes of interpretation that explain and legitimize particular identities and the practices and rules associated with them" (March and Olsen 1998).

Nevertheless, the definition of what constitutes an institution depends on the analytical level in question; it is a relative concept, and the specific institutional focus will depend on the context of analysis. Jepperson (1991) suggests four dimensions to take into account when defining the extent of what institutions are: 1) a practice becomes an institution depending on the particular context; (2) within a system, specific levels might become institutions when taken in relation to other levels. "Within any system having multiple levels or orders of organization, […] primary levels of organization can operate as institutions relative to secondary levels of organization. A microcomputer's basic operating system appears as an institution relative to its word-processing program (especially to a software engineer)" (Jepperson 1991); (3) depending on a specific dimension of a relationship (parents are more institutions to their children, etc.); and (4) relative to centrality.

Some of the institutions that are important for innovation are the following:

- Intellectual property rights understood not in the strict legal sense but as "the rights of an actor to use valuable [intellectual] assets" (Eggertsson 1996). The author notes that its economic importance depends on how well these are recognized and enforced by others. Enforcement is a key factor in the overall institutional environment. In agro-biotech patents are not extendedly used. On the contrary their utilization is very limited. The protection of plant varieties is through certificates and registrations. "Patent protection is used mainly by biotech firms for specific genes or specific techniques. Agrochemical firms protect innovation by producing complementary products, especially plants with genes resistant to specific herbicides." (Senker, van Zwanenberg et al. 2001).

- Both IPR and certification act as incentives or disincentives to engage in specific research areas, depending on the specific regulations in the country. For instance, plant varieties are patentable in New Zealand and in Uruguay but not in Costa Rica. This situation may act as a disincentive to research into plant varieties, which in turn would impair technological capability in that area.

Institutions could be formal or informal. The balance between formal and informal institutions is important for the overall dynamics of the environment. These balances certainly differ between countries. It is easier to look at formal ones as they are more visible, and codified, while to study informal institutions one might need to indirectly observe them "…through the behavior of people and organizations. […] In a country such as Denmark with almost no large firms, relatively low levels of R&D, and conspicuous technology policy, the relative importance of informal institutions in the system of innovation might be much greater than in a country like Sweden with many large firms and a considerable amount of formal R&D activity" (Edquist and Johnson 1997).

3.3.4.2. Organizations and their interactions

The web of related organizations might include universities, research centers, R&D laboratories, financial organizations, government agencies, trade associations, professional communities, NGOs, international organizations, higher education centers, bridging institutions such as university-industry agencies, and biotechnology users, including other firms and agricultural producers. The organizational structure is framed and analyzed through the lenses of sectoral systems (Malerba 2002).

Not only the structure of organizational actors is important but also, and fundamentally, their interactions and relationships: the degree of connectedness, and the types and purposes of interactions and linkages. Interactions and relationships are of fundamental importance in biotechnology, a science-based sector in which linkages are crucial, and universities and other research organizations play a key role regarding commercialization (Sharp and Senker 1999). In the following section I analyze both the level of connectedness of the sector, and the types and purpose of interactions.

(i) Degree of connectedness

Connectedness refers to two levels of analysis. On one hand it entails the degree of tightness of connections between sectoral actors. Systemic approaches to innovation highlight the importance of connectivity and linkages not only between firms, but also between firms and non-firm organizations (Lundvall 1992a; Nelson and Rosenberg 1993; Nelson 1993; Edquist 1997). On the other hand, and more in relation to the technology than to actors, it refers to the concept of complementarities, and the degree of complexity and interdependence between products and/or processes within the system. Nelson (1984) stresses the importance of having tightly integrated technological systems: "[P]articular technological advances seldom stand alone. They usually are connected both to prior developments in the same technology and to complementary or facilitating advances in related technologies". Furthermore, for high-tech firms to be successful, they must be 'plugged in' a wide range of technologies (Nelson 1984). So for the author, the institutional recognition of this interdependence leads either to the development of these companies oriented to different components, or to strong interactions between companies dedicated to distinct components. Connectedness thus refers to both, the complexity of the technological system from the view point of the different complementary components (in terms of structure), and to the interactions between complementary firms (Nelson 1984). In this research the latter is stressed throughout the analysis.

(ii) Types and Purposes of interactions

Sectoral actors might engage in different types of interactions, with varying intensity, for different purposes, stability and degree of symmetry. It is important to distinguish with whom, what type, and for what purpose do they interact. Interactions could denote pragmatic and punctual exchanges of tangible or intangible goods and/or services. They could get involved in joint action varying from bilateral to multilateral action, and could be either horizontal or vertical (Schmitz 1997). Schmitz (1997) notes the importance of joint action in determining growth and competitiveness in clusters.

Biotechnology firms may develop three types of relationships: upstream, downstream, and with competitors. Co-opetition is a hybrid type of relationship in which cooperation and competition coexist. Co-opetition relationships might include cooperation agreements between direct competitors (firms), upstream cooperation where there is also competition (when research centers compete with firms for instance), and downstream cooperation with large firms, where as well as cooperation there is also competition (Quintana-García and Benavides-Velasco 2003). These authors have found that co-opetition relationships, rather than purely competitive or cooperative ones, are the most effective type of relationship for innovative capability.

Arora and Gambardella (1990) identify four types of linkages: (i) research and/or joint development agreements with other firms; (ii) research agreements with universities; (iii) investments in the capital stock of NBFs (minority participations); and (iv) acquisitions of NBFs. These four types are complementary from the large firms' point of view, and target different goals: (i) are often product-specific and focus on 'downstream' activities of the innovation process, often developing and commercializing a particular discovery of NBFs. However, they (ii) are means for large firm's acquisition of basic scientific knowledge; these are complementary to linkages between firms; (iii) provide large firms with the possibility of monitoring research processes within NBFs, and get a 'preferential' link with the company. Finally (iv) enhances internal knowledge of large firms.

User-producer relationships are critical sources of innovation (Lundvall 1988; von Hippel 1988). At the same time, lack of competition in demand is as negative as lack of competition between producers (Lundvall 1988). The level of symmetry in these relationship is an important feature for innovation processes (Lundvall 1992b; Laursen 1996). These relationships could also vary in their length and sustainability. Close and durable interaction enhances the implementation of long-term investment, particularly when it is between firms and financial actors (i.e., banks, venture capitalists, seed capitalists) (Amable and Petit 2001). The degree of institutionalization of certain practices and collaborations between different actors, such as researchers with businesses varies between countries, and sectors. Whether interactions are institutionalized and embedded in a broader context, or whether they start from the beginning every time matters for the accumulation of skills and experience, for learning and also for building trust. Punctual interactions in which there is a one-shot exchange entail different commitments, and different opportunities for learning than more stable patterns of interaction, and collaboration. Interactions could vary in their degree of reciprocity as well. Asymmetric user-producer relationships and inertia in those relationships are serious disablers of innovation.

3.3.4.3. Policies

The key role of the State for development in general, and for technological development in particular has been extensively stressed across different schools of thought, from Development Economics, to Political Sciences and Studies of Innovation; yet with qualitative differences in the normative aspects of the role it should play. In the field of Innovation Studies the state is seen as playing a role of catalyzer and facilitator, one that contributes to a healthier competitive environment attending to the well-known failures that characterize innovation, and science and technology, rather than claiming for state interventionism. Thus, instead of focusing on how much state, the emphasis is on what kind of state involvement (Evans 1995).

Evans (1995) stresses that the state capacity to make decisions and implement policies depends on the combination of autonomy and embeddedness. The resulting mix of "embedded autonomy" lies on the linkages and bridges between state and society. States operate and function in a "concrete set of social ties", and these bridges or institutional channels enable (re)negotiation processes, as well as feed-back processes between state and society. The combination of 'internal coherence' and 'external connection' leads to "embedded autonomy". This mix is fundamental, as according to the author, "either side of the combination by itself would not work. A state that was only autonomous would lack both sources of intelligence and the ability to rely on decentralized private implementation. Dense connecting networks without a robust internal structure would leave the state incapable of resolving "collective action" problems, of transcending the individual interests of its private counterparts " (Evans, 1995, p.12).

Thus the need for an ‘intelligent’ ‘transformative’ state, with appropriate kinds of involvement is even larger in developing countries, where markets are far from complete, and institutions might face predatory traditions (rather than developmental) (Hirschman 1958; Evans 1996), or other problems such as the individualistic free-rider attitude of firms, typical characteristic of Latin American firms (Ramos 2000).

Along this same framework, the discussion here is not about presence/absence of a state role, but it is a matter of kind of involvement: what kind of policies, and in general, what kind of institutional environment. Public policies are fundamental enablers/constraints for the building of capabilities. Government support is about ensuring coherence and cohesion in the overall system, and providing a supportive organizational environment, while orienting and framing the learning processes (Lundvall 1994).

Learning is at the root of the process of building capabilities, and policies could decisively affect learning strategies, mechanisms/channels, and their degree of institutionalization in the sector. State actions (or inactions) could support and reinforce the building of capabilities, or the process of forgetting, or even processes of de-learning. Lundvall (1994) stresses some of the policy issues that are fundamental for supporting innovation. Some of the dimensions of these policy issues are the following: (a) means to learn; (b) incentives to learn; (c) capability to learn; (d) access to relevant knowledge; and (e) remembering and forgetting (Lundvall 1994). I include some complementary dimensions, as seen in the following table which summarizes the main dimensions of learning and the correspondent state policies, based on Lundvall (1994).

Table 3.3. Policies based on dimensions of learning

Dimensions of Learning	Strategy/Policy	Indicators
Means to learn	Investment on education and training Continuous renewal and revision of the form and content of these activities Orientation of education system and specific competencies focused Adaptability of education and training system to new social and technological developments	Spending on education (primary, secondary and tertiary) Update and revision mechanisms to change programs and plans Goals of the education system/Emphases Integration between different education levels Degree of horizontality between university careers Multidisciplinary programs and careers Flexibility of the higher education system
Incentives to learn	Salaries and wages systems designed to stimulate learning and creativity, at individual level Non-pecuniary and collective rewards at firm level and government programs	Scholarships Incentives to engage in collaborations
Capability to learn	Experience in education and training system stressing capability to learn Specialized adults training and re-training Flat organizations with horizontal information flows, firm level Circulation of personnel between departments and functions	 Continuous education programs Horizontality within firms Circulation of personnel within and between organizations
Access to relevant knowledge	Access to universities and technical institutes; Information and communication strategies (where to go within university, bridging-translating mechanisms); Libraries; Network formation; maintenance and development of communication infrastructure; Access to relevant data bases	Accessibility from the point of view of students and firms Interface offices within universities Libraries and information resources (existence and access) Mechanisms promoting network formation Communication infrastructure
Remembering and forgetting Opportunity to learn[28] Policy learning[29] Social learning[30]	Forgetting obsolete skills/professional expertise; Incentives to change and forget Generating encounter dynamics; Problems looking for solutions + solutions looking for problems. Using (promoting) External and independent sources for policy reformulation Public participation	Promoting mechanisms for continuous education and re-skilling Bridging mechanisms/instances between government, industry, university Mobility of individuals across spheres Policy evaluation mechanisms (peer review, internal, external?), monitoring, use of evaluation results in redefinition of policy; embedded mechanisms within policies, policy fora, feedback instances for policy review and learning Mechanisms for public participation Parliament participation

Source: Adapted from (Lundvall 1994)

[28] This dimension is added by the author.
[29] Idem previous note.
[30] Idem previous note.

3.3.5. Bringing back the institutional environment: what common features to focus on and how do they change?

After unfolding the specific components of the institutional environment in the previous section, now the focus shifts to the broader level of the environmental dynamics, analyzing general patterns of the institutional environment: how consistent/coherent the environment is; how thick; how cohesive; how rigid it is; what are the carriers and extent of change; and how stable and persistent the environment is.

(i) Coherence/inconsistency

The level of coherence of institutional environments matters for actors to know how to respond to environmental factors, particularly regarding strategies and mechanisms to build technological capabilities. The level of coherence depends on the level of complementarity of the environment components; that is, whether they reinforce each other in ways that are functional to innovation, or whether they contradict each other and diminish the overall coherence of the institutional environment (Amable, Barré et al. 1997). Capabilities could hardly be built in an environment lacking complementarities. This applies both at the individual level of the organization (Levinthal 2000), and at the meso-institutional level, too.

(ii) Institutional thickness

The thickness of the institutional environment matters for innovation and capabilities building. The thicker the environment the larger the resources for firms and research related actors to draw upon. The concept of institutional thickness is multi-faceted and involves at least four factors: (a) the presence of multiple institutions of different kind; (b) high levels of interactions among different organizations; (c) the emergence of coalitions and/or domination structures resulting from those high levels of interactions; and, (d) the actors' mutual awareness of involvement in a shared enterprise (as it could be illustrated by a common sectoral agenda) (Amin and Thrift 1994). This last item leads to the following category of cohesiveness analyzed by Parto (2002).

(iii) Institutional cohesiveness

The degree of cohesiveness of the institutional environment refers to that commonality of purpose mentioned above (Parto 2002). This issue centers on the extent to which sectoral actors perceive, and/or pursue a common purpose. Cohesiveness entails some level of strategy, and focuses on whether the institutional environment shows signals of cohesiveness regarding biotechnology in particular. It relates to the way biotechnology is framed at the environmental level, and the related level of cohesiveness (Parto 2002).

(iv) Inertia and rigidity

The institutional environment itself changes, and the question of how does it change is very relevant to this study. As Johnson (1988) points out, "[I]f institutions change too slowly, or too fast, or without coherence, this could easily result in higher levels of uncertainty, more severe conflicts, incompatible incentive systems and reduced creativity" (p.282). Thus, it is important to analyze how the components of the institutional environment have changed. Is it or has it been dominated by inertia and rigidity? Overall, are the constituent elements of the institutional environment complementary to each other, or are they largely inconsistent? The institutional environment could show patterns of *inertia and rigidity*. Inertia is functional to stability and signposting. But inertia could become rigidity if it impedes institutional learning in times of change (Johnson 1988). Whether the environment can respond to change by adapting itself or not is of critical relevance for the overall evolution of the sector in its interaction with the environment. As noted by Robertson and Langlois (1988) “If the institutional environment is inert and unsuited to a new technology, change will be difficult to implement. When existing institutions are flexible or well-adapted to the requirements of an innovation, however, change will be accomplished relatively easily” (Robertson and Langlois 1994). Inertia could become a major obstacle at times when knowledge bases are changing, as it is the case of the transition from traditional to more modern biotechnology. Resistance to change in knowledge structures that were functional and suitable to former knowledge bases could impede learning and the building of novel capabilities which would be necessary to follow up the ongoing change in the knowledge base (Edquist and Hommen 1999). Structural inertia leads to a lag between the rate of environmental change and the speed of reorganization; it means that organizations respond relatively slowly to the emergence of threats and opportunities in their environment (Hannan and Freeman 1984).

(v) Extent and carriers of change

Thelen (2003) suggests two main *types of change* of the institutional environment: change by *layering* and change by *conversion*. The former entails partial change: some elements are renegotiated while others remain in place. The latter however, refers to existing institutions but that are redirected to new purposes; it involves changing the roles and/or the functions (Thelen 2003). As stated by the author “The dual notion of layering and conversion open the door for a more nuanced analysis of *which specific elements* of a given institutional arrangement are (or are not) renegotiable, and why some aspects are more amenable to change than others. As such, these conceptualizations provide a way of thinking about institutional reproduction and change that steers a course between deterministic "lock-in" models on one hand, and overly fluid "one damn thing after another" models on the other hand" (Thelen 2003). The underlying point here is that institutions can (and do) change, but could be a partial change: there are some elements more amenable to change than others (Thelen 2003). The reproduction of institutions and their transformation are intertwined processes.

Besides the extent of the changing process, institutional change could respond to external and/or internal factors. In the former the drivers of change come from the environment (including relationships with other institutions, social behavior, etc.), while in the latter change is triggered from within. Whether change is processed from within, or in parallel structures matters for the process of change institutionalization. If change has to be carried on through parallel structures because inner ones cannot adapt or process change is revealing in terms of these structures' rigidities.

(vi) Persistence and stability

Another relevant dimension in the evolution of the institutional environment is the one related to persistence and stability (Scott 2001). There are different perspectives about the inherent evolution of the institutional environment. For some authors, institutions, once created, tend to persist; it is almost inherent to their nature. Others however, take a different stand, highlighting the importance of social action in their evolution. Giddens (1984) for instance, suggests that structure persist only as long as it is continuously produced and reproduced by actors. Persistence requires then, some sort of social appropriation; it should not be taken for granted for the mere (structural) existence of institutions. Rather than being persistence the natural trend, it could be entropy or deinstitutionalization (Zucker 1988, referred in Scott 2001). If this is the case, institutions might weaken and then disappear. Different causes could lead to this process. According to Oliver (1992, cited in Scott 2001) they could be grouped in three: functional, political and social pressures. Functional pressures are about the inadequacy of performance levels in institutionalized practices, and further loss of legitimacy. Political pressures could take place when there is a change in the power distribution that was underlying the original arrangement. Social pressures refer to coexistence of discordant practices, which at the end prevent their stability (Scott 2001). Deinstitutionalization could be gradual or institutionalization could be abandoned at once.

In sum, up to now and regarding change of the institutional environment, the research focuses on the following questions:

- Is the environment coherent? If so, how? How was it at earlier points in time?
- Overview of institutional thickness, and cohesiveness
- Has change taken place at the meso-level (institutional environment)? How has change taken place (mechanisms and processes)? What are (have been) the dynamics of change (inertia, rigidity)? Has change been coherent within the institutional environment?
- Direction and orientation: How has the institutional environment changed in the last decade in terms of direction and orientation? What are the main directions towards which the environment aims at? Is it possible to identify a direction in the evolution of the environment? Are there shared objectives, goals, and views?
- Extent of change: up to what extent has change crosscut all the involved factors? Has change taken place radically or incrementally?

- Process of change and institutionalization: Has change been carried through within structures or in parallel to existing dynamics/structures? Up to what extent are there mechanisms to make change an institutionalized process?
- Carriers of change? (within/in parallel)
- Through what processes, and with what actors
- Has change been sustained over time?
- How have the components (policies, organizations and interactions, and institutions) of the institutional environment changed?
- What are the obstacles and facilitators of change at the environmental level?

3.3.6. Innovating in small countries

Country's size is an important factor in technological change. Small size imposes some constraints with regard to innovation and competitiveness. One disadvantage is that firms in a small domestic market carry the burden of having to export to benefit from economies of scale and R&D effort (Walsh 1988). Small countries also lack critical mass, which in some cases is aggravated by a significant brain drain driven by the lack of resources and employment opportunities (Vuori and Vuroinen 1994). When it comes to knowledge and learning capabilities, "smallness" often leads to greater reliance on distributed knowledge bases, as well as to greater reliance on regional and international scientific resources. The search to extend the pool of resources that contribute to strengthening S&T capabilities in small countries also involves the reinforcement of complementarities among sectors, and between sectoral types, such as 'supply-dominated', 'scale-intensive', 'specialized suppliers', and 'science-based producers' (Pavitt 1984).

However, smallness is also seen as entailing few advantages. One of them is that reduced size may enhance the countries' flexibility and 'preparedness to develop appropriate productive structures' (Walsh 1988) and specialization in knowledge-intensive products, as in the case of Finland for instance[31]. It is argued, then, that size is not the main determinant, and what matters more are a country's flexibility, adaptability and preparedness. However, whether or not small countries have flexible structures that enable them to adapt to and adopt technical change and learning strategies is an empirical question. In small countries, the characteristics of the institutional set-up and its level of flexibility and preparedness to successfully respond to changes in production dynamics are key factors and could make an enormous difference to the country, as was mentioned above. In this sense, one of the referent works on small countries and their potential strengths is Katzenstein's (1985), who studied the smaller European countries[32] and their adaptation to economic change via a combination of economic flexibility and political stability (Katzenstein 1985). This author concentrates on their industrial policies and the strategies implemented to cope with change and adaptation.

The empirical question about institutions and whether they hinder or foster technological capabilities is crucial because of the relevance of environmental flexibility for small countries' competitive advantage (Johnson 1988, Walsh 1988). It is particularly the issue of flexibility that has triggered and motivated this comparative study.

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[31] See Lemola and Lovio (1988).

[32] The book referred to includes the study of Scandinavia, Low Countries and Central Europe, while a second one of the same author is on *Corporatism and Change* focuses on Austria and Switzerland.

3.4. Summary

This chapter reviews and discusses the building blocks and dynamics of technological capabilities and the institutional environment. It outlines the theoretical discussions, critically reviews previous empirical research on these issues, and sketches the analytical framework guiding the rest of the dissertation and the case studies discussed in the next chapters. In this chapter I have stressed the duality between capabilities and opportunities. Technological capabilities refer to the set of abilities, resources and processes possessed by actors, yet they entail a potential for achievement. To become concrete achievements, they require to be enacted, and for that, it is necessary to have environments that enable their materialization; they require environments that facilitate the encounter between opportunities and capabilities. Institutional environments, a second cornerstone in this dissertation, might enable or hinder those opportunities for transforming capabilities into achievements. The attempt to elaborate this argument includes the characterization of the components of the institutional environments (organizations and their interactions, institutions and policies), and their dynamics.

CHAPTER 4.

INSTITUTIONAL ENVIRONMENT AND AGRO-BIOTECHNOLOGY CAPABILITIES IN COSTA RICA

4.1. Introduction

This chapter presents the Costa Rica case study. Here the discussion is centered on both, the institutional aspects of the environment and their relationship with the building of agro-biotechnological capabilities. For this, I first concentrate on the identification of the sector: what are the organizations involved, and what is their role. Secondly I focus on their linkages and relationships: how connected they are, and through what type of linkages. Is it a fragmented sector, in which isolated actors engage only in punctual linkages? Or are interconnections strong and sustained over time? Then I move from that organizational focus into institutions and policies. Regarding institutions, some guiding questions are: What are the institutions ruling some of the sectoral dynamics? Are IPRs important? Are they being utilized? What other institutions are in place regarding biosecurity, for instance? And with respect to policies the focus is on some of the mechanisms implemented that might contribute to learning and to a more flexible system. Finally, the chapter ends with a broader overview of the dynamics of the institutional environment: is it coherent, is it a thick environment, how cohesive is it, and how does it change. These sections introduce and narrate the features of the environment, its dynamics and functions, and whether these are enacting opportunities to build and put capabilities into function. After the discussion on the features and dynamics of the institutional environment, I turn into the analysis of capabilities, and how do these two interact.

4.2. Setting the country

Costa Rica is known for some exceptional characteristics within the region. It stands out due to several reasons, among which are the following: its political, social and economic stability over time, the longstanding respect to democratic values, a strong equalitarian society, the extended coverage of education and health, and high levels of alphabetization among others. Costa Rica's singularity is even more valued when considering the context and countries surrounding it where sociopolitical stability, democracy and equality have been fragile and hampered.

Costa Rica has conceived itself as a European country. Unlike its Central American neighbors, Costa Rica has had lower influence of native populations, which have reinforced that image of Europeanization. Traditionally Costa Ricans' have proudly seen their country as an agricultural, pacifist and equalitarian republic, oriented to democratic values and social justice (Molina Jiménez 2003). In 1949 under the Presidency of Figueres Ferrer the Army was abolished; and in the 1980s Costa Rica was the only country that did not suffer violent conflicts. Its pacifist trajectory has been rewarded with the Peace Nobel Prize granted in 1987 to the ex (and currently in charge[33]) President Oscar Arias Sánchez for his efforts to get the region out of armed conflict.

Historically the country grew in relative 'isolation' from the rest of Central America. Costa Rica's low population density, its scarcity of natural resources compared to its neighbors, and its rural character allowed this country to grow with relative

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[33] Mr. Oscar Arias Sánchez is for the second time Costa Rica's President for the period 2006-2010.

independence from them. The high level of alphabetization of Costa Rica has also distinguished it, and public investment on education has increased over the years. While in the 1920s it was 1/6th of the national budget, in the 1970s it meant 27% and more than 30% in the 1980s.

The lack of natural resources triggered the search for an export crop, and it was finally found in coffee. The country became the first coffee exporter of the region, and in 1890 this crop accounted for 91% of export gains (Larraín and Tavares 2001; Tavares 2001) (see Figure 4.1.). The region has heavily depended on export of primary agricultural products. In Costa Rica, agriculture has traditionally been the main economic activity: by the mid 20th century, 66.5% lived in the countryside, and agriculture employed 55% of the economically active population. However this trend is changing, as agriculture is no longer the main source of exports (see Figure 4.1.).

Furthermore, social status has been based on land ownership. During the 19th century, coffee and banana growers dominated both the economic and political arenas. Coffee has been a key factor in Costa Rica's historical development. The first banks opened during 1860s and were in national hands until the 20th century. Their creation was tied to coffee growers, as well as their aim at supporting small-farmers and cooperatives (Larraín and Tavares 2001). Coffee, unlike banana, remained in domestic hands for the most part. In the early 1900s banana production turned into foreign control in part because of the state unwillingness to invest on the required infrastructure (i.e. railroads) (Larraín and Tavares 2001).

In spite of its smallness in population terms, this country has grown steadily. From little more than half a million people by the mid 20th century (656 thousands in1940), it grew up to 4,169 millions in 2003. From Costa Rica's total area of 19,652 square miles (50,900 square kilometers), agricultural land grew from 1,395 in 1961 to 2,870 in 1994 (Larraín and Tavares 2001).

During the 1960s Costa Rica fostered an import substitution model (ISI), as the rest of Central America did, with tariff preferences to industrial products from the Central American Common Market[34], extremely low (or negative) real interest rates, state participation in employment creation, tariff exoneration to imported raw material, subsidized interest rates for national and international investments in the industrial sector, an overvaluation of the Costa Rican currency, and export subsidized policies (Buitelaar, Padilla Pérez et al. 2000; Cordero P. 2000).

The ISI contributed to the "…transition from a rural economy to a modern one" according to Villasuso (2000, p.7) with a national and international communication network, transport infrastructure and financial and commercial services. (Villasuso 2000). While in 1960, manufacturing represented 13.2% of GNP by the end of the 70's it meant 22% of GNP (Buitelaar, Padilla Perez et al. 2000). During that time, state involvement led to the expansion of education and health services (Villasuso 2000). In the 1980s Costa Rica suffered the consequences of the *debt crisis*, experienced by almost all Latin American countries. Some of their manifestations were an inflationary process, unknown until that time; a drop in the GDP of 10% between 1980-82; an open unemployment rate of 9.5%; and a decrease in the national income close to 22% (Villasuso 2000).

After 1982, with a new administration, and loans from IMF, World Bank and USAID, Costa Rica embraced a new economic model to overcome the debt crisis. The new model was strongly recommended by these international funding organizations to all Latin American countries. The new model was based on its openness towards the

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[34] The Centro American Common market was established in 1962.

international market, the retirement of the state as a developmental actor, FDI attraction, and the increase of internal savings to finance the economic growth (Villasuso 2000, p.11).

Location has been another asset of Costa Rica, and Central America in general. Costa Rica has a strategic location being a cross-regional passage, close to United States. For some authors, this is known to be its greatest source of competitive advantage[35] (Larraín and Tavares 2001). This location asset has helped the country's attraction of FDI, a strategy forged during the 90's, which came to success in 1997 when the firm Intel installed a plant in the capital of Costa Rica.

Intel's presence in Costa Rica led to some crucial changes in the country's social and productive structure. Intel has benefited the country's economic growth, employment levels and the productive landscape, though the technological spillovers have not been as expected, as backward linkages to the domestic industry have not happened in the expected levels, and most R&D activities are still carried on in the headquarters (Buitelaar et al, 2000). However, a positive outcome of Intel's presence has been that in the effort to attract it, the country has implemented key transformations in the educational system, and the overall infrastructure and communications network. More particularly the interest in attracting it acted as a cohesive force for the tertiary education system, the local industry and services providers, and government to come together with the determination to contribute to turn Intel decision's towards their country. Government was strongly involved in the strategy of attracting foreign investment as well as in the attempt of diversifying its production (Egloff 2001).

The Costa Rican economy is acquiring a dual character: there is a very dynamic

[35] Costa Rica is 2047 miles away from US.

foreign-capital sector and at the same time, a reduced domestic industry (Cordero 2000). Still Intel continues to contribute to Costa Rica's economic growth. As highlighted in the ECLAC overview of the 2005 regional economies: "[in Costa Rica] economic growth took place on the back of an expansion in exports, which was driven, in turn, by an upturn in sales of microprocessors produced by the Intel plant and a buoyant performance from tourism and international business services."

Tourism has been another important source of Costa Rica's growth strategy. For the last decade, the country has flourished as a paradise for eco-tourists.

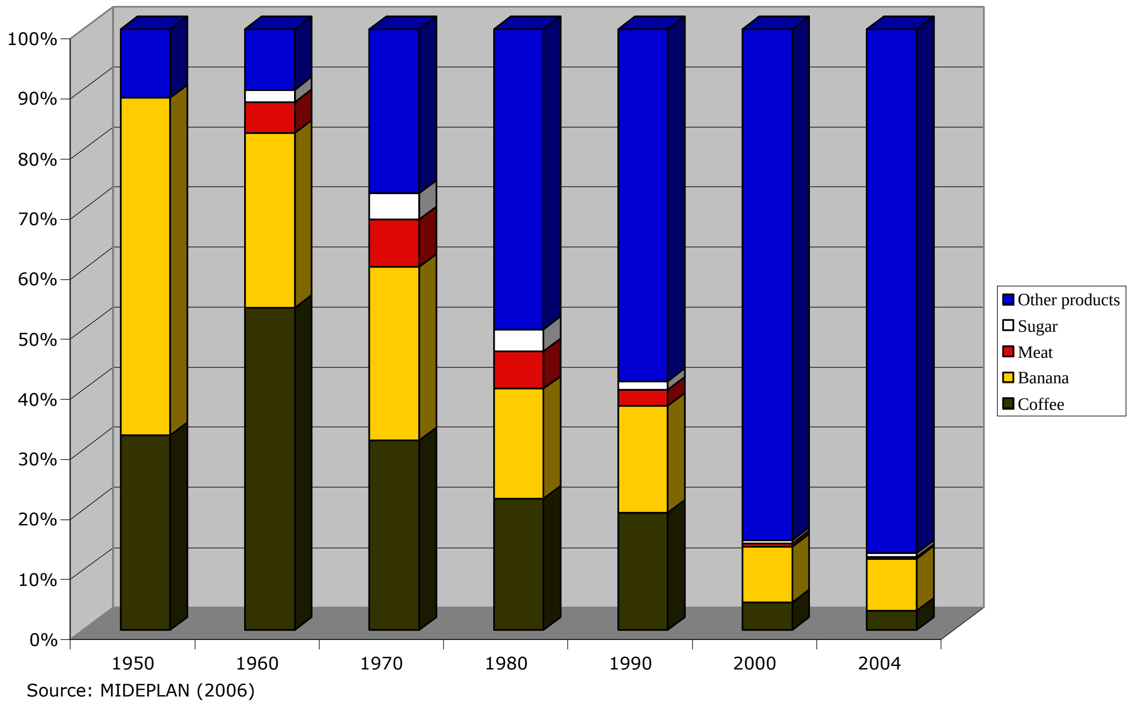

Figure 4.1. Costa Rica: FOB Exports by Main Products, 1950-2004

Table 4.1. Costa Rica: Exports by main product, 1950-2004

	1950	**1960**	**1970**	**1980**	**1990**	**2000**	**2004**
Exports by main product (%)[1]							
Coffee	32.4	53.8	31.7	24.8	19.5	4.6	3.2
Banana	56.2	29.2	29	20.7	17.8	9.3	8.7
Meat	0	5.1	7.9	7.1	2.7	0.5	0.3
Sugar	0	2.1	4.4	4.1	1.4	0.5	0.6
Others[2]	11.4	10.1	27.4	43.4	58.5	85	87.2

1. Source: Mideplan (www.mideplan.go.cr[36])
2. Since 1976 the ‘others’ category includes agriculture and sea products, industrial, active perfection, and free trade zones.

[36] Accessed October 2006.

Table 4.2. Costa Rica: Overview of some economic indicators, 1940-1996

	1940	1950	1960	1970	1980	1990	1996
Rural density[a]	N/d	N/d	284.1	366.2	459.2	563.3	600.2
Agriculture as share of GDP	33.5	38.5	29.7	25.0	19.2	15.9	15.5
Government spending as share of GDP	5.08	5.92	10.74	11.95	11.21	N/d	N/d
Export agriculture as share of GDP[b]	14.7	20.9	11.6	11.8	8.4	N/d	N/d

a. Number of inhabitants in rural areas divided by arable land area in square kilometers
b. Agriculture includes coffee, banana, sugar, and cotton.
Source: (Larraín and Tavares 2001)

4.3. Main milestones in research-related organizations and institutions

During the 19th century several biology expeditions and foreign naturalists traveled to Costa Rica attracted by its biological diversity. Most of them did not stay in the country, neither their research results were accessed or published there. However, later in the second half of the century, some scientists from Germany, France, Spain, England, Italy and Belgium arrived at Costa Rica invited as high school teachers (Rocha 2000; Zeledón 2000). They established the National Museum (1887) together with the Physic-Geographical Institute (1888) which became key botanical and zoology research references (Rocha 2000).

Biology in Costa Rica has been a fundamental research area, one of the eldest scientific fields with a recognized trajectory. Research on the country's biological diversity and concern over the use of natural resources permeated the history of science-making in Costa Rica since its origins. This accumulation is evidenced through well-established achievements such as the production of anti-ophidian serum in the Clodomiro

Picado Institute[37] (University of Costa Rica) that is exported to many countries, or the internationally known journal *Tropical Biology* (*Revista de Biologia Tropical*), which is indexed in the *Science Citation Index*.

Science in Costa Rica has been about solving problems, framed by pragmatism and oriented to provide responses to local problems. Science making has been practiced as an ordinary activity, and scientists are perceived as approachable unpretentious individuals doing their work. The history of science in Costa Rica stands, to a large extent, over the shoulders of a cohort of scientists who have moved across different organizations, leaving their printing in their way and building pragmatic institutions[38]. In that sense, the scientific community has relative mobility across different settings, between academy, private sector, and government agencies. This mobility is not generalized nor so much in terms of labor mobility; rather it is an advising mobility as these scientists have played an important role in advising and designing policies, and organizations. They have moved between public and private arenas with an entrepreneurial attitude, shaping every single organization they have belonged to. Thus, academy, government and to some extent, the private sector have been relatively porous environments, with *relatively* open exchanges and flows between them. In spite of the relative character of this pattern, it has been of fundamental relevance for the science endeavor in particular, but for Costa Rica in general, as well as these scientists have took

[37] Clodomiro Picado was a Costa Rican scientist who in the beginnings of the 20th century begun a line of research on biological and medical sciences that today gives name to one of the most respected research institutes in the country and its production of horse-based anti-ophidian serum which today is exported to several countries in Latin America and Africa.

[38] See for example the two volumes of ANC, Ed. (2000). Ciencias y Sociedad-Marco Institucional, Relevancia y Perspectivas de la Ciencia y la Tecnología [Sciences and Society-Institutional Framework, Relevance and Perspectives about Science and Technology] Desarrollo Científico y Tecnológico en Costa Rica: Logros y Perspectivas [Scientific and Technological Development in Costa Rica: Achievements and Perspectives]. San José, Academia Nacional de Ciencias.

science and the value of science towards different arenas, and have contributed to make science a visible enterprise.

Agro-biotechnology has benefited because of this group of scientists' focus on Biology. One of these individuals has been Dr. Rodrigo Gámez Lobo, who has participated in the creation of key organizations in this sector such as the National Institute of Biodiversity (INBIO), a public-private organization dedicated to the further advancement of research and utilization of the country's biodiversity, or the Center of Cell and Molecular Biological Research (CIBCM) at the University of Costa Rica jointly created by Dr.Pedro Leon, and Dr.Gabriel Macaya Trejos. Both are paradigmatic organizations in agro-biotech in Costa Rica. Both share a pattern of active, modern and pushing forward organizations each one it its own domain. Dr.Macaya has been rector of the university during two periods of time; all of these scientists have been recognized outside Costa Rica for their scientific contributions in different fields.

The first step in the definition of a S&T policy was with the creation of the CONICIT in the 1970s (1972). This was the first organization related to S&T in the country, following the same trend than the rest of the countries in the region. Almost every country had its own version of S&T council. After then, there were almost two decades of inertia, until the late 1980s and beginning of the 1990s when the law on scientific and technological development was passed. This law established the formal framework to support science and technology, and the creation of the Ministry of S&T (1990) as the coordinator of the national system of S&T (SINCIT). CONICIT would be the organism in charge of executing and implementing the Ministry's policy. Two years later another law led to the creation of the National Academy of Sciences (1992). Apart from the academy of sciences, the system also includes a chamber of technological-based companies (CEBATEC), and a National Biotechnological Commission. This national biotechnological commission has remained silent, and not delivered tangible outputs. In turn, the University of Costa Rica has created an Institutional Biotechnology Commission to articulate the University's internal resources.

In the 1990s the national legislation on biological diversity has undergone a revision process that culminated with the law of Biodiversity of 1998 (Rocha 2000).

ITCR, the Technological Institute of Costa Rica, played an important role when Intel decided to establish a plant in the country by supplying engineers and technicians, and by responding to specific demands of the company in terms of curricula for instance. Because of the Institute's technological profile, it became a substantial component in the plan for attracting Intel.

Science-making in the country faced an important change during the 1980s based on an IADB loan, which triggered many of the changes mentioned above in the policy and institutional arenas. The first loan of US$ 25 million enabled the building of the "City of Research" at UCR during 1990. This new complex of buildings located within the main university campus was developed in 21 has (around 52 acres) in San Jose, the capital city. This city of research hosts different research centers and academic units, all of a multidisciplinary kind. Its creation meant a key improvement for the research community in terms of the quality of the existing infrastructure but also in other dimensions such as the symbolic and relational ones. Research became more visible, and identified with a modernized infrastructure, with new buildings transversally organized and composed of scientists from different schools and disciplines.

4.4. Overview of the agro-biotechnology sector

4.4.1. Description of sectoral actors

Agro-biotech actors are classified as follows: (i) public and semi-public academic research organizations; (ii) private, and semi-public organizations/laboratories which offer biotechnological products and/or services; (iii) intermediate and bridging organizations; (iv) companies-users and/or producers of biotechnological developments; (v) suppliers; (vi) funding organizations; (vii) policy-advisers, and (viii) regulatory organizations.

(i) Public and semi-public academic research organizations

There are four public universities, from which one is a distance university. The University of Costa Rica (UCR), the older and bigger one, was created in 1941, but its predecessor school existed long before then. The school of Agronomy for instance was established in 1843 when the University *Santo Tomas* was created. Short after then, by the end of 1880s, the university was closed for political and economic reasons, but the schools of Law, Agronomy and Arts remained operating independently. The Technological Institute of Costa Rica (ITCR) was created in 1971, and in 1973 the National University (UNA) (Rodríguez Vega 2003).

Academic research concentrates in public universities, which have distinct core strengths and complement each other. UCR hosts most of agro-biotechnology research laboratories[39]. Since 2001 it has an institutional biotechnology commission oriented to

[39] Most academic research in the country is carried on by the University of Costa Rica according to a bibliometric analysis of SCI publications for the period 1999-2001 Lomonte, B. and S. Ainsworth (2002). "Publicaciones científicas de Costa Rica en el Science Citation Index: análisis bibliométricos del trienio 1999-2001 [Costa Rica Scientific Publications in the Science Citation

enhance and coordinate the different units and their strengths within the university, and with the outer community. By 2001, this university included 14 centers/institutes, 11 academic units and 167 researchers (Valdez Melara 2004).

Within *UCR*, agro-biotechnology crosscuts several research centers and schools. These centers are organized around programs and/or projects; most of them are multidisciplinary, and involve researchers associated to different schools and units within them. They are relatively independent in their management. They are directly tied to the Vice-rectory of Research.

CIBCM, the Cell and Molecular Biological Research Centre was established in 1977 at the University of Costa Rica. It accounted for the first research on plant virology. One of its current strengths is on genetic engineering and molecular biology, and hosts the leader national research vis-à-vis agro-biotechnological research, one on rice with more than a decade of accumulation, since the 1990s. Rice, which is a key staple crop in the country, is affected by phyto-sanitary constraints including the rice hoja blanca virus disease (RHVD). This affection is typical of the tropical region of America and has no natural resistance in the *Indica* varieties. The research project carried on at CIBCM took the gene of the virus' protein, and introduced to rice as its own protein. There is a process of interference, and as a result this plant becomes resistant to the virus, which is transmitted by an insect. This project is also pursuing a bio-pesticide based on a compound found in the rich biodiversity the country has.

An interesting feature of this project is that because of its regional singularity, the research project has integrated and be very exhaustive in the dimensions analyzed, including aspects ranging from basic research to the transformation of local germplasm,

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Index: Bibliometric Analysis for the period 1999-2001]." Revista Biología Tropical **50**(3/4): 951-962..

and intellectual property rights (Espinoza, Sittenfield et al. 2001). The lab related to this project within CIBCM involves 11 graduate students (9 Master, and 2 PhD).

CIA, the Agronomic Research Centre was established in 1955, and five years later it became part of the Agronomic School at UCR. Its strength is on plant biotechnology: micropropagation, free of virus plant production, seed production, variety characterizations, germplasm bank, phyto-pathological studies and phyto-improvement of potato, and tiquisque; and its main research areas are: biotechnology, post-harvesting, natural resources, and soils.

CIGRAS, the Research Centre on Grains and Seeds also at UCR focuses on post-harvesting of grains and non-perishables products, and on genetic improvement, production and post-production of seeds. Besides its research role, it provides consultancy and offers services such as quality analysis of grains and seeds, quantitative analysis of mico-toxines, and training courses, apart from selling soy seeds. It employs 12 researchers, and 11 technical and administrative employees. The biotechnology laboratory exists since 1980. CIPRONA, the Research Centre on Natural Products, was created in 1978, but only recently started to use biotechnological tools. Traditionally it has been strong in the chemical study of plant compounds, and is now turning into bio-remediation.

The *Universidad Nacional's* main campus is placed in Heredia, around 15 km North from San Jose. Their agro—biotechnology-related research concentrates at PIET (Tropical Diseases Research Program). This program is a confederation of laboratories, and it is multidisciplinary in nature but with a common focus: tropical diseases of animals and zoonoses (animal pathogenesis transmitted to men) in Centro America. These laboratories keep their independence but reunite from the strategic point of view. The program is associated to the School of Vet, which is part of the Faculty of Health Sciences, and involves academics and scientists from seven research units[40]. They have the freedom to pursue their own research lines, and share teaching programs. The Vet school provides the physical space, as well as the research and technical staff. But research activities are financed with external resources from contestable funding, often from international funding agencies. Complementary resources come from contracted research, training and diagnose services which are turned into research and education, maintenance of the plant, laboratory equipment and for acquiring scientific literature for the School library. These funds are managed by the Foundation of the University, a non-for-profit entity.

The *Technological Institute of Costa Rica* (ITCR) is a public university with a different orientation than the other two public universities. ITCR focuses on engineering and technical careers. It has developed its own profile, successfully recognized by researchers and professors elsewhere in the country. Professors from UCR and UNA recognize the strength of ITCR students in applying technical tools, and their entrepreneurial orientation. The approach of ITCR is less universalistic in its training, with a stronger entrepreneurial profile. Its graduates are sought because of that and because of their emphasis on application and solving problems.

This Institute has a main campus in Cartago, 20 km South from San Jose downtown, and is also decentralized in two secondary campuses, one in the capital with few careers, and the last one in Santa Clara de San Carlos, 105 km North from San Jose. Within ITCR, agro-biotechnology concentrates at the Centre of Biotechnology Research

[40] The research units are: Bacteriology, Entomology, Epidemiology, Immunology, Toxicology, Virology and Zoonosis; with nine laboratories: Bacteriology, Centrifugation and PCR Unit, Molecular Biology and Microbiology, Entomology and Ecology, Parasitology and Zoonosis, Immunology, Virology, Toxicology, and Poultry Pathology.

(CIB) in the campus located in Cartago. This centre is responsible for the career of Biotechnology Engineering. This career has been very positively accepted in the country by both firms and researchers from other universities. Agro-biotech is exclusively about plant-based biotech, and within it, it is about micro-propagation. They focus on applied research projects, on a contract-basis in the following areas: horticulture, fruit trees, forest, ornamentals, and medicinal plants. And also sell services related to: reproductive biology, vegetative propagation (tissue culture), in vitro conservation, crio-conservation and acclimatation, genetic improvement, molecular characterization, microbiology, and Microbial ecology.

The next category presents organizations which also relate to research but slightly differ in terms of their nature. These are CATIE, CORBANA and INBIO.

(ii) Private, public and semi-public organizations/laboratories that offer biotechnological products/services

Apart from universities, there are two other research organizations: CATIE and INBIO. These two are not strictly similar to the previous organizations. They are in between public and private. *CATIE* is an international organization created in 1973, after IICA's initiative and Costa Rica's government. But its origins go even further to 1940 when the US Secretary of Agriculture suggested to create a research organization dedicated to tropical agricultural. Some years later IICA was installed where today is CATIE, in Turrialba, 70 km from San Jose. Training and education of human resources[41] in agriculture-related areas is at the center of its mission, as well as conducting tropical research. It has 481 personnel and a budget of US$ 15-20 millions.

[41] Since 1947 CATIE has graduated 1,700 students. For more details see http://www.catie.ac.cr/, February 2006.

CATIE has a biotechnology laboratory with modern infrastructure and an accumulated trajectory in different areas, including coffee, plantain and banana, among others. One of their core strengths is the cell regeneration: from a piece of tissue the whole plant is regenerated. CATIE is organized around thematic groups or areas. There are 11 of these: (i) Cacao; (ii) Livestock and Environmental management; (iii) Musa; (iv) Plant Genetic Resources; (v) Center for Competitiveness of Eco-Enterprises; (vi) Agro-ecology; (vii) Coffee; (viii) Forests, Protected Areas and Biodiversity; (ix) Global Change; (x) Watershed; and (xi) Socioeconomics of Environmental Goods and Services.

INBIO is a non-profit institute dedicated to research and management of the country's biodiversity, which is a key national asset given the enormous biodiversity of Costa Rica. It was created in 1989 aimed at managing and researching the country's wild biodiversity. Its missions refer to: monitoring, conservation, communication and diffusion, bioinformatics, and bio-prospect. Bio-prospection is a fundamental focus of this organization. Research activities at INBIO are always partnered with other organization (private international in many cases) and oriented by the search of genes, secondary metabolites, compounds, etc. This institute is paradigmatic in its dealing with private companies. It is very experienced in negotiating royalties and IPRs in general. The bio-prospect unit is self-sustained based on these partnerships. The firms engaged in these partnerships carry on with the research costs, and provide an extra 10% for conservation of the natural resources which goes to the Ministry of Environment and Energy (MINAE). Some of its contracts are about constraining access to natural resources (in time and quantity), equity and compensation, technology transfer, training local researchers, and non-destructive use of resources.

A third organization in this category is *CORBANA*, the National Banana Corporation. It was created in 1971 as a public non-governmental organization constituted by the central government, the three State Banks and banana farmers, who support the organization through a share of their exports (levies), though its president has always been a banana grower. CORBANA's research agenda is decided based on farmers' needs and problems, which directly benefit from it. Other roles include: advise the government on technical issues, promote and conduct scientific research on related issues, provide credit for labor capital (with part of farmers' funding CORBANA created a fund to supply them with a soft credit with competitive interests rates and easy access, and other types of credits), and provide farmers' with information on markets and commercialization.

(iii) Intermediate and bridging organizations

CONICIT plays a supportive role for the scientific, the business and the policy communities. Its links with the private sector are not very many; it does so through providing contestable funding for both firms and researchers. But funding is really small, and serves as capital seed more than any other thing. It also keeps a database of researchers, projects, technology-based firms, and laboratories, as a directory to facilitate 'knowing who is doing what'.

The Chamber of Technological based firms do include biotechnological firms but has not played a visible role in terms of developing the sector, nor articulating them or the related firms. Finally, banana farmers are indirectly involved given their direct relationship with CORBANA.

(iv) User/producer companies of biotechnological developments

The private sector is composed of few firms mainly concentrated in plant-biotechnology (micro-propagation). This sector is not organized, nor are they actively involved in any collective instance.

Banana, tiquisque, potato, flowers and ornamentals concentrate most of micro-propagation activities. There are mainly two types of firms: few subsidiary of multinationals, or associated to multinationals, and then local firms. There are around 9 firms in this area. These firms could be categorized in three main groups based on their production: one single firm dedicated to provide services utilizing molecular biology, such as identification of animal sexing or paternity tests, and some services to plant-based firms. It is a local, very small and young firm. Then the second category concentrates the resting majority, and these produce biotechnologies-based products (plants) from banana to ornamentals, flowers, etc. Within this second category there are both local firms, and some associated to multinationals. The third group is comprised of three firms which do not produce any type of biotech nor use it, but plant and grow genetically modified seeds which original seeds are provided by the customer and towards whom the grown plant is sold to. So it is really about utilizing the land and benefiting from the counter seasonal effect to get the seeds grown in a nursery mode, and then selling them back. This group of firms is not included in the analysis; yet it is worthy to note that they are perceived as part of the agro-biotechnology sector by key informants I talked to in Costa Rica.

Firms dedicated to micro-propagation of ornamentals are very focused on some activities and phases. They constrain their activity to the phase between reproducing the original material, growing it in vitro, and then it is sold immediately after they are taken from the 'jar'. Most of its production is exported, and only a small share is sold locally.

One of these companies for example, exports around 70,000 plants/per week, while local sales account for around 3,000 plants/per month. And this production represents 50% of the installed capacity. They expect to continue growing and by the end of the year (2005) reach their ceiling. This ornamental firm relies on its main US customer for obtaining the initial material or mother plant, which originates the process of in-vitro propagation. This firm really concentrates in the mid step of in vitro propagating the plant. It is something like a sandwich activity in between the first step of having the mother plant, and having the small descendents. The mother plants are sent by the US company. "Many of our customers have patented species, so they send those plants to us and we start the process." Many of those plants are originally from Costa Rica, but have been genetically modified and patented by foreigners in foreign countries. So local firms do not micro-propagate these patented species, unless in 'partnership' with those companies. Many of the rest of their inputs are also imported but provided by local suppliers-intermediaries. There are two main types of processes, but in both the original material is sent by them, and the difference stands on where the process starts in the Costa Rican firm: they could start it further down or earlier in the process of micro-propagation. All research initiatives in this firm are in hands of the technicians, three from ITCR (Biotech B.S.) and one from UCR (Master), and some of this research is towards new varieties.

(v) Suppliers

Almost all supplies are imported, reagents being the most critical one. There is not an attempt to develop supplies locally. Often the preferred mechanism is to purchase from importers to avoid the extensive list of bureaucratic requirements. Suppliers decide when to bring the required inputs, and research has to adapt to their schedule.

If a firm wants to import equipment for instance, the process is extremely difficult and time consuming. The time spent in banks and public offices to comply with the procedures is enormous. Time is a critical resource for a small firm. A manager of a small new biotechnology firm refers to this as something like a punishment: "It is easier not to pay taxes than to do it" (Interviewee MB). Getting reagents is a labyrinth, according to one of the interviewees. Red tape preventing efficient import of perishables needed for experiments has been reported as one of the system's bottlenecks (León 1993).

The National Institute of Apprenticeship (INA) provides technically trained human resources in the area of plant propagation.

(vi) Funding organizations

Research funding is scarce, and constrained to public sources. CONICIT has some funds that distributes through contestable processes. Funding then acts mainly as seed capital. MICIT also has some funding at times, which distributes in the same way as CONICIT. A private local provider of funding is the CR-USA Foundation (Costa Rica-USA). The rest, and largest funding sources for research are international organizations.

The universities budget covers salaries for teaching, and infrastructure. Then, almost in all cases, researchers have to seek their own funding for research. These are international sources such as The Academy of Sciences for the Developing World (TWAS), the International Atomic Energy Agency (IAEA), Rockefeller Foundation, German cooperation (Federal Ministry for Economic Cooperation and Development, BMZ), and others. Another source of seed capital in the country is CRUSA, a private non-for-profit organization that provides bilateral funding to various areas of activity, including research. It operates based on USAID funding.

One of the most substantial influxes of resources for the sector, and for sciences in general has been the US$ 34 million loan from IADB that took place in the 1990. This loan for strengthening S&T infrastructure has enabled the building of new infrastructure (labs and research centers), purchasing equipment, funding of 50 research projects and few scholarships.

(vii) Policy advisers

S&T policy-making is mainly carried out by the Ministry of Science and Technology which was created in 1996. The basic objective of MICIT is to set policy priorities: ICT, materials, biotechnology, and the regionalization of science and technology. They regularly use their own resources to call for projects, open to both researchers and private companies.

On the other hand, since 1973 there is the National Council of S&T, following the same trend of other countries in Latin America. This council is in charge of compiling a database and S&T indicators, funding contestable-based projects, and following up the implementation of S&T policy. It also plays an advisory role, even though since the creation of the Ministry of S&T the specific contribution of CONICIT towards that role has been shaded. A relative overlap exist between these two organisms regarding the implementation of S&T policy.

The rectors of the four public universities form a council that acts as a policy adviser body (CONARE). This council mainly plays that advisor role, with a highly respected voice. CENAT, the Center for High Technology plays a dual role of policy advisor, but also conducts some research in its facilities. Three of these bodies, CONARE, CENAT, and MICIT share physical space in a building that used to be the office of USAID.

The National Academy of Sciences is another player in this field. It was created in 199 through a mandate from the Executive. Three years later was the law of creation of this academy was passed, in which it is created as a non-government public ‘institution’.

(viii) Regulatory organizations

The National Commission on Biosecurity is the organization in charge of monitoring, controlling and regulating all issues related to biological issues. It was created in 1998. It was created to fulfill the necessity to be able to respond technical and scientifically to questions and local demands. That necessity was identified by the Ministry of Agriculture, which led the process of bringing together individuals from different organizations such as the rector of the UCR at that time, who was one of the founding members, together with molecular biologists, people from the Sciences Academy, among others.

One of its main tasks is risk assessment; it provides technical-scientific advise about living modified organisms to the ministries of Environment, Science and Technology, Public Health, and Agriculture. It operates within the Phyto-sanitary services of the state.

The Seeds Office also within the Ministry of Agriculture is, since 1978, in charge of seeds’ certification as well as keeping the registration of varieties.

The Ministry of Agriculture has played an important role with regard to the control and regulation of biotechnology related matters. As mentioned above, the ministry has been able to gather individuals with important trajectories from different arenas, including the scientific community.

Table 4.3. Costa Rica: Snapshot of interviewed firms and research centers

	Year of origin	Number of workers		Ownership	Outputs and markets	Area of application	Main techniques utilized
		Current	At beginning				
FIRMS							
Firm A	1985	90	3	Started as subsidiary of foreign company. Now owned by domestic. Economic group with three firms.	Started dedicated to ornamentals. Now larger share Local and export: 500,000 plants (capacity). Germplasm bank with more than 20 tested banana varieties.	Vegetal	Plant-based Micropropagation: banana, ornamentals.
Firm B	1990	8	1	Private, local	Local (local growers and multinationals) and regional markets.	Vegetal	Plant-based Micropropagation Banana, pineapple, and ornamentals
Firm C	1990	Current: 40 (5 technicians)		Larger shareholder US capital	Ornamentals Mainly export to US (70,000 plants/week), some local (3,000 plants/month)	Vegetal	Plant-based Tissue culture In vitro
Firm D	1955	Current: 1500 average/year (60 production) (1 Biotech + few professionals such as Agronomists)		Subsidiary	Export. 2 products: seeds and cuttings (more than 100 million/year)	Vegetal	Plant-based Tissue culture: Ornamentals
Firm E Molecular Analysis	2001	3	1	Private, local	Services, paternity analysis	Animal and vegetal	DNA analysis
UNIVERSITIES							
	Year of origin	**Total workers-current**		**Type of org.**	**Outputs**	**Area of application**	**Main techniques utilized**
UCR - CIBCM	1957	Around 20		Public	Research projects, publications, partnerships, internships (local and abroad) education and training, services' providers.	Vegetal	Molecular virology, genetic engineering, molecular biology
UCR – CIA – Plant Biotech Lab	1977	Around 70: 16 researchers (partially dedicated), 25 postgraduate students, 20 undergrad.				Vegetal	Genetic engineering, DNA research
UCR - CIGRAS	1955 (1980)	4 (PhD)				Vegetal	Genetic enhancement; variety assessment; production of free-pathogen plants; clonal propagation of plants; molecular characterization.
						Vegetal Citrus, bamboo, ornamental	Metabolomics, vegetal propagation, plant bioprospection

Table 4.3. Continued

UCR - CIPRONA	1978 (1997 w/ biotech.)	2 researchers in biotech.			Vegetal – natural products	Bio-remediation, metabolomics
UNA- PIET	1987	40 (7 PhD)			Animal	Genomics, genetic engineering, cell and tissue culture.
ITCR - CIB	1972	11			Vegetal	Tissue culture and Molecular biology: potato,
ITCR - Career of Biotechnolo gy Engineering (B.S.)	1997	16 stable staff + satellite from other schools		Vegetal		
Other RESEARCH ORG. (hybrid)						
	Year of origin	**Total workers-current**	**Type of org.**	**Outputs**	**Area of application**	**Main techniques utilized**
CATIE – Biotechnolo gy	2 labs: 1978: Biotech lab. 1989: molecula r biology.	5 main researchers + 8 assistants + students (Biotech lab.) (Thematic group:15 phyto-genetic resources)	International (regional) organization	Research projects, training, and some services sold (vitro-plants) They have developed methodologies for cell regeneration for coffee and Musaceas (banana & plantain). Share IPR with France, based on collaborative research	Vegetal coffee, banana	Plant-based In vitro culture, micropropagation, molecular techniques, improvement assisted by molecular probes
CORBANA – R&D area	1970 (1980 research initiative s; 1992 biotechn ology laborator y)	80 research and mgmt., 21 professional, 2 MSC, 1 PhD) (200 total in whole org.)	Levy-based	Research projects, genetically improved plants	Vegetal	Micropropagation of banana; molecular biology
INBIO – Bioprospecti on	1989	22 (6 biotech)	Non for profit (self-sustained)	Partnerships and collaborations w/foreign companies; Seek sustainable uses of biodiversity	Vegetal	In vitro culture Fermentation DNA isolation

Source: based on interviews and secondary data (see Appendix III).

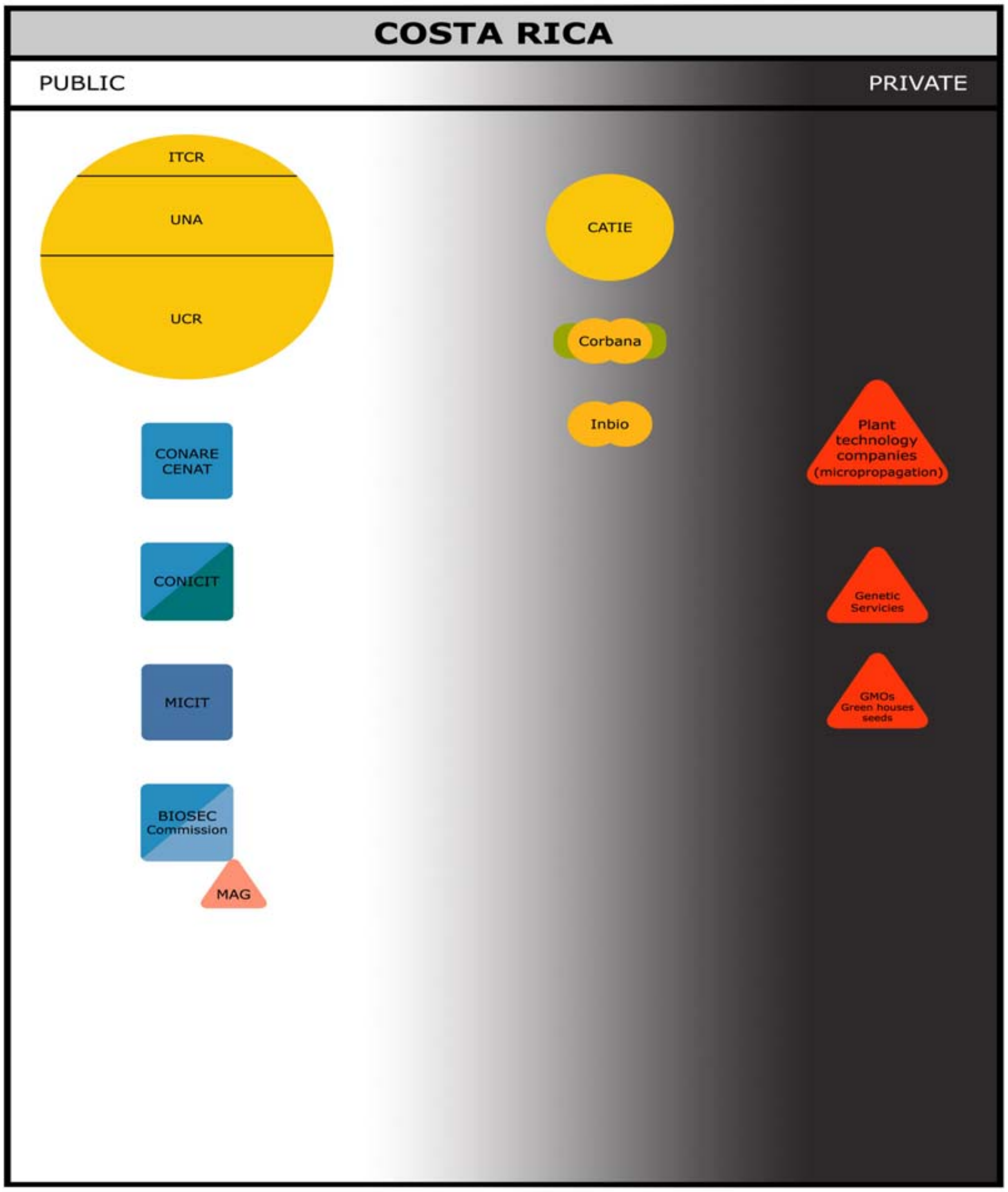


Figure 4.2. Costa Rica: Diagram of sectoral related organizations

4.4.2. Interactions and relationships in the sectoral system

(i) Degree of connectedness

Agro-biotech in Costa Rica involves individuals who have participated in different types of organizations related to research and policymaking in the areas of biology, and science and technology in general. They moved around research organizations (public and hybrid), and policy agencies, and in their way they have left an imprint, while carrying on that accumulated experience, and more importantly have contributed to shape a vision about the role and relevance of research for Costa Rica. These loops between different types of organizations, which are bridged by those individuals, involve some like CIBCM, INBIO, the UCR's research provostship, and the Biosecurity commission. These organizations share some common orientation and framing of innovation and a focus on bio- and biotechnological research.

One of the features that distinguish this case study is the way research centers are organized. In general these centers bring into researchers from different disciplines and schools from the same University, who work together around specific research projects. In some cases researchers belong to one school, though other times they are related to more than one. Thus, their regular research life takes place in these centers, which internally embody connectedness and complementarity given their multidisciplinary character.

Interactions between research actors other than those from the reference group are mainly of the type 'when needed': "collaboration happens when needed, depending on the goals and requirements of the time" (Interviewee BO), depending on what skills and/or resources are required, researchers seek collaboration mainly abroad, and sometimes in the country. The research community has close ties with actors outside Costa Rica, closer than to other colleagues within the country and outside their immediate research group.

Researchers are relatively connected to farmers based on the research projects they have. The weakest link still is with private firms, but research groups are slowly starting to interact and collaborate with them: “We are working with a company trying to improve one of its ornamental plants utilizing molecular makers. It is our first experience with a private company” (Interviewee AR).

On the other hand, hybrid organizations are inter-connected, as well as strongly linked to local communities and farmers. However, with universities linkages are not as strong. They interact on a very punctual basis and with some difficulties. “It is interesting but it is much easier for us [hybrid research organization] to collaborate with colleagues outside Costa Rica, than internal. We have a cordial relationship with universities for instance, I keep in contact and talk with researchers from the university, but never have worked together in a project. I do not know why that is” (Interviewee AC).

Firms are fundamental parts of the sectoral puzzle, even though they are quite disconnected among themselves, and with research actors. Universities in turn, are formally articulated through CONARE, the Rectors council. Each university has developed its own strength and distinctive profile. Each one has also created programs or centers that are multidisciplinary in nature, and bring researchers from different schools from within the universities, who share research projects and laboratories. They are configured in a way that permeates through the school hierarchical structure. There is one case of a researcher from UNA who for ten years conducted his research at a research center in UCR. This is mentioned as an exceptional case.

Researchers from universities interact and are complementary, but that complementarity has not translated into partnerships and steady collaborative efforts. It has been more a tacit complementarity by way of each one concentrating on its own strengths, and not colliding between them. However, they do act as a community when need to defend science and research making in Costa Rica. There are several examples that show their responsive ability to react in that collective pattern. One example is when the debate on GMOs, they came together to argue about the scientific connotations of organisms genetically modified. Another case of their engagement in joint action took was in the context of lobbying to get a biotechnology processing plant from the European Commission. This project is estimated in 15 million Euros, and is aimed at scaling up biotechnological projects. Very similar way of proceeding took place when Intel was deciding where to set its plant. The very interest of the European Commission shows the potential for synergy that this sector has. This project might not only scale up biotechnological projects, but also leverage the sectoral dynamics, and relationships. But this potential is not evenly distributed across actors, nor are all of them equally open to collaborate.

(ii) Type and purpose of interactions

Interactions among researchers takes place in the context of already institutionalized spaces. Researchers have their groups and colleagues with whom they have been working on for some time. The locus of interactions between academic researchers at the national level is mainly the research center that is, between researchers within the center. In the University these centers are multidisciplinary and congregate researchers from different schools. This is the case of centers in the sector studied at the University of Costa Rica, the National University and the Technological Institute of

Costa Rica. Interactions between researchers from different centers are seldom, and less frequent. Students are the most common bridge between centers from different universities when in they work with researchers in other universities for their thesis.

Increasingly researchers tend to engage farmers in the research process. It used to be that farmers got involved at the end of that process, once the new technology was already developed in the lab and it was ready to be transferred to them. This top-down scheme of doing research in which users' participation was missing, resulted quite inefficient as researchers lack information and insights on farmers needs and problems. The ongoing change has been in part triggered by requirements from funding/donors demanding closer involvement of farmers since the beginning of the research process.

Researchers and firms have emphatically mentioned that there is little collaboration between them. There are several reasons underlying their weak interaction, but according to interviewees an important part of it has to do with cultural problems, and different rationales. Firms and labs have different time frames, as well as goals: academic researchers are expected to enhance public knowledge and often refuse to accept firms' limitations, particularly publishing research results for instance.

The lack of connectedness between researchers and firms is notorious. Firms are weakly tied to the rest of the sector; they are even weaker in their ties because operate in relative isolation from each other. Their linkages with the university are weak, and for very specific, short-term purposes. Within the sector firms are the most isolated actors, though they are tied to customers, mainly foreign companies. They complain that university labs are not open, are slow and reactive, or that they are too focused on academic research. Some interviewees from firms point out that firms are extremely closed. They do not held relationships with colleagues within the country, least with researchers. When students in the area of biotechnology need to visit private firms' labs it is not easy. According to an interviewee: "When I call a firm to take our students there, and ask, "Can we go there" The response is "No". There are only a couple of firms that have a different response and are more accessible" (Interviewee BI). Another interviewee working at a firm refers to that problem as follows: "In Costa Rica we have a problem of lack of sharing and exchanging information between firms' laboratories. They are super-closed and jealous of what goes on inside its walls" (Interviewee SL). Rather interaction is easier with other firms across borders, from other countries. A firm's manager states that: "paradoxically with local universities we have not done much together. There is a Napoleonic conception of research. Universities are isolated from the real world, and publish to ascend in the academic ranking, which is needed to justify wages and income but have no repercussion on national production" (Interviewee AT).

In the case of banana things seem to work rather different as far as connectedness between research and production is concerned. CORBANA plays an important role not only by facilitating linkages and interactions for farmers, but also in terms of the orientation of the research agenda towards farmers' needs. However, even here connectedness is constrained and atomized between farmers, CORBANA and few research organizations. Firms interact with farmers mainly as suppliers of banana plants, but their interaction is constrained to the action of supply and purchase. Firms and research centers do not interact, through it has been mentioned that it is slowly changing. Private companies are timidly becoming players through financing some projects.

Across the sector, running into each other and holding informal interactions is part of actors' everyday life. Everybody knows each other in this area, and can easily contact whoever they need; and that is what they do when needed but for very punctual, pragmatic needs.

The mapping of interactions shows a strongly connected sector towards the outside, trespassing the national borders. But interaction between similar types of organizations in the national context is weak. Researchers tend to relate to those within the same university, though rarely they cross-organizational borders to interact with peers in other organizations. Linkages are bilateral, and tend to be within same type of organization: between researchers from the same center or institute. Unless co-participating in a project, relationships are mainly informal and not hold for other purposes that the strict punctual one.

Tracing some of the sectoral changes and structures illustrates the importance of few individuals who have moved around the sector, imprinting some features across these different types of organizations, and enhancing them with that experience of variety and diversity. A distinctive feature of this sector compared to the other countries is the role of certain individuals in the building an institutional and organizational trajectory. In that sense connectedness is very different in Costa Rica. Many of the leading research organizations in this sector have been created by the same small group of individuals; and in spite of these organizations' differences in terms of type, each one has succeeded in its respective area. They have been successful at obtaining steady funding from international sources. They have also a strong national and international presence, ability for negotiation, and have identified relevant themes in the national context to work on.

Connectedness with international sources has a somehow different pattern, but these differences are only partial. One difference is that those actors that are weakly articulated within the sector hold stronger connections with foreign actors. At the same time these differences are attenuated because of the quality of linkages and exchanges, their content, and the context of those connections. Many of those connections reproduce the same general pattern of local linkages constrained to specific purposes, not sustained over time, and with asymmetric types of exchanges. Furthermore, those differences are partial because those who are more disconnected at the sectoral level do not engage into sustained, cumulative and more symmetric relationships. It is also partial because those that do engage in higher quality, more cumulative and symmetric interactions with outside actors are those that are already more connected within the sector: universities and research centers.

Firms' interactions and articulations with foreign actors are of the following types: (a) subsidiary firms interact with mother companies for commercialization, marketing, and technology transfer. Local subsidiaries are closely engaged in interactions with their mother and sister companies over the world; (b) local firms interact with foreign customers for commercialization and marketing. In the case of micro-propagation firms, these are often nursery companies which grow their plants; (c) with universities or research centers to have a lab test run, or to get a certification, and linkages do not persist after that; (d) in few cases interactions are with international funding sources for getting funds to participate in fairs, or internships; and, (e) with foreign regulatory actors for exporting their products.

Within Latin America, the Research and Advanced Studies Center of the National Polytechnic Institute of Mexico (CINVESTAV, 1961) has been a very important partner for both universities and hybrid organizations in Costa Rica. At the broader international level, interactions are with researchers and organizations from both US and Europe, such as Universities, USDA, and the International Commission of Atomic Energy.

Universities and hybrid organizations maintain strong interactions with international funding organizations and donors like the Rockefeller Foundation. Local research is heavily reliant on foreign sources of funding; these linkages are crucial, and local researchers have managed to have mid- and long-term sustained funding. Depending on the specific area of research, it is with whom they collaborate. Experienced researchers in Costa Rica are part of international clusters, or ‘knowledge alliances’ (Rogers and Bozeman 2001), which oftentimes come together to solve a specific research problem. Each one fills in a special need and plays a role based on their expertise in the area of research, their degree of complementarity, previous collaboration experience, connections with policy actors, and very importantly access to international funding sources. “The current project I am managing is funded by the International Commission on Atomic Energy for five years. My role is to search for and put together a group of scientists who will be looking for solutions to the research problem. In this project, part of it is going to be done from Vienna; another part is going to be done with UC Davis; some is going to be done by a Brazilian center, and another part with a group in Puerto Rico. But most resources are in the country: laboratories, and the Frijol program, a key component of the project” (Interviewee PB).

Researchers in Costa Rica are totally dependent on these international sources. International linkages and collaboration show to be crucial condition for projects to be successfully completed. These linkages provide different types of resources: access to a wider set of funding opportunities, infrastructure, and access to tacit knowledge through internships, consultation, and visiting positions, but mainly in one direction from Costa Rica to foreign countries. Researchers keep linkages with peers from the rest of the world, and more particularly with their colleagues from the postgraduate training. The most extendedly utilized instance is to go out to foreign labs, conferences, etc. Least often they bring into researchers from other countries. Thus local universities and hybrid research organizations keep strong interactions with foreign universities and research labs. Finally, local suppliers interact with foreign ones to import inputs such as reagents, and other lab supplies.

4.4.3. Summary of the main characteristics of the institutional environment

As seen above, this sector involves several types of organizations. The majority of them and the largest variety are at the research end. Academic research concentrates at UCR, but still UNA and ITCR play an important complementary role. These universities have different profiles: UCR leads the plant-based research, and moves along the spectrum of basic-applied types of research projects. Within UCR there is a wide spectrum of centers related to this sector, such as CIA, CIBCM, CIGRAS, CIPRONA, etc.

UNA fills in the area of animal-based research, while also provides services on these issues, and stands out with programs such as the one on tropical diseases (PIET). This program has an outstanding trajectory in the field of animal health, both national and internationally. ITCR in turn supplies the sector with trained plant-based biotechnologists, which have been hired at large by the private sector, while few get go after postgraduate courses at UCR. This institute also carries on research projects, but more applied and constrained to demand-oriented research from the private sector.

These research organizations are complementary, but their interactions and complementarity takes place mainly tacitly, through students and/or graduates who are then involved in other organizations across the sector. In general terms, these research organizations are tacitly connected through: (i) graduated researchers moving from UCR to other universities as UCR is the major provider of researchers to other centers, and almost all sectoral academic researchers and professors both at UNA and ITCR have been trained as undergraduates at UCR; (ii) students who get involved with researchers in other universities to do their final thesis; (iii) biotechnologists trained at ITCR are absorbed by local firms. Students act as bridges between firms and universities, such as ITCR, and also between research centers from different universities. Students conform the stronger connecting path between local research centers from different universities.

Researchers are aware of the different strengths and profiles of their colleagues at other universities, and of their potential complementarities. In spite of their awareness and knowledge of who is doing what and where, there is not much engagement in collaborative projects at the research level between research centers from different universities. Apart from the universities there are other research organizations different in nature, and in the type of function they play, and niches they have. CATIE for instance has oriented itself towards small farmers, dismissing private firms as potential partners. They are now reviewing this strategy, and looking for expanding their connections to the private sector. As mentioned by a researcher from CATIE: “there was not a nexus between CATIE and private firms because CATIE had to favor small farmers. That has changed completely and now we ought to get closer connections towards firms.” This change has to do with different reasons. One of them is the need to become self-sustainable, and this requires looking for markets and commercialization of services such as selling micro-plants. Before micro-plants used to be donated; now that is no longer the case.

Hybrid types of research organizations are key complements to universities. They both nurture the sector with core scientific activities, make it visible outside the country, deliver technological development, and are the reference to the rest of the actors in the sector. They both have in common a research agenda strongly embedded in the local context. In general in Costa Rica research projects focus on local and regional problems where there is competitive advantage (León 1993) such as maize, corn, rice, coffee, some roots (tiquisque, potato), and tropical viruses. Furthermore, universities are decentralized throughout the country. They hold multidisciplinary horizontal programs in the three universities, and those multidisciplinary centers and/or programs related to this sector are leading ones in their respective universities. And as mentioned earlier, research problems are tackled with multidisciplinary approaches. It is not a vertical structure oriented by a teaching rationale of schools, but rather by research goals and shared problems. This is a very distinctive feature of the sectoral mapping of Costa Rica.

Within the productive sector, firms are few and dedicated to plant micro-propagation. They vary in terms of products (banana, ornamentals) and markets (local, regional, Europe and US for those that are or have been subsidiaries of MNC).

Changes in the productive sector has had to do with higher quality standards, higher professionalization, training of their human resources, improved infrastructure as many of them have moved and installed new laboratories and production plants, and development of new varieties. In each of the firms I interviewed they have hired biotechnologists trained at ITCR. Those subsidiary firms conduct the crucial phyto-improvement processes in their mother-companies. When a technical problem appears the local technicians might try to solve first by trying to get responses from local sources, such as UCR, or CATIE according to one of these professionals.

Regarding the interactions between the sectoral actors, firms are the actors with weaker connections to the rest of the sector. They interact with research actors on a punctual basis, even though at the individual level there is strong overlapping and connections between them. Furthermore they are disarticulated among them, and are scarcely visible as a collective. They know each other, and there is nothing that particularly prevents them from engaging in collaborations, but their fear, secrecy practices, and individualistic culture. They do engage with other firms outside of the country, either as subsidiaries if they are so, or for commercial purposes. In any case, connections are scattered, punctual, and rather asymmetric.

Intermediate organizations are few, associational mechanisms are missing. Funding mechanisms are attempting to strengthen their articulation, but still there is a long way to go, and more strategic tools should be used.

The research actors are the ones with higher connectedness to the overall sector, even though their inter-organizational relationships are also weak. They are highly connected at the international level, with research peers, and with funding organizations.

Regulatory organizations naturally hold close links with all actors to comply with their function. Suppliers are a necessary but problematic link, because of the obstacles related to getting imported inputs in the country.

4.4.4. Institutions

(i) Intellectual Property Rights

- Legal status

In Costa Rica biological processes, transgenic plants, and vegetal varieties are not patentable. The legislation regarding genes and microorganisms is in turn unclear (Salazar, Falconi, and Cohen, 2001). Right now Costa Rica is going through a discussion about protecting plant varieties, and both for and against it arguments are intensive.

The Patent Law goes back to 1983, though it was amended in 2000. Patent law in the country follows WTO and WIPO. The main conditions for patenting are: novelty, non-obviousness, and utility. Patents are granted for a period of 20 years from the filing date and its exploitation in the country is compulsory within three years from the date of issue. Scientific discoveries are not patentable, nor are plant varieties, animal breeds or biological material in general (Espinoza, Sittenfield et al. 2001).

- Appropriation and utilization of patenting mechanisms

The reality is that patents are scarcely used to protect intellectual property. Industry mainly operates with secrecy agreements, and researchers are not too keen about patenting, in part because of their conceptualization of knowledge as a public good, and in part because of the lack of conviction about its use and effectiveness. But still it is worth noting that they are extremely aware of this issue, and are very active in protecting their work though through other means than patents, secrecy mainly. Furthermore, students in the process of completing their graduation are asked to sign a contract of secrecy at UCR for instance. Confidentiality contracts are widely used by firms as well.

At UCR this issue is perceived as very important and efforts are being made to change this pattern. The office of technology transfer and the research vice-provostship have been working on these issues in an attempt to stimulate a change in the practices of researchers. They have a unit and a lawyer specialized in biotechnology dedicated to assess and overview how are researchers dealing with these issues, while also ‘educating’ them in the importance of patents. The project on transgenic varieties of native rice has helped in this process because of the length, sustained and multidimensional character it has, and the need they have had to face and solve IPRs related issues.

For example, in that project there has not been much of a problem within the country because there are not patents affecting them in Costa Rica. But the problem does not finish there, because of the complexity of IPR issues and the many interactions involved. As stated by an interviewee: “Our rice farmers are very aggressive, they have crops in Panama or Nicaragua. And what would happen if Venezuela is interested in this seed, or any other country. So we have to conduct those studies because patents are territorial. And what happens if one of these rice varieties’ sub-product gets into US. So things are not so simple as we might think. And it is not patents what concerns us the most. When we bought the Helio gun we signed a contract in which we stated that it would only be for research purposes but if something is commercialized then we would have to negotiate with them. We have learned these issues in the way through. Those things make us richer as researcher and individuals as we now know how to proceed and negotiate.” (Interviewee AR). Nowadays, genes for research purposes flow relatively easily. Researchers exchange genes and information about them very easily. That input is crucial.

But that free exchange coexists with secrecy and confidentiality. “For example laboratory protocols are also critical. Or when the manager of Company X (seeds) wants to negotiate with us about their potential interest in commercializing these seeds. Now I do not talk with them unless they do not sign us a confidentiality contract. I did not know that before. Or students when start their theses have to sign contracts of confidentiality. Their results are not theirs, but of this laboratory. The same applies for the thesis committee” (Interviewee AR).

The UCR has not always been concerned about intellectual property rights (IPRs); on the contrary it is a relatively new issue. What is interesting is its commitment and decisive effort to alter this pattern. As contractual relationships with the private sector became stronger in the decade of the 1990s, universities in Costa Rica have faced the need to tackle on these subject matters. UCR in particular has responded to those challenges and new problems basically by learning about the issue and getting the required resources. Biotechnology is one of the bottlenecks in this sense, as this rice project has had to specifically respond to legal issues. So the lawyer is closely related to the rice project, while also taking part of the higher level in the university contributing to shape the institutionalization of IPRs. There are still many issues to overcome. But as new situations appear, the university is looking for ways to cope with those. For instance, as researchers are starting to engage in collaboration with private companies, new problems arise. When working on a specific research project with a private company, students are oftentimes the immediate bridge and are who really embody the practice of collaboration. So how are IPRs issues faced? If the student presents the results of his/her research against a committee for thesis approval, how are the intellectual interests of the company protected? The university does not have any mechanism to prevent or slow down the process of publishing thesis research results.

(ii) Bio-related regulations

Within its 51,100 km^2 of land area (0,03% of the world's land) and 589,000 km^2 of sea territory, Costa Rica is one of the 20th countries with larger biodiversity in the world, thanks to the geographical position, its two costs, mountains, and several micro-climate and eco-systems. It hosts more than 500,000 species, which account for 4% of the world's species; more than 300,00 of those 500,000 are insects (INBIO n/d).

The country is extremely aware of the importance and value of this asset and the resources it entails, and has developed a rather sharp inclusive and integrative framework. Sharp because they are well aware of the economic value, but have been concerned and attempted to emphasize the relevance of sustainability and the value of holding the property of those resources. These resources are seen in a broaden way than the mere direct and immediate economic value to involve their intellectual value, and as a source for the development of the country. It is inclusive and integrative in two senses: because it is seen as a multi-dimensional endeavor and because the process behind the law had included the peasant and rural communities who are aware of the role of biodiversity in terms of its value and its appropriation (Miller 2006).

In this context, the biodiversity-related regulations include the biodiversity law (1998)[42], and a National Strategy of Sustainable Conservation and Use of Biodiversity (1999). The Law of biodiversity points to the National Commission of Biodiversity Management (CONAGEBIO) to manage the natural resources of the country together with the national system of conservation areas (SINAC). Through this system the country is divided into 11 areas of conservation, which are overviewed by several public offices from different entities, coordinated by the Ministry of Environment and Energy, in a decentralized approach, bringing into the process the local communities from these areas. Other complains refer to the new Law of Biodiversity passed in 1998. Again, according to this regulation, every project related to biodiversity has to be authorized on a case-by-case basis by the National Commission on Biosecurity. Costa Rica is divided into eleven

[42] This law defines bioprospection as: the systematic search, classification and research with commercial ends of new sources of chemical compounds, genes, proteins, micro-organisms, and other products with current or potential economic value, part of the biodiversity. Biotechnology is in turn defined as: any technological application that utilizes biological systems, living organisms or derivatives to make or modify products or processes with a specific use.

different conservation areas and the authorization must be asked in each one of the areas in which the research is developed, even if it is the same project.

The change in regulation is generating some challenges. The process is described as follows: “Costa Rica subscribed to the Agreement on Biological Diversity of 1994, and only in 1998 the Law of Biodiversity. In 1992 the law on Wild life was passed, and we were operating based on an article of that law. The process was very efficient. The regulation was established through a single window in the Ministry of Environment and Energy where the permission to access wild life to collect a sample was requested and if it complied with the requirements, it would take 15 days to be granted. In 1998 the law on biodiversity was passed but it was not implemented because it was not regulated. In December 2003 the chapter on access and use of biogenetic and biochemical resources was regulated. The problem is that the volume of things and procedures requested that they are now asking is enormous. We have been working for more than 10 years with them, and they ask for things as if it would be the first time we request a permit. The problem besides is that now we have to ask for permission in each area of conservation where resources are. Costa Rica has 11 [geographical] areas of conservation, and as the process is not centralized we have to request the permit in each area. They do not respond, and time passes and the process of getting the permission to access and use the resources is too long, and mismatches the research timing” (Interviewee GI).

Thus, the challenges are at the implementation and enforcement level. Costa Rican scientists consider the necessity of regulations for the access and utilization of the country’s biodiversity and also argue that companies using natural resources for profitable objectives must pay back. But still they perceive that the new laws, even if they are for good purposes, are a bureaucratic hazard and the implementation needs to be reviewed.

Regarding the status of GMOs in Costa Rica, there have been 663 authorized GMOs events between 1991 and 2004 (Cabrera Midaglia 2004), from which the majority have had to do with imported seeds, 54.4% in soy and 41.3% in cotton, both of which are not consumed nor sold in Costa Rica. Only few events in rice and banana result from ongoing local research projects. The regulation on GMOs is part of the Law of Phyto-sanitary protection of 1997, yet the original law of 1997 did not refer specifically to GMO. Then in 2001 a decree was added which extends the procedures to be applied to imported plants, vegetal products, seeds and other products that could bring plagues with them, and establishes that seeds an other GMOs should comply with the norm and be approved by the National Commission on Biosecurity together with a later in-the-field assessment by the competent authority.

Researchers are concerned with the future of their activity because of current attempts to forbid any type of field trial even for research purposes. At present every research project to be developed in the country has to be authorized by this commission and "…usually permissions come late, even six months or more after it was requested; after such a long period sometimes the plants are dead or the material is spoiled before the permission arrives" (Interviewee AC). Complains about the time lags and delays of these new procedures are common across researchers. As stated by a researcher "I had to collect some samples for a research project in collaboration with a foreign organization, and for 5 months I asked for the permit: I never got a response during that time" (Interviewee SI).

Now things are changing again, as during 2005 the discussion on GMOs has crucially intensified. An NGO led by the son of the president of that time, has actively questioned the position of the country regarding GMOs, and asked to change the current acceptance and move into a moratorium. As a result of an ongoing debate, and as a first step, the decision in 2005 was to include this person in this Commission.

Research on transgenic varieties of a native rice is going through difficulties because after completing all the lab research and proves phases, and conducting trials in a non-rice land following a precautionary principle, is now stopped as the next step is to test and evaluate the rice in a rice area but the permission did not arrive[43].

Researchers also complain about the long time required by the assessment process. For instance, CATIE was looking for a gene resistant to Black Sigatoca, the main disease affecting the family of Musaceas. But they have not been able to continue with that because of bureaucratic problems from CNB. The problem is that the material (biological) cannot wait the time that CNB takes. Life cycles go on, and bureaucratic processes take too long to accommodate both processes.

The law of wild life conservation is from 1992. This law is of particular importance because any type of collection of any wild specie for research and/or commercialization purposes is within its scope. And any export that involves component of the native flora is also ruled by it: apart from the phyto-sanitary certificates required, it must show the permit provided by SINAC.

(iii) Sectoral framing institutions

The S&T law passed in the 1990s has set the background and framework for all related S&T activities as part of the established National System of S&T (SINCITi)

[43] This was the case at least when this research was being conducted.

which involves the creation of few organizations such as MICIT, and the Costa Rica National Academy of Sciences.

4.4.5. Policies

In the next paragraphs I outline the existing mechanisms that might affect they mechanisms utilized for learning at the sectoral level. The section is organized around a set of categories, based on (Lundvall 1994). These categories are the following: (i) what are the means put in place related to education and research in terms of mechanisms and strategies; (ii) what are the incentives to engage in learning; (iii) what are the education and training system mechanisms to include those who have remained outside, and to facilitate mobility and circulation; (iv) what are the mechanisms to access knowledge and to have it flow between universities, and other actors; (v) are there incentives to recycle, forget and remember, and if so, what are those; (vi) what are the mechanisms to stimulate mobility across organizations, and arenas; (vii) what are the mechanisms embedded into policies for enabling change, correction and redefinition; and finally, (viii) is there social participation and inclusiveness. In some cases, categories are grouped as not always there are mechanisms in place in the country.

(i) Means to learn

Education accounts for 18% of government total expenditure. The majority of public investment goes into preprimary and primary levels (2004). Costa Rica’s investment on R&D accounts for 0.4% of GDP (2003-2004) (UNDP 2006). Unemployment rates have been low. In 1995 urban unemployment was 5.4% while in one decade later it was 6.9%. From total urban open unemployment, the smaller share belongs to the group of individuals with higher years of education (13 and more) (2004) (ECLAC 2006). Domestic sources of research funding are very limited. In most cases the University only supplies salaries for teaching but research relies on external donors and resources, as the private sector is also marginal in the funding of science and technology.

Foreign sources of funding have been quite large and fundamental for the scientific endeavor. The scientific community has been successful in getting not only enough funding to keep projects alive, but also sustained funding over long period of time. This is something that has made a substantial difference: they have been able to build a sustained and cumulative path on a specific set of problems that are critical and require deep understanding at different cognitive levels. Furthermore they have been able to build specialized learning trajectories with embedded research groups, which have also been relatively stable, and multidisciplinary research groups.

Over-reliance on external funding is complex and problematic. Even though the research actor has been successful in getting foreign resources, it has a negative counter-effect, and that is the agenda gets partially set depending on the donors. For instance, CATIE relies on its members' funding and donor agencies. At some time the main donors were Nordic countries, and they lobbied against GMOs, which prevented their ability to keep going the research they had in that area.

In Costa Rica, the education system is divided into the following levels: preprimary, basic general, and diversified. Access to these levels in the public system is free. It also includes education for adults and special education. Basic General education is compulsory, free and universal. It starts at the age of 6, and includes primary schools which constitute primary and secondary cycles. Once the secondary cycle is finished the student gets a certificate of completion of primary education. The third cycle (high-school or colleges) includes courses by discipline. Once the third cycle is completed the student can choose to go to diversified education, which takes between 2 to 3 years. And here there are three options: academic (2 years), artistic (2 years), technical (3 years) which opens up in Industrial, Agricultural, and Commerce and Services.

This system is designed in a way that the student can move horizontally and re-orient their selection, without going back to the beginning of the third cycle. The key to this horizontal flexibility is that each option has a branch of common disciplines, which enable such transitioning.

Finally the system comprises adult, and special education. Apart from the traditional education, the former includes functional alphabetization programs closely tied to work requirements. And finally it involves education from professional training in charge of the National Institute of Apprenticeship (INA). The latter refers to education for populations with special needs (OEI n/d).

A broad education policy for the beginning of this new century has been outlined and designed in a new plan for education. The plan, which is for the period 2003-2015 includes a considerable time span, a comprehensive set of activities, and more interesting it was elaborated based on the discussion and participation of more than 1,000 people from more than 20 regional forums.

As presented above in the section on the organizational mapping, public universities are four, two universalistic more traditional-like ones, one technological institute, and one for distance-education. Their rectors conform a policy body, CONARE, which not only advises in broad education matters, but also acts as policy-maker in the subject of higher education. For instance, it has elaborated some guidelines for higher education policy for the period 2006-2010 (CONARE 2005), and it has coordinated an update of the information on the whole education system (CONARE 2005).

The education policy entails several programs oriented to bring back those that for one reason or another have either exited the education system of have never gone into. The national college for distant education (CONED) offers tailored education to adults who have not completed their secondary education. The program on open education (Educación Abierta) is for youth and adult population who have had limited possibilities for continuing and completing their education at all levels. Another program, Open room (Programa Aula Abierta) orients to young children and youth which have either remained in the system without advancing (over-age), have not gone into the system, or have exited it. All these programs attempt to make the system porous, and flexible emphasizing the importance of schooling and completion of the education process (OEI n/d).

(ii) Incentives to learn

Incentives to learn are scarce. CONICIT has some funding aimed at fostering partnering between productive sector and researchers. In postgraduate courses for instance there is not direct financial support in the way of scholarships. Neither are incentives for firms to keep employees updated or re-skilled.

(iii) Capability to learn, and (vi) Opportunity to learn

Bridging instances are there at the structural level. CONARE is one of them. The policy system has shown adaptability on punctual instances. When required actors rapidly have responded and acted collectively to achieve a specific goal. It has done so few years ago when they faced the challenge of responding to Intel's needs (Buitelaar, Padilla Pérez et al. 2000).

The circulation of research elites has characterized the sector. Some star researchers have transited through different spheres, from policy making, to universities and businesses. This has imprinted a specific sectoral shape and dynamic, while also has facilitated articulation of efforts when needed. However, this has not translated into sustained collaboration particularly between research groups and firms. The organizations through which these individuals have circulated share a common pattern in terms of their ability to adapt and access resources.

(iv) Access to relevant knowledge

Communication infrastructure has been subject of dedication and improvement in Costa Rica. Access to new technologies is the goal of few education programs, and others aimed at more isolated rural populations. Universities have created inter-face units to bridge their relationship with the private sector. They have invested on improving the diffusion of information on their resources through brochures, websites, and some workshops and talks. Knowing who is who and who does what is not difficult in the sector. There is so much circulation of people through different spheres (university, firms and policy agencies) that they form an easily identifiable tacit collective.

(v) Remembering and forgetting

Specially oriented education programs are available and could be, to some extent, tailored, particularly in the technical training area. But remembering and forgetting are not pursued or perceived as crucial for getting new learning and capabilities. If wanted, some options are available. But that is different from fostering a strategy to forget, and remember based on the orientation of the sector. These mechanisms are not seen as tools for gaining new skills in areas that are key for the sector, such as biodiversity, or bioinformatics. These strategies were somehow fostered when the Intel case that required filling some gaps in terms of skills and training. The goals were set, and the education system aligned and responded to fulfill those needs.

(vii) Policy and (viii) social learning

Policy instruments do not entail institutionalized process for learning and reviewing, nor do they include ongoing reflexive and corrective mechanisms. These processes take place informally through for instance, the elite circulation mentioned in earlier paragraphs.

Public involvement is sought at the policy level, and constitutes a mechanism of social learning. The education policy design based on the participation of several actors, as well as the case of the framework for biodiversity protection and exploitation indicates mechanisms for social learning. The latter is relatively new, but has had enormous connotations not only because it places the country in a powerful position to negotiate with foreign companies interested in those resources, but also because it is doing so with an inclusive approach with participation of the local communities.

4.4.6. Bringing back the institutional environment

(i) Institutional coherence

Within the research collective and regarding patenting practices there are inconsistencies between the intention and goal of institutionalizing IPRs among researchers, *vis a vis* the assessment and valuing of the tenure track and what counts as valuable academic practice.

MICIT and CONICIT structure and functions also entail some incoherence. They duplicate efforts on one hand and compete for functions and resources, on the other. Divisions of functions are not clear, CONICIT has been in place for a long time, and the role of MICIT is not clearly bounded. Formally MICIT is supposed to coordinate and define policies, while CONICIT is more of the executing arm. But these limits are not clear, and in some cases overlapping functions lead to conflictive coexistence. Generally the existing environment entails some complementarities, though there are some vacuums that enlarge the gap between the existing organizations, institutions and policies, and weaken the real complementarity of the sector. Some of these are the lack of a financial system for leveraging the sector; the lack of businesses associations that pool together and frame firms' interests.

(ii) Institutional thickness and (iii) cohesiveness

As described above, the environment counts on several institutions and organizations. The research collective is thick, diverse, and is inherently multidisciplinary. Policies and regulations are also there, inclusive and widely covering different aspects but implementation holds results back. For example, the matter of biodiversity is very thick in terms of design and sharp in the framing, though the implementation and enforcement are disturbing the functioning of the sector, particularly with respect to researching. Timing, requirements, and red tape are being dysfunctional and constraining the environment. The mapping has some absolute vacuums, such as the financial system, as well as active business associations, and more explicit attempts to bring different types of organizations together. The very recent access to European Union funding has acted as a trigger to align interests and glue visions together. This has happened before in Costa Rica in a different sector with Intel. In that sense the country is quite resourceful in responding to pressures and putting efforts together and setting overarching goals in the interest of the country. It is likely that a re-framing of the sector will occur, and the collective effort put together to attract the EU funding will lead to some synergy between actors. Across the sector and as a collective, firms are the weaker and more blurred link.

Another characteristic in this context, is that across the different policy issues (biodiversity, GMOs, etc.) there is a common underlying pattern beyond the technical specificities, and the differences in who is affected by these issues, and that is the active involvement of different and multiple groups: NGOs and grassroots movements, policy makers, and the research community. The private firms as such are not involved, even though some of those leading individuals whose trajectory has shaped many organizations, including private firms and hybrid ones, do get involved. Thus, there is a type of indirect second-order involvement of the private sector by the way of having some 'ambassadors' whose voice include some general aspects from the private interests.

(iv) Inertia and rigidity

Most of the sectoral changes have been embraced during the decade of the 1990s. At that time the country put a new organizational and institutional system in place particularly for framing science and technology. New laws (Biodiversity, Science and Technology, etc.) and new organizations (ministry of S&T, academy of sciences, etc.) were created. Furthermore a big push was driven by the influx of resources from an IADB loan, which among others meant the building of some UCR research facilities in a common space. Undergoing change has encountered organizations that in turn, have been rapidly responsive to change.

Sustained agro-biotech research projects have also triggered some of today's sectoral shape. These have had key implications at different levels, in terms of concrete achievements as well as in terms of the institutional issues it has triggered (IPRs among others).

(v) Extent and carriers of change

As it has been discussed above institutional change has taken place by incrementally adding layers of new institutions. The S&T framework that started in the 1990s exemplifies that pattern. The creation of a ministry that supposedly complements the existing S&T council, and then an academy of sciences, a center of high technology, and changes in the regulations to support this new framework. They have been adding to a broad common framework aimed at strengthening the science and technology system and performance. The existing structures have shown responsiveness to change and have been co-shaping the current sector, in a way that resembles a more or less fitting puzzle. Still there are actors that have not been involved and are not fitting the expected puzzle. This is the case of the private sector: again it has not mobilized itself to change this pattern.

(vi) Persistence and stability

The agro-biotech sector is fragmented, but still entails responsive dynamics. Engagement and participation appear at some specific sectoral instances and channels. Legitimacy is relatively high among actors. In spite of complaints and fragmentation, sectoral actors perceive themselves as part of the sector, and act as belonging, even firms whose action is more isolated and shape a much weaker collective actor. Persistence of institutions relies on actors' enactment of those institutions, even if enactments take place to disagree about them. But disagreement does not translate into exiting mechanisms and dual practices to avoid those rules, for instance. In general, compliance with rules seems to be a persistent character of the institutional environment, which leads to functioning within the system.

4.5. Agro-biotechnology capabilities in Costa Rica

This section presents the agro-biotechnology capabilities in Costa Rica. These are analyzed based on the set of skills, processes and resources. Skills focus on: (Sa) what are the educational backgrounds of the individuals behind the sectoral organization, and what have been their trajectories concerning previous work experience and mobility; and (Sb) what are the types of knowledge. Secondly, I review processes identified as: (Pa) mechanisms and strategies implemented to access and absorb knowledge. Finally, the focus on resources refers to: (Ra) infrastructure; (Rb) R&D investment and funding; and (Rc) future regard: research and productive agendas.

4.5.1. Skills

The set of skills analyzed include: (Sa) the educational backgrounds of the individuals behind the sectoral organization, and their trajectories concerning previous work experience and mobility; and (Sb) Areas of application, actors involved and knowledge structure.

(Sa) Education and experience backgrounds and trajectories

Organizational and sectoral capabilities are strongly determined by the specific backgrounds and trajectories of individuals. In the Costa Rican case, interviewees' have pursued studies on the following areas: agronomy and plant virology, agronomy, Chemistry, Genetic of populations, plant molecular biology, molecular and cell plant biology, genetic improvement/biotechnology, biotechnology engineering, molecular biology, veterinary immunology, biotechnology, Molecular Biology, and Genetic Engineering. Doctoral studies have been undertaken in Denmark, France, Germany, Canada, UK, and US. From these, individuals holding PhDs are researchers in the university, both at UCR and UNA, and at hybrid research organizations like CORBANA and CATIE. Very few firms have PhDs, and in most cases those correspond to the founders of the firm. In almost all cases, undergraduate studies were pursued in the University of Costa Rica, and then went abroad for postgraduate training. Once they finished, went back to the University, CATIE or CORBANA, respectively. Only one of these, and from a hybrid organization, spent some time working abroad at CIRAT in France; the rest of them did not held a position abroad or in other types of organizations in the country, yet they have been in close interaction with research groups across the world and some of them have crossed the boundaries of the university for some concrete tasks, in the national policy arena for instance. Costa Rica characterizes by an elite of scientists who have moved around different positions and arenas. The first ministry of S&T was a recognized scientist involved in the area of human-based biotechnology. For instance, the director of the Center of High Technology also belongs to that generation of scientists.

Researchers have deepened their skills and knowledge on a continued basis thanks to stable and sustained sources of funding for their research projects. As described by a university researcher: “We as a group had the advantage that since very early we were able to incursion in advanced techniques but guided by countries that were leaders in developing those techniques" (Interviewee AR). They were able to build a wide range of skills. "We are about to put in the market a new variety of rice that was improved here locally; the variety is resistant to a virus and an herbicide. We did all the work, from the molecular characterization, developed the in vitro culture which was challenging because at the beginning *Indica* varieties were very recalcitrant to in vitro culture; they still are but we learned a lot and optimized this technique that is critical for GE. We got all the plants and now we are about to assess them at the field level" (Interviewee AR).

One of the skills of a group of researchers in Costa Rica is their ability to access and maintain international sources of funding: "I do the research part of my work at the Center, if my projects are tuned with the goals of the Center. Until now my projects have been aligned with the Center's objectives. But to work there I have to find my own resources. Since very early all of us at the Center learnt to look after our own resources to do research, because we were trained for that. [Who did train you?] The founder of CIBCM, Dr. Rodrigo Gámez. He also founded INBIO. It was not valid to just have interesting new ideas. If I do not get my own resources I cannot stay in the Center. I would loose all the equipment I have managed to put together. The system has ability zero to sustain somebody that do not get resources" (Interviewee PB).

Within the set of firms dedicated to micropropagation, technical personnel involve agronomists, and young biotechnology engineers recently graduated from ITCR. They also rely on technically trained personnel who have been either trained in the firm or by institutes like INA (National Training Institute) in plant related techniques.

The next table (Table 4.4.) briefly shows the type of backgrounds of the interviewees.

Table 4.4. Costa Rica: Interviewees' background paths

Agronomy (UCR) → MAG → work at National Seed Office → work at INBIO/Master in Foreign Relations (UNA)
Biology → work at CATIE → Master studies at CATIE → PhD (France) → since 1996 researcher and professor at CATIE
PhD in Biotechnology (France) → research at CIRAT → manager of R&D at CORBANA
Sea Biology → Master studies at UCR → PhD Genetic of populations (France) → Post-doc in Plant Biotechnology (Rice) (France) → since 1990 Researcher and Professor UCR
Agronomy (UCR) → Researcher and professor UCR → PhD Molecular and Cell Plant Biology (Canada)
Agronomy (UCR) → Master in Biology (UCR) → PhD Plant Virology (UK) → researcher and professor at UCR
Agronomy (UCR) → PhD in Genetic improvement → director of research center at UCR
Agronomy (UCR) → researcher at Biotechnology Center, ITCR
Master in Plant Biology (UCR) → PhD Plant Molecular Biology (Germany) → researcher and professor at UCR
Molecular Biology (Structure of Genetic material) (US) → researcher on Human Genetics (UCR) → Director of High Technology Center (CONARE)
Microbiology (UCR) → Master on Immunology (UCR) → Veterinary Immunology (PhD, US) → researcher at UNA and UCR → researcher at UNA
Agronomy (UCR) → work at Ministry of Agriculture (MAG) → coordinates the National Commission on Biosecurity
Biology (UCR) → Master Microbiology (UCR) → Molecular Biology (PhD, France) → Post-doc in Genetic Engineering USDA (US) → professor and researcher at UCR
Microbiology → work at Ministry of Science and Technology
Master in Forest Engineer → researcher and director center UNA
Chemic (UCR) → researcher at UCR → Master in organic chemistry (Canada) → director research center at UCR
Biology (UCR) → researcher and professor at ITCR (molecular biology)
Food technology (UCR) → Master in Bacterial Fermentation (US) → Director research center UCR
Microbiology → PhD in Virology → director of research center at UCR
Microbiology → PhD in Protein Biochemistry (Sweden) → researcher at UCR
Agronomy (UCR) → Master in Agribusiness → director technical department at private firm (for 16 years)
Agronomy (UCR) → research assistant at UCR → creates private firm (1990)
Agronomy (UCR) → working at private firm selling agrochemicals → working at private firm (subsidiary) related to seeds
Agronomy (UCR) → PhD Molecular Biology (Denmark) → researcher at UCR → creates private firm (Molecular Biology)
Agronomy (UCR) → researcher and professor at UCR → Plant Physiology (PhD, Belgium) → researcher and professor at UCR → creates private firm (for some time keeps both, but currently exclusively dedicated to the firm)
Engineer in Biotechnology (2003, ITCR) → works at private firm (ornamentals)

Source: Data based on interviews

(Sb) Areas of application, actors involved and knowledge structure

Plant-based biotechnology is a very relevant, common research and production area in the three countries. In Costa Rica, it captures most research efforts. Core strengths in firms' production, and in research emphases concentrate on plants. At the research and production ends, and up to now, plant-based biotechnology has entailed mainly micropropagation techniques (León 1993) applied to relevant economic products like banana, potato, tiquisque (yautia), cassava, flowers and ornamentals, among others. Micropropagation of banana has been crucial for banana exporters, and carried out since the late 1980s by a pioneer national firm, whose CEO started doing it at the University's Centre of Agronomic Research (CIA) that he in turn, contributed to create. In-vitro plants of banana are a key input for the industry: they are healthier plants, and the industry relies on them as nowadays: "almost all planted banana are not other than laboratory-created, in vitro-plants"(Interviewee CB). Costa Rica is a regional reference in plant micropropagation. And has achieved that mainly thanks to very few firms, CATIE and farmers organized through CORBANA and its own research.

Molecular biology has also been applied to banana, but research wise. Banana R&D involves few groups and organizations. On one hand, there is CORBANA, which has its own research lab provided with molecular tools since 2004. On the other hand, and working in close collaboration with it, there is CATIE. Besides, they both collaborate with international partners such as CINVESTAV (Mexico), Louvain University (Belgium) and Wageningen University (The Netherlands). But research towards genetic engineering of the fruit itself is constrained as GE for consumption is banned, and even worst in this case in which the fruit is consumed fresh and directly. In both cases, the application of molecular biology aims at tackling sanitary problems and enhancing plant's resistance. This kind of research is about the interaction between the host and micro-organisms, such as the plant and the pathogen.

Research groups in Costa Rica take part of broader networks outside the country. They are closely connected to peers in US, Mexico, and Europe, though to a much lesser degree, this is also the case for firms which interact and relate to firms outside the country, particularly to MNEs. The weaken link however is between firms and the academic research groups within the country.

Molecular biology and genetic engineering are increasingly utilized and developed, although still for research purposes mainly. The leader research project along this line is on rice, and is carried on by a star research centre, the Centre of Cell and Molecular Biology (CIBCM) at the University of Costa Rica, oriented to conduct research on cell and molecular biology in virus, bacteria and other organisms. Rice, a key staple crop in the country, suffers from phyto-sanitary problems like the *Rice Hoja Blanca Virus Disease* (RHVD), typical from America's tropical region and which in the *Indica* varieties does not have natural resistance.

One of the outstanding characteristics of this research project is that it has integrated different aspects and dimensions, both at the research and institutional levels: a multi-dimensional systemic project including different aspects related to rice, from basic research to the transformation of the local germplasm, and, intellectual property rights associated with it (Espinoza, Sittenfield et al. 2001). This project is strongly embedded in different collectives, including the scientific, political and business ones, and seen as a key project for the country in part because of its social and economic relevance as a staple crop, reinforced by the singularity of this rice variety to the region, plus the lack of accumulated knowledge elsewhere.

In the area of animal health this country has an important program on tropical diseases and on Zoonosis -those animal diseases that can be transmitted to humans, that is part of the National University (UNA). This program provides some services to the Ministry (MAG), and some specific services to end-users.

4.5.2. Processes

(Pa) Mechanisms and strategies to access knowledge

The access and absorption of codified types of knowledge heavily relies on external sources. External refers not only to the organization level, but also to the national one. For researchers, formal postgraduate education in foreign countries is the most common mechanism to get training and access new knowledge. That is a strongly institutionalized path for researchers. In later stages of their careers, they remain connected to those academic references, and often collaborate either formally in projects or informally when specific resources are needed. The most utilized mechanism for local researchers is going outside either to get trained, or to participate in seminars, or congresses.

For the sectoral population that is outside the academic research level, mechanisms vary. Firms' strategies could be divided in two types. On one hand, in general local firms search for knowledge within the country, or if needed might look for outside sources but for a very specific request, like a lab test that could be cheaper outside. Within the country, they get in contact with former colleagues, or search through the Internet. But their productive tasks and activities are routinely managed within their knowledge scope. That is, they do not recognize major bottlenecks and subsequently, consider that what they know allows them to work. Contracting skilled personnel is another mechanism for accessing new knowledge, so they count on biotechnologists trained at ITCR, for instance. On the other hand, there are those subsidiary companies of plant and ornamentals that concentrate on plant cloning and industrial processes. They master those phases of the whole process, but in general backward and forward linkages are carried on outside their scope by the headquarter company. The local firm counts on some technical personnel at the intramural level, typically biotechnologists, agronomists, and a large number of individuals who are trained within the firm. They also might have some expertise in phyto-improvement. But the large bulk of phyto-improvement takes place in the headquarter company. When there is a problem at the local level, the first attempt is to look for local resources, according to one of the technicians at an ornamental company. In the interviewee's words: "When I have a problem in the lab I first try to look for solutions here, with people at UCR, TEC, or CATIE, or then I look in the Internet. There is a chat at Michigan University for instance, in which the company participates" (Interviewee SL). But in general responses come from the outside. "The problem with local resources is that answers are too general, or they dominate too advanced techniques and I am looking for a solution to a very concrete problem that might not be related to an advanced technique, but just to a very specific issue" (Interviewee SL).

Other mechanism mentioned, though only by few organizations and mainly of the hybrid type, is to bring into the organization foreign experts. It is not the same to send researchers to foreign countries to be trained, than to bring that outside expertise into the organization: not only the focus is different but also differs the *ex post* ability of local personnel to incorporate that new knowledge into their context of production. "We have done interesting things. For instance we have had workshops in which we bring the experts here for two or three weeks. They come and train our people here. We like it very much that they come here, because when people go to those universities or institutes, often they have technologies and capacities that we do not have. Then our scientists come here dreaming about all the things that he/she could be doing if only we would have that equipment that they've seen outside. So what really interests us is that the researcher who comes to train personnel here, adjust things to the conditions we have that are not bad either, we have the essential. So then the expertise and training is fit to the internal capacity. Of course sometimes it is required to improve our capacity, and it's important to have that noticed by the expert, but when it is a real necessity and not just to display equipment that is not essential" (Interviewee GI).

Researchers do take part of international networks and linkages. But they are also closely connected to farmers in the country. For researchers contact with first hand productive problems is crucial, and that is nurtured by farmers' perspectives. Farmers' perspectives are valued not only because they provide researchers with research inputs, but also because it is part of the strategy to have more reliable and attractive research proposals in international contestable funding processes. The sequence of a research proposal is described as follows: "[…] First we decided what was the problem. That, I decided with authorities here. They [Ministry of Agriculture] told me what was the most important problem that has not been solved with other technologies. The problem identified is 'How to have smaller and poorer farmers here in Costa Rica a good quality frijol to be competitive at the regional level given that in Costa Rica production costs are higher (labor mainly). For them not to disappear they need a seed that has an advantage. Through genetic engineering is very difficult because of the problems associated with the family of frijol. We decided then to try mutagenesis but in an accelerated way. Seed improvers will decide which one of the seeds we get is the best one. [The research manager in Costa Rica brings together scientists from different parts of the world who are experts on different dimensions of the project.] So chances of success are enormous because everybody knows what are we doing, why and for what. I did not need to sell the project, it sells by itself" (Interviewee PB).

4.5.3. Resources

(Ra) Infrastructure

Universities have their own laboratories and infrastructure located in their campus. Hybrid organizations also rely on their own equipment and infrastructure. Firms have their own infrastructure and laboratories, basically with equipment for plant propagation. If they need more complex tests they rely on local universities or foreign organizations, as access to international resources is not a problem for them.

The UCR counts with several research laboratories, many of them co-located in an area developed thanks to an IADB loan of US$ 25 million. The "City of Research" occupies 21 has and was built within the UCR area, in San Jose, during the 1990s. Several laboratories of multidisciplinary character conform this conglomerate, from which many are related to Biology. They involve researchers who work together in these centers, but belong to different schools for teaching purposes, from Biology, to Agronomy, Chemistry, etc. Within these centers, each group has to build up their labs' equipment from the research projects supported by external funding, yet the final owner of those is the University. UCR has few laboratories loaded with the essential equipment to perform tissue culture and plant propagation, sequencing, diagnosis and characterization of viruses, and genetic transformation, among others.

Some of the neighboring research centers and laboratories have same type of equipment; for instance almost every center related to plant propagation has its own equipment for tissue culture, in part because it is more comfortable to have it handy and use it when needed. This duplication of resources is more than simply that. These groups have different expertise, and focus on different research problems and niches, but to some extent they compete for scarce resources. This might harm those labs with less resources, and more regular and repetitive types of activities which have been traditionally oriented to agronomic activities: having other research groups with more innovative projects use their facilities would benefit and leverage the former which expertise and facilities could serve as a platform for other groups while strengthening their relative position in the research mapping. Both groups could learn from each other, and strengthen their complementary assets. This duplication happens not only with tissue culture labs, but also with more expensive equipment like PCRs, which maintenance is costly, and it is likely underutilized by both groups.

(Rb) R&D investment and funding

In Costa Rica, R&D is informally held within firms. Subsidiaries conduct some adaptation, but the bulk of R&D is conducted at the headquarter offices. CORBANA conducts R&D. As mentioned earlier academic research relies on international funding, and some seed capital from local sources, even though these are very small amounts of money. Similarly in Uruguay local research funding is very small and concentrated in two sources. Funding for the public sector is largely dependent on international resources. This is largely true for all actors, but researchers are highly vulnerable as a consequence of their reliance on external funds given their meager budget. Researchers get most of the funding for equipment from projects, or international donors, or funding sources. This is almost identical in the cases of Costa Rica and Uruguay. Funding sources in the sector in Costa Rica are scarce and when available, amounts are small. Two government agencies provide funding: CONICIT and MICIT.

In both countries, universities support salaries and teaching. CIBCM research funding for instance is totally depending on foreign funding from organizations like IAEA (International Atomic Energy Agency), and Rockefeller Foundation, among others. But continuity of funding has been a key feature of the latter. “The oldest project that started in the 1990 is on rice genetic engineering. We are part of the network on rice GE of the Rockefeller Foundation. A network that the Foundation supported for 10 years, and the idea was to put in touch groups from small countries to access frontier technologies for the genetic improvement of rice. Product of all that work is the ‘golden rice’.” (Interviewee AR).

(Rc) Future regard: research and productive agendas

In Costa Rica an important dimension of the future regard related to this sector lies on bioprospection. This is an important issue both at the normative and at the factual levels. At the normative level it is so because of the relevance of the biodiversity resource for the country. At the factual level, it is so because the country counts with an institute dedicated to take care of biodiversity research and production.

Future plans and research orientations are present both at the research and productive ends. Researchers have proposals in mind, and are often seeking for resources to complement existing projects or to start new ones. So for instance, in the rice project the new path is to look for biopesticides that complement the transgenic variety of rice, so that they reinforce each other and thus become more powerful and complementary. Firms' managers have also mentioned their interest in new productive areas or crops that they are willing to explore, though in general not concrete investments have been made in that direction.

The research and productive agendas in Costa Rica are dedicated to plants. Still the extent to which each one utilizes biotechnology and the mastering of the techniques and knowledge on fundamentals are far apart. At the aggregate level, most skills are held within the research loci, are built around specific projects, and are driven by research needs, which in the country are not removed from productive problems. On the contrary the identification of problems is very coincident between the two communities. Overall, agro-biotechnologies are utilized for research purposes but driven by the attention to solving specific productive questions around economically relevant crops such as rice, banana, and others. Even if at the level of skills and processes utilized related to biotechnology, these two actors are closely looking at similar problem areas. Points of departure vary, resources, skills and processes vary, but concerns are common, as the broader agenda is. More complex and modern biotechnologies are almost exclusively utilized for research purposes.

A positive aspect of few key projects is that their permanence across time has enabled knowledge accumulation and the tackling of multiple dimensions. In other cases, the common practice is to focus on the fine-tuning and adaptation of techniques to the specific context of application. Plant research is distributed across several research groups, yet this subset of techniques applied to plants concentrates at the UCR, which is not only the larger reservoir of skilled human resources, but also entails the loci of knowledge accumulation, infrastructure, linkages, and research projects in the country. ITCR and UNA, both also public universities, have also their research niches, the former complementary to UCR projects are very applied and have an engineering approach. UNA however accounts for the animal health niche within the country. At their side, CATIE, CORBANA and INBIO share an important role as enablers of more complex biotech capabilities. These three organizations are of a hybrid type, as discussed in the previous section on the sectoral mapping.

Micropropagation takes the first place in Costa Rica's productive agenda. One of the leading companies in this sector concentrates on micropropagation of banana. They started twenty years ago to work on micropropagation of ornamental plants. Today their strength lies on banana, as they were the first ones in applying that technique to it: "We were pioneers as a micropropagation firm in Latin America, and of course in Central America. One of the merits we have here is to demonstrate in the case of banana that this technology could have applicability in banana and that could lead to higher returns for firms. And for my great satisfaction I think that is the larger technological change that Banana has had. I have had to fight with everybody including transnational corporations which did not believe that this could be possible or attractive. Furthermore, the first money I got in my attempt to open this laboratory I found it in a venture capital bank in Florida, US." (Interviewee AG).

These techniques are useful for their production, fit their recognized needs and are mastered by them. Capabilities within firms are constrained to routine-based, though adaptation and searching is also part of their scope. Their work is isolated from the Universities unless they need to solve some specific issues like sanitary problems in the plants they produce. In those cases, they ask for academic support, but it is on a punctual basis and only oriented to solve specific problems. Firms concentrate on what they routinely do and have been doing, and do not risk or invest on new R&D areas unless pushed from outside markets.

4.6. Summary

In this chapter I have analyzed the characteristics and dynamics of the institutional environment and the building of technological capabilities in Costa Rica. The mapping shows a sector with several organizations of different kind, though most of them concentrate in the research loci. Research centers constitute the core of the sector, while firms function in a rather second order, more at the boundaries in terms of connectedness and further advancement of biotechnologies. Still they constitute the motor of production of agro-biotechnology, but constrained by their dispersion and weak connection to the core, and even weaker cross-interactions.

The sector has changed during the 1990s regarding the configuration of institutions, organizations and approaches. It is still weakly connected, but entails strengths in terms of the potential for synergy particularly given its responsiveness to change. The latter is an important distinctive feature of the institutional environment. It indicates high responsiveness in terms of facing problems and looking for solutions. Still triggers for higher collaboration are extremely necessary. And firms should be specially the focus of any attempt of this sort.

CHAPTER 5.

INSTITUTIONAL ENVIRONMENT AND AGRO-BIOTECHNOLOGY CAPABILITIES IN NEW ZEALAND

5.1. Introduction

This chapter lays out New Zealand's institutional environment and technological capabilities, and their interaction. It starts by describing some of the country's features connected to this research: its remoteness, reliance on agriculture-based exports, and the efforts to increase agricultural productivity and competitiveness. This country has undergone radical changes in the last two decades with respect to its institutional environment. One critical change related to this sector is summarily presented in the third section, and that is the transition from a government research department (DSIR), into ten Crown Research Institutes and their impact on the science making landscape in the country. The description of this process helps to structure the rest of the chapter of the processes underlying the institutional environment, and the direction towards which is it moving, with questions such as: what other actors have emerged, and through what dynamics? And how older ones respond to those changes? How do they cope with obstacles? Are there mechanisms in the institutional environment to respond to those difficulties? Then, the next section displays the organizational mapping and actors are described, and their interactions, after which I summarize some of their main dynamics. In the fourth and fifth sections of the sectoral mapping, I concentrate on institutions, and policies respectively. The dynamics of the institutional environment is overviewed, according the categories established in chapter three (coherence thickness, cohesiveness, inertia, extent of change and carriers of change, and persistence). The next section concentrates on the analysis of capabilities, and their interaction with the institutional environment. Finally a short summary attempts to close this chapter.

The institutional environment in this sector involves plenty of organizations, which vary in their kind and functions played, still there is some crowding at the research level. Research organizations are learning to function in a setting that has recently changed radically. Biotechnology firms are also of various types and most of them are around Fonterra, the leading dairy company. They shape very complex interactions, with CRIs and other labs taking part of those organizational arrangements. Universities are not highly involved in those arrays. Bridging and supporting organizations are also numerous, and add a layer of complexity in this very dense sectoral mapping that is undergoing change and redefining itself.

5.2. Setting the country

New Zealand was Maori territory until the eighteenth century. The first known European to sight New Zealand was a Dutch explorer, Abel J.Tasman in 1642, who was sent to find out if Australia, back then called New Holland, extended to the South as the Antarctic continent. But Tasman's discovery remained an isolated fact, until Cook's voyage in 1769. This event, and the following trips and publication of Cook's impressions, set the beginning of European trade and settlement (Condliffe and Airey 1960).

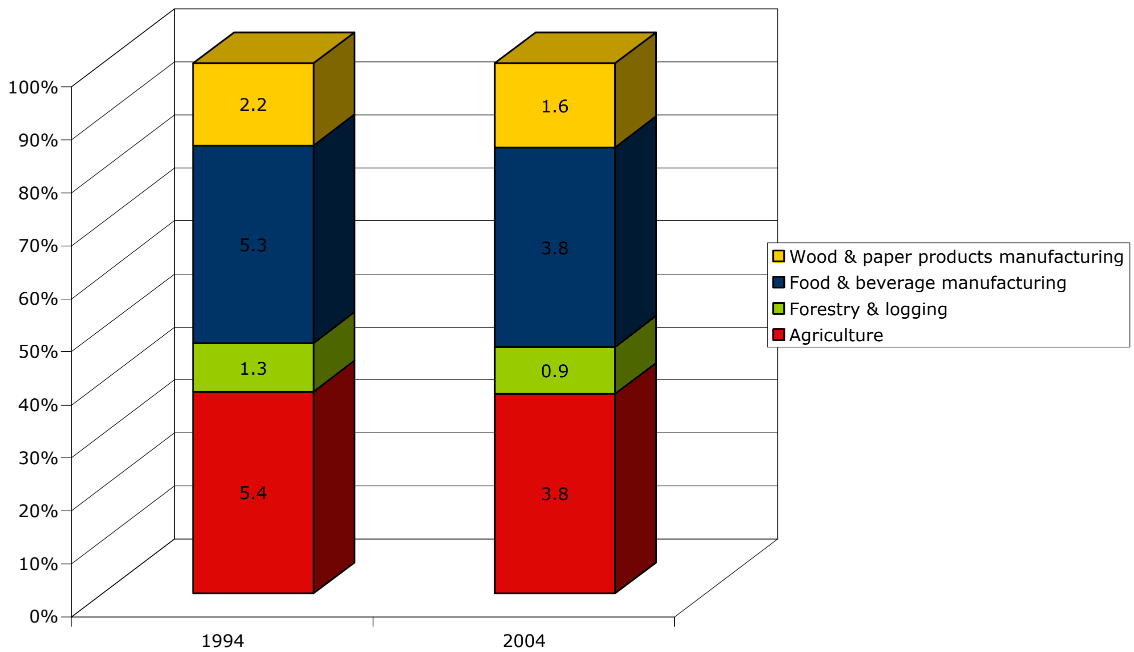
New Zealand, a temperate country with a chain of mountains above the South Pacific Ocean, is compounded of two islands, North and South Islands, plus several smaller ones. From a total of 26,870 thousand hectares, 11,709 thousand hectares were Grazing, arable, fodder and fallow land, 121 thousand hectares were dedicated to horticulture, and 1835 thousand hectares were planted with exotic timber (2004) (MAF 2005).

Remotely located, its closer large neighbor is Australia, 1,500Km (930 miles) to the West. A journey between Auckland and Sidney is more comparable to one between London and Athens or Moscow, than from London to any Western European city (Hawke 1985). Its remoteness has been a fundamental factor in New Zealand’s development. Its distance from markets triggered agricultural efficiency and productivity, which still continues to increase. In a ten year period, between 1991 and 2001, the value of GDP per agricultural worker (current terms) increased from NZ$74,000 to NZ$89,000 per employee, which accounts for more than 20 percent gain in agriculture (real terms), compared with 7 percent for the total economy over the same period (MAF n/d).

Agriculture is and has been at the foundations of New Zealand’s history, shaping its society and economy, as its position in the international market. New Zealand was often seen as Britain’s farm in the South. Sheep-farming for wool was at the core of the settler’s economy. New Zealand’s wool became the first agricultural commodity for export to feed the British woollen mills (Hawke 1985). Extensive pastoralism became highly attractive in the South Island, whereas the North Island, with extended bush-covered areas and Maori ownership, was not as suitable for that type of production. By 1881 the South Island, which was more populated, had 9 million of sheep out of a 13 million total (Sinclair 2000). By the mid-1890 agricultural activity involved around 35 percent of the labor force, and absorbed close to 50 percent of private investment in some years during the 1870s (Ville 2000).

The dairy industry in the country is strong, has a long export tradition, and has triggered innovation and linkages. Refrigeration meant a turning point for the country's economy and exports, bringing dairying to a position alongside sheep-farming. The first shipment of cheese exported to Australia happened in 1846. Almost forty years later, in 1882 only four years after the first successful attempt in the world, the first refrigerated shipment of meat and butter was sent to England. Thus, the late nineteen century brought a significant expansion of exports thanks to the availability of refrigerated shipping, which also benefited manufacturing activities. Dairy processing constituted the largest manufacturing units, even more when by the early 1950s (1951) whole milk began to be collected in tankers which enabled the expansion of the area of influence of an individual factory (Hawke 1985; Sinclair 2000; Ville 2000).

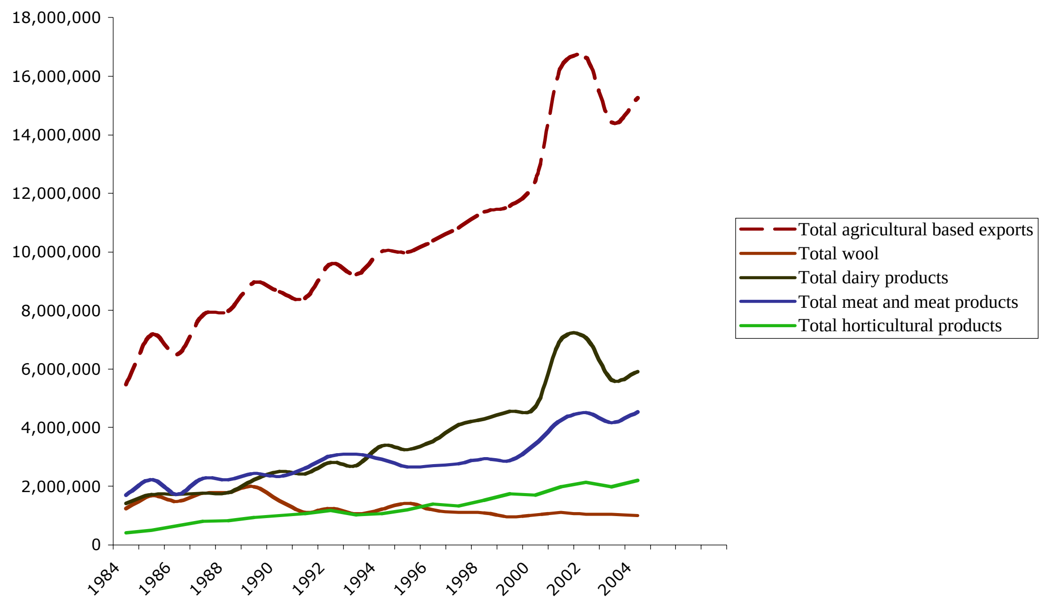
Today, agriculture, horticulture and forestry (including processing and manufacture) account for around 20 percent of GDP (current prices), and for about 47 percent of total exports. In 2004, agricultural, forestry and horticultural exports were valued at $18.5 billion or 65 percent of New Zealand's total exports. And in 2001, the agribusiness sector accounted for 9.6 percent of total employment. As it was mentioned above, productivity in agriculture has also increased, due to technological change, targeted investment, cost cutting and improved efficiency, apart from economies of scale given the increase of farm and orchards average size (MAF 2005; MAF n/d). Total GDP in 1994 was NZ$ 85,676 millions, while a decade later was NZ$119,525 millions (MAF 2005). The next figure shows each item's contribution to GDP.



Source: (MAF 2005)

Figure 5.1. New Zealand: Contribution of sectoral GDP (%), 1994-2004

Within agricultural exports, dairy products have substantially increased during the period 1994-2004 (Figure 5.2.). While in 1994 they accounted for NZ$(000 FOB) 1,426,700, in 2004 they did so for 5,896,945. In 1994 dairy products ‘ exports were slightly over wool exports (1,232,000) and under meat and meat products (1,704,900). However, one decade later, dairy products have surpassed both of them: meat and meat products accounted for NZ$ 4,527,522 (million, FOB), and wool represented NZ$ 996,357 (million, FOB) (MAF n/d).



Source: (MAF n/d)

Figure 5.2. New Zealand: total agricultural exports, 1984-2004 (NZ$, 000, FOB)

Grasslands in New Zealand were crafted by four or five generations of nation-builders, who carried on a ‘grassland revolution’, a strategy based on bush clearance, the introduction of exotic grasses, and the combination of herbicides and fertilizers. Such was the effort that 51 percent of the surface of the country became grasslands (King 2003). Until the mid twentieth century, natural resources were exploited carelessly and abusively, involving the use of high doses of fertilizers and substitution of natural species by foreign species (trees, grasses, etc.). But during the late 1950s this started to change triggered by the national conservation campaign to save Lake Manpouri in the South Island. This issue served as a basis for a national debate involving multiple and plural actors, from national and local politicians, to scientists, planners, citizens, etc. (King 2003). During the years to come, a series of environment-related events[44] nurtured, and relied on, the emergence of an actively organized 'public' voice, intense debates, regulations and policies starting with the Environmental Act passed in 1986 that led to the creation of the Ministry of Environment. Progressively, environmental issues became relevant part of the public and policy agendas. Changes in state structure, rationale and practice have been the common pattern of the country's recent history, and particularly in this field of research, as it is discussed in the next section.

5.3. Main milestones in research-related organizations and institutions

This section describes a process of change in the agro-biotech organizational mapping, as well as in the practice of science. During 1991-92[45] ten Crown Research Institutes were established as a substitute of the government research department, Department of Scientific and Industrial Research (DSIR) of the Ministry of Agriculture and Fisheries (today Ministry of Agriculture and Forestry).

Science has pervaded farming practices in New Zealand. Scientists were part of the country's government since the late 1850s; the Department of Agriculture had several

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[44] In 1985, the *Rainbow Warrior*, a Greenpeace vessel, was bombed when it was about to leave Auckland Harbour to Muroroa in its opposing campaign against the French nuclear testing in the French Polynesia. That bombing and consequent intervention carried on by the French secret service (DGSE), resulted in an enhancement of Greenpeace membership and support for the anti-nuclear movement in New Zealand. This attitude was strongly led by the Labour's Prime Minister David Lange, who banned the passage of nuclear-armed ships through its territorial waters. Three years later, in 1988, the Bola *Cyclone* heavily affected the North Island East Coast, which also contributed to new policies, and an overall environmentally responsible citizenship (King 2003).
[45] For a detailed history of DSIR changes and evolution, see Galbreath (1998), from which this section draws on.

biologists at its creation in 1892. Farmers claimed a new state-supported university-level agricultural college was needed in dairying area of the North Island. The establishment of

DSIR in 1926 was part of the same movement. Agricultural research has been oriented to the direct improvement of agricultural efficiency and productivity. Pastoral research has been one of the focuses for its direct impact on milk and meat production. DSIR originally established in 1926, following the British model, as the rest of the New Zealand scientific structure, with the difference that in the latter a scientist was appointed as the first head of that department. One of Dr. Marsden's first tasks was to look for industrial support and to establish, as a joint effort of government and industry, a dairy research institute, which was launched in 1927. During the first decade it developed linkages with the wheat, and leather industries, apart from the relationship with the dairy sector. DSIR was not supposed to conduct research for industry or to have research divisions but to support and oversee research conducted in other organizations. In spite of that formal constraint, it started to expand and conduct research during the 1930s, when the Labour Party came into power in 1935. Since then, and in line with an overall change in the role and scope of the state, that trend of expansion and centralization of the scientific role continued until it got consolidated to the point that one of its heads said: "We will look after research, let the universities look after teaching" (Galbreath 1998).

DSIR became a leading scientific organization, accounting for almost half the government expenditure on scientific research. Furthermore it was a service provider for other agencies and industries, a government advisor, research grants manager, and supported 14 research associations, which were co-funded by government and the respective industry. By 1976 it had 2,097 staff (893 scientists, and 712 technicians). In 1974 this *de facto* became *de jure* situation with a new legislation that would formalize the ongoing practice of DSIR, that is plan and conduct research in the national interest of New Zealand.

That process of DSIR consolidation and expansion was interrupted after the oil crisis and economic difficulties in the late 1970s. A requirement to charge for government services was introduced, and the size of the department was reduced. But what started as specific ways of coping with the need to recover costs slowly became a fundamental transformation in the rationale of the agency's role in particular, as well as the overall government's role. The 'user's policy', as it was known, or customer-contractor approach meant not only a radical change in the way government perceived and presented itself, but also in the relationship between government and users (i.e., farmers in this case). This change in policy and rationale settled down, and was reinforced by the Labour Government of 1984. After a reduction of government funding in the order of 25 per cent between 1984 and 1988, DSIR had to actively look for customers for its research and services. As mentioned above, in the New Zealand history the 1980s represent the transformation of the State and the beginning of fundamental reforms in its structure, rationale, role, etc. These reforms, which touched all units of government in their structure, operation and principles, followed a market model driven by competition. At the beginning dialogue was difficult and rather frustrating "…between scientists who do not understand economics and economists who do not understand science" (Galbreath 1998). Economists prioritized criteria such as efficiency and performance, while scientists could not see themselves as other than working for the public good. Not only the underlying motives differed, but also their estimations about the rate of return of government investment[46] and expectations about the science budget and the science agenda: what type of research should be supported by government (Galbreath 1998).

Nightingale (1992) noted that “the last decade has been a period of major change within the Ministry of Agriculture and Fisheries (MAF), with a move away from its traditional role as farmers’ advocate, to a more detached view which places considerable importance on monitoring the efficiency of the agricultural sector as a whole” (Nightingale 1992). This debate was somehow solved by the intervention in 1988 of the Science and Technology Advisory Committee (STAC), in which proposed three research categories worth funding, ‘public good science’: non-marketable research (socially valuable), pre-commercial applied research (potential economic benefits), and strategic research (maintain national research skills) (Galbreath 1998). The new structure of science was developed in three stages. First, in 1989, a Ministry of Research, Science and Technology was created; and one year later, in 1990, the Foundation for Research, Science and Technology. Finally the DSIR itself was restructured, as suggested by the STAC report, together with the other State science providers such as the research division of the Ministry of Agriculture and Fisheries, the Forest Research Institute of the Forestry Ministry, and the research unit of the Meteorological Service of the Transport Ministry. This structure was dismantled to give place to ten new research organizations, the Crown Research Institutes.

DSIR played a fundamental role in improving the agricultural science of the country. Its relevance lied not only on the department’s research efforts and impact, but

[46] An estimation of the DSIR rate of return shows a rate of 30 per cent per year in real terms (Galbreath, R. (1998). DSIR: Making Science Work for New Zealand. Wellington, Victoria University Press..

also on its influence as a partner of several research associations that were jointly funded by industry and government, through this department, to undertake research of interest for those industries. Apart from the first one created in 1927 with the Dairy Industry, many more were established[47]. The responsibilities previously carried on by DSIR were taken over by different organizations, most of them specially created for those purposes, such as the CCMAU, FRST, MoRST, apart from the CRIs.

A fundamental feature of this process of transition from DSIR into CRIs is that it was embedded in a web of existing organizations, old and young, pre- and post-reform ones, which are deeply connected to the sector, though with varying levels of engagement.

5.4. Overview of the agro-biotechnology sector

In New Zealand, agricultural biotechnology permeates its main agro-export commodities: wool, dairy, and beef. A first approximation to the mapping of agricultural biotechnology indicates a sector with several layers of intertwined organizations, shaping a fuzzy landscape both at its core and boundaries, yet a dense one in terms of organizations, interactions and linkages, and institutions.

[47] Galbreath (1998) presents the list of industry-based research associations, which are: Wheat Research Institute (1928-1988), Fuel Research Association (1928-1932), Leather Research Association (1928), NZ Pelt Research Association (1931), Shoe Research Association (1937, later merged with the Leather one becoming the NZ Leather and Shoe Research Association), NZ Wool Manufacturers Research Association (1937, which in 1945 became the NZ Woollen Mills Research Association, and in 1968 merged with the Wool Research Organization of NZ, established in 1961), Tobacco Research Station (1937-1966), NZ Pottery and Ceramics Research Association (1945-1984), Research Institute of Launderers, Drycleaners, and Dyers (1947-later becoming the Research Institute Textile Services), NZ Fertiliser Manufacturer's Research Association (1947),

5.4.1. Description of sectoral actors

At a first look, New Zealand agro-biotech involves multiple organizations of different types which are intertwined in various layers. These actors are described through the following category: (i) public and semi-public academic organizations; (ii) private, and semi-public organizations/laboratories which offer biotechnological products and/or services; (iii) intermediate and bridging organizations; (iv) companies-users and/or producer of biotechnological developments; (v) suppliers; (vi) funding organizations; (vii) policy-advisers, and (viii) regulatory organizations.

(i) Public and semi-public academic research organizations

Science-making is currently carried on by two main actors: universities and the Crown Research Institutes. From a total of eight public universities the country[48], four are largely influential on agro-biotechnology, though in different manners: Massey, and Lincoln Universities are very focused into agricultural research, and are involved in agro-biotechnology research. Otago and Auckland in turn, have a different scope as their strength are on human health, but still related to agriculture through partnering in intersecting areas between human health and agriculture, functional foods for instance. In 2004 the eight public universities enrolled around 165,000 students, (125,000 full time equivalent students (Ministry of Education 2006). Massey University is an agriculture devoted university located in the Northern Island, in Palmerston North, about 145 km (90 miles) north from Wellington the capital city. Massey University's agricultural research is world-class, and attracts international students from over the world. That is an

[48] University of Auckland, Auckland University of Technology, University of Canterbury, Lincoln University, Massey University, University of Otago, Victoria University of Wellington, and University of Waikato.

important component of its identity. The Massey University Agricultural College was established in 1927 with 85 students offering degree programs from Bachelor to Master of Agricultural Sciences, as well as short programs dedicated to specialized issues like Management and technology, Horticulture, etc. In 1963 it achieved the status of University and in the next few years apart from Agricultural and Horticultural Sciences, it offered Technology, Veterinary Science, Science, Humanities and Social Sciences, and extramural teaching; and one decade later it also had Business and educational studies (Massey University n/d). Now it has two more campuses, one in at Albany close to Auckland, and in Wellington where since 1999 it merged with Wellington Polytechnic to become Massey University Wellington. There they offer a wide range of different programs like design, fine arts and music (Massey University n/d). In 2005 the university had 21,128 EFTS, and 1,255 FTE staff (Massey University 2006).

The Institute of Veterinary, Animal and Biomedical Sciences at Massey University provides the only Veterinary degree in the country, which is part of the top ten international vet degrees. This institute is within the college of Sciences, together with: Food Nutrition and Human Health, Fundamental Sciences (Chemistry, Mathematics & Physics), Information and Mathematical Science, Information Sciences and Technology, Molecular Biosciences, Natural Resources, Technology & Engineering. It is noteworthy that this college as such was established in 1998 to articulate the previously independent faculties of: Agricultural and Horticultural Sciences, Veterinary Science, Technology, Information and Mathematical Sciences, and Sciences (IVABS n/d).

Lincoln University is located close to Christchurch (360,000 population), in the small rural town of Lincoln, in the South Island. It is 424 km (263 miles) from Nelson, the northern point of the South Island. In 1880 it had its first students as a school of

Agriculture, linked to a close by college (Canterbury college which then became University). In changed status and its institutional ascription two more times, until 1990 when it became Lincoln University and offered programs from diploma to doctorate levels. This university, the third oldest in the country, is also a research-led organization dedicated to land-based disciplines and their related industries: agriculture, horticulture, viticulture, biotechnology, environmental science, and management, tourism, landscape architecture and commerce (Lincoln University n/d). By 2005 this university offered 103 qualifications and 728 subjects to 4,268 students (3,396 EFTS), with 613 full-time equivalent staff (FTEs) (Lincoln University 2006).

Auckland and Otago University are not as sectorally involved as the previous ones. They absolutely differ in their degree of closeness to agricultural research and agro-biotech. The previous two are agricultural-research led, and world known because of their research advances and focuses. These two are also highly reputed but in other areas, Health sciences being one of them.

Auckland University is the largest university in the country, and was established in 1883 with 95 students and 4 teaching staff dedicated to education and training; since 1962 it is an independent university. Today, it is home to more than 40,000 students (29,331 EFTS) distributed in five campuses around Auckland. It has a high research profile: almost all teaching staff is engaged in research, and has 5000 students in postgraduate studies (1200 doctorates). It involves 4.361 FTE staff, from which 1,956 are academic (2006) (The University of Auckland 2007).

Otago University is the country's oldest university. It was founded in 1869 in Dunedin, a city in the South Island, 362 kilometers (225 miles) south of Christchurch, with the authorization to grant degrees in Arts, Medicine, Law and Music. Apart from that main campus, today it has four more campuses, two in the North Island (in Auckland and Wellington), and two more in the South Island (Christchurch and Invercargill). (University of Otago 2007). This university takes part of the world's top 100 universities (The Times Higher Education Supplement) in the rank 79th. In 2006 this university introduced 16 new qualifications adding to a total of 172, and was home for 17,449 EFTS, and 3,250 FTE staff, from which 1,044 were academic and research staff (University of Otago 2007).

CRIs are one of the most visible outputs of the undergone government reform; they are fully by government; their shareholders are the Minister of Finance and the Minister of Crown Research Institutes. From a total of nine CRIs in 2005[49], three conduct research in the agro-biotechnology sector: AgResearch, Crop & Food Research, and HortResearch. These CRIs assets represent $475.6 million, and employ 4,230 staff members, from which 3,264 are related to research and research support. The three CRIs are recognized within the country and abroad because of their world-class science.

AgResearch's main campus, Ruakura, is in Hamilton, 126 km (72 miles) south from Auckland, in the North Island. Ruakura's main research areas are: molecular biology (genomics and cloning), reproductive technologies, dairy, and meat sciences, agricultural systems modeling and land management. Research in the other campuses involve plant breeding, and plant molecular biology (functional genomics), ruminant nutrition, immunology, parasitology, reproductive technologies, biocontrol & biosecurity, seed technology, wool & skin biology, animal fibres & textiles, and deer and sheep. One of these campuses, the Molecular Biology Unit one is placed in the campus of Otago University (AgResearch n/d). AgResearch is the largest CRI, it employs more than 1,000

[49] For more details see http://www.ccmau.govt.nz/crown-research-institutes.html, July 2006.

staff, and is seen as one of the most clearer inheritors of the old DSIR. AgResearch has been instrumental in supporting the bovine-genome project in US.

Crop&Food Research in turn is located in Lincoln, in the South Island. Besides, it has regional offices distributed across the two islands, apart from one in Australia. These center employs 370 staff (25 percent PhDs) working in five core research areas: sustainable land and water use, high performance plants, personalized foods, high value marine products, and biomaterials and biomolecules. Part of its recent achievements include the invitation to take part of the International Consortium for Potato Genome Sequencing, which is led by Wageningen University (The Netherlands) (Crop & Food Resarch 2007).

HortResearch involves more than twenty research programs on fruit, plants, and sustainable production systems for improving human health, wellbeing and performance. It claims to be at the forefront of world horticulture research. It has one of the largest world databases of fruit gene and compound, and breeding and cultivar development. Research involves fruit genomics, crop management and fruit quality optimization, integrated fruit production and insect and disease control solutions in plants, post-harvest and process technologies, product formulation and identification of health enhancing benefits, novel flavors and fragrances, and consumer and sensory science. This CRI is home to more than 500 staff distributed in 10 locations in the country; and involve different types of ‘commercialization pathways’, such as licensing, joint ventures, spin out, collaborative agreements, and paid services (HortResearch 2007).

(ii) Private, and semi-public organizations/laboratories that offer biotechnological products/services

One of the distinctive features of this sectoral case study, as compared to Costa Rica and Uruguay, is the variety and multiplicity of R&D organizations which resemble biotechnology dedicated organizations in more industrialized countries, but also of supportive and intermediate organizations that play the function of bridging science and innovation, productive problems with the involvement of farmers through their levy-based organization. This and the next category present these wide range of actors.

New Zealand has a longstanding tradition in the existence of intermediate organizations aimed at supporting farmer's life and economic activity, which take part in private, and semi public biotech labs. Within the dairy industry, dairy farmers are behind many key organizations as shareholders, and as crucial knowledge demanders and users. Farmers are members of the cooperative Fonterra, which apart from its intramural R&D department, it has spun off few companies, such as ViaLactia. ViaLactia is a biotech company subsidiary of Fonterra, oriented to develop and use biotech to enhance farm productivity and new products development. This company attempts to identify and select genes that are important for dairying, including pasture grasses, milk production and composition, and animal health. Fonterra also hold shares of Dexcel, the industry on-farm research and extension organization, supported by DairyInSight, the farmers levy organization[50].

LactoPharma is the result of a joint venture between Fonterra and the commercial knowledge transfer office of Auckland University, in part funded by FRST. It focuses on

[50] Every 3.4 cents per kgMS levy investment, Dexcel gets 1 cent to invest on education (0.06 cents), research (.43 cents) and extension (.51) dexcelink (2005). What is Dexcel doing with its share of your levy? dexcelink. **Autumn**..

the development of a production niche, based on combining the relevance of milk as a rich and diversified source of biologically active compounds, with fostering human health and wellbeing. It aims "…to become a global leader in the discovery of commercially exploitable milk bioactives for human health."[51]

Sheep farming is supported by a biotechnology sheep company, Ovita Ltd. It is partially owned by Meat & Wool NZ, together with AgResearch and Wool Equities Ltd. (a technology investment company).

Livestock Improvement Corporation Ltd. is a dairy farmer cooperative based in Hamilton with more than 2,500 employees (peak season). Besides its headquarters, it has few more regional offices in the country and abroad in countries like Australia, UK and Ireland, and agencies in South America (Argentina, Brazil, Chile, Costa Rica, Ecuador, Peru, Uruguay), United States, Asia (China, and India), and South Africa. Its research scope goes beyond the strict dairy sector. It includes research and development, and services on a wide range of areas, including: DNA across species; progeny testing for dairy and deer industries; beef, deer and dairy animal recording; dairy herd testing and milk analysis laboratories; animal health management; farm automation solutions for beef and dairy; traceability systems for beef, deer and dairy on-farm consultancy service; female productive technologies for beef, dairy, sheep, pigs and goats; and artificial breeding for the beef, dairy, and deer industries (Livestock Improvement Corporation Ltd. 2005). Its origins in terms of research area go back to 1909 when farmers, supervised by the Department of agriculture first organized a routine Herd test in 1926 the Dominion Group Herd Testing Federation was established[52].

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[51] For more details, see LactoPharma's website at http://www.lactopharma.com, April 2006.
[52] For more information see http://www.lic.co.nz/main.cfm?menuid=1&sub_menuid=53, July 2006.

(ii) Intermediate and bridging organizations

Ville (2000) has pointed out the dominance of small family farming units typical of New Zealand (and Australia), which compared to United States where economic development strongly relies on large manufacturing corporations, constitutes an 'entrepreneurial gap' yet filled by "…a well organized group of intermediaries and business advisers commonly known as stock and station agents" (Ville 2000). This institutionalized actors have played, for the author, a key entrepreneurial role in terms of finance, marketing and business advice, and furthermore as guiders of the success of the farming sector in the country.

This is the case of a wide range of industry bodies managers of farmers' levies[53], which are very powerful not only in terms of budget, but also because among other tasks, they are research purchasers, thus play a fundamental role as research agenda setters. Dairy farmers also have their own levy organization (Dairy InSight) that among other things are crucial purchaser of R&D, while playing a fundamental role of agenda-setters and bridging technology, science and innovation and farming. Meat & Wool New Zealand (M&WNZ) is another one among those, which resulted from the recent merging of the Meat and the Wool levy organizations. Its funded is based on levies from livestock producers on all beef, sheep and goats slaughtered, and wool levies from shorn sheep (Meat&Wool NewZealand n/d). Among its R&D portfolio it is included solving problems related to: farm health, i.e., improving livestock growth rates and health; reducing livestock emissions of greenhouse gases; improving farm productivity, etc.

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[53] As of October 2004 there were around 25 industry levy-based organizations.

Furthermore, for the last 60 years farmers have been nationally united through Federated Farmers of New Zealand Inc.. It has a decentralized structure oriented to defend farmers' interests both at the national and local levels. Its goal is to add value to farming through "…an open, free, enterprise economy to promote employment, economic growth and to increase living standards in the best interests of all New Zealanders. [It envisions] a productive, high income and high employment market economy. This requires flexible markets for labour, goods and services, low inflation, maximum sustainable use of capital and people, and sustained investment in technology and education." (FFNZ n/d)[54]. Not only farmers are part of this organization, but it also includes seven industry groups such as Dairy, Meat and Wool, Mohair, Rural butchers, High country, Grain farmers, and Beekeepers.

Universities have their own transfer and commercialization units, which focus on issues such as IP, marketing, licensing, and overall partnerships with private companies or other parties. For instance Otago University does it through the Otago Centre for Innovation (2003), Auckland University has its Auckland UniServices Ltd. (1988), and Massey University has its Massey University Research Commercialization Office.

Local and regional agencies are oriented to strengthen the linkages among universities, CRIs, and private companies. BioCommerce Centre is one these, located in Palmerston North where Massey University is, in the North Island.

The Biotechnology industry also has its own voice. NZ Bio, created in 2003 as a response to GIF recommendations, resulted from the merging of two separate groups Biotenz and the NZ Biotechnology Association.

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[54] For more details see http://www.fedfarm.org.nz/about_ffnz.html, March 2006.

The Royal Society of New Zealand (RSNZ) is an independent national body comprising around 60 S&T societies, and individual members. This academy plays three key roles: one related to fostering awareness about science within the country and overseas, and diffusing scientific knowledge through the publication of seven scientific journals; secondly, it simultaneously manages research funds on behalf of NZ government, including the Marsden Fund; and, thirdly it acts as a policy advisor to government (in the case of GMOs for instance), while also being a vehicle for the scientific community, through a visible voice.

New Zealand Trade and Enterprise (NZT&E), is part of the Ministry of Economic Development. It is aimed at helping the biotechnology and agrotechnology sectors to develop within New Zealand and abroad with a biotech sector for export. Biotech is seen as a transformer of the primary sector. Their mission is to grow the sector, and for that firms should be grown, through small funding, and connections and offices throughout of the world. This organization plays a small funding role, and policy advisor at some circumstances.

(iv) User/producer companies of biotechnological developments

Fonterra is at the core of this sector, both as a user of ‘biotechnology products’ and as a trigger of research and development, and underlies many of the research ventures mentioned here. It goes far beyond being a single processing company. Fonterra Co-operative Group Limited is a dairy cooperative owned by 13,000 New Zealand supplier shareholders, the world’s largest single exporter of dairy products. It exports 95percent of its production to more than a hundred countries, collects 13 billion liters of milk/year, and manufactures and markets more than 2 million tones of dairy products (MAF n/d). At the manufacturing level, Fonterra has an ingredients business that manufactures and markets more than 1,000 ingredient products under the *NZMP* brand. It also has several brands[55].

To an important extent, Fonterra unfolds throughout the while pastoral sector, and the organizational mapping. It is connected in one way or another, via direct partnership of more indirect linkages, with most R&D agro-biotech labs.

Some other Farmers levy organizations such as Dairy InSight and Meat & Wool NZ (see below) play different roles, one of them being the demand of knowledge and bridging the ultimate users, i.e. farmers, and knowledge producers like universities, CRIs, and/or private labs.

Another type of firm in this category is one dedicated to bridging science and business in agro-biotech. They define themselves as integrating new biotechnology into pastoral agricultural systems. Placed in Dunedin, this firm relies on a strong scientific experience and background combined with investment opportunities, and knowledge of and linkages within the sector and overseas. Their outputs are consulting services, new businesses development, and investment opportunities. Customers include farmers, companies, and investors. They design research but do not have labs or do R&D themselves. They play a broking role, by bringing together the need and the potential response to that need.

(v) Suppliers

Wrightson is a very important provider for New Zealand agriculture both in terms of size, and incidence across the sector and throughout the country, as well as outside: they also operate in Australia and South America. They provide a wide range of services

[55] Some of its brands are *Anchor*, *Anlene*, *Andec*, *Anmum*, *Chesdale*, *Fernleaf* and *Mainland.*

from seeds, livestock, wool, and animal nutrition, to finance, real estate, insurance, irrigation and training. They also conduct their own research on issues like grass breeding, forage evaluation, animal production, seed enhancement, arable and process crops, and seed production and cultivar maintenance. In a different scale, there are other pastoral-related suppliers such as Agriseeds. Grasslanz is a different type of supplier company, R&D-focused and more specialized; it is a spin-off from AgResearch, a plant technology provider that through alliances with other companies commercializes its products.

(vi) Funding organizations

Research funding, and biotechnology research funding in particular, is in hands of few major actors: The Foundation for Research, Science and Technology (FRST), The Health Research Council[56], and The Royal Society of New Zealand (RSNZ)[57], which purchase science on behalf of government. Producer boards also act as funding sources, as they purchase research to solve for their levy payers agenda.

The FRST was created in 1989 in alignment with the radical government reforms. Its establishment was part of the restructuring of the government research departments, emerging as an intermediary organization in charge of purchasing science outputs on behalf of the government. It is the larger single investor on S&T, reaching an investment close to NZ$ 400 million/year in portfolio outlines.

The NZ Venture Investment Fund (NZVIF) was established in 2002 as an equity investment program. It was aimed at fostering the emergence and growth of young innovative firms by supplying capital, and in the longer run, to boost the development of

[56] This organization mainly funds human health research, and therefore is not included in this study.
[57] The Royal Society contributes to the funding of biotechnology through the Marsden Fund.

the venture capital market[58]. It presents itself as a venture capital "fund of funds", and invests NZ $100million along private sector co-investment.

The Royal Society of New Zealand (RSNZ) manages research funds on behalf of NZ government, including the Marsden Fund.

A tertiary research funding is handled by a Tertiary Education Commission (TEC), a Crown-owned entity under the Ministry of Education established by the Education Act 1989, which funds post-compulsory education and training offered by universities, polytechnics, education colleges, private training establishments, industry training organizations, among others[59]. This Commission also manages and allocates a Performance Based Research Fund, and provides funding for the Centres of Research Excellence[60].

Private funding companies include Wool Equities Ltd. oriented to invest in the biotech sector and in commercialization of pastoral sector research.

Venture capital is available for startups and established companies related to the area of Life Sciences, and more particularly those interested in the intersection between food and health: novel foods related to health prevention. The focus is on Australia and New Zealand, and its investment ranges between NZ$2 to NZ$10 million (BioPacificVentures 2005).

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[58] For more details see http://www.nzvif.com/invest_Programme/overview.asp, July 2006.

[59] For more details see at http://www.tec.govt.nz/, July 2006.

[60] The seven Centres of Research Excellence (CoRE) are: Allan Wilson Centre for Molecular Ecology and Evolution, Centre for Molecular Biodiscovery, New Zealand Institute of Mathematics and its Applications, The National Institute of Research Excellence for Maori Development, The MacDiarmid Institute for Advanced Materials and Nanotechnology, National Centre for Growth and Development, and the National Centre for Advanced Bio-Protection Technologies.

(vii) Policy advisers

The Ministry of Research, Science and Technology (MoRST) is the main RS&T policy adviser government body. It is also responsible for negotiating, managing and monitoring contracts with purchase agents and service providers, apart from being the bridging organization between all the RS&T actors. It provides secretariat services to the Growth and Innovation Advisory Board (GIAB), entity that was created in May 2002 following the GIF report (February). It attempts to bridge the relationship between government and private sector, by improving their dialogue, and providing an independent view about the how government moves towards the strategy of growth and innovation. GIAB replaced the previous *Science and Innovation Advisory Council* (SIAC), established in 2000 to work closer with the private sector and help to eliminate innovation barriers.

The NZ Royal Commission played a key role regarding the analysis and further regulation of GMOs in the country. It is one more advisory body.

The Ministry of Agriculture and Fisheries (today Ministry of Agriculture and Forestry) was originated in 1892, through the merging of two departments of the Department of Crown Lands, the Stock and Agricultural Branches, becoming the Department of Agriculture (Nightingale 1992). The FRST also has a policy advisor role, yet its main function is to purchase public good RS&T.

(viii) Regulatory organizations

Every Crown-owned organization, or 'Crown company', is monitored by the Crown Company Monitoring Advisory Unit (CCMAU). CCMAU was created in 1993, and even though it is an operationally independent unit, it is administratively attached to the Treasury. Its role includes monitoring government's investment in these companies, assisting with boards' appointments, and advising shareholding Ministers on performance and governance issues.

Among the monitored companies by CCMAU, there are state-owned enterprises, Crown research institutes, other Crown companies, and companies in which the Crown has shareholding involvement (airports, and shipping)[61].

MAF is the leading agency for 'end-to-end biosecurity' in the country. Biosecurity New Zealand is a division of the Ministry established to prevent, control pests and diseases, and manage or eradicate them if go into the country.

ERMA, the Environmental Risk Management Authority, was created as a response of the Hazardous Substances and New Organisms Act (HSNO), passed by Parliament in 1996. As a regulatory, decision-making body, it evaluates the risks, costs and benefits of the organisms and/or substances in question, determines conditions on approvals and decides on transitional licenses and other types of approvals (ERMA n/d). The import, development, field-testing, or release of any GMO must be approved by ERMA. This agency operates under the Ministry of Environment.

[61] Information available at http://www.ccmau.govt.nz/crown-company-overview.html, December 2005.

Table 5.1. New Zealand: Snapshot of interviewed firms and research centers

	Year of origin	**Number of workers**	**Ownership**	**Outputs and markets**	**Area of application**	**Main techniques utilized**
FIRMS						
Supplier Firm	1851	2,000 (in R&D 25 in NZ and 5 in AU)	NZ stock exchange (+ than 38,000 shareholders)	Local and export; wide range of products and services (see above)	Plant development, plant breeding, gene discovery	Genetics, tissue culture
Services Firm	1997	8 (3 PhDs)	Private shareholders	Services, consultancy, tailored research projects. Local and exports	Agro-biotech: sheep, dairy, livestock. DNA-based genetic improvement	Informatics
Livestock Improvement R&D team	1926 (origins)	15	Cooperative	Innovations, Patents, and publications, traits,	production traits, fertility traits, animal health traits.	Gene function, genotyping work
ViaLactia R&D team	1999	10	Subsidiary of Fonterra (genomic research of Fonterra)	Innovations, Patents, and publications, traits,	cow and milk composition traits	Genomic research
LactoPharma[62]	2002	10	Joint venture between Fonterra, Auckland UniServices Ltd.(investment from FRST)	Innovations, Patents, and publications, traits,	Functional foods: mining milk the formation of bones, immunity treatments; dietary supplements	pulling all the proteins apart
Meat&Wool New Zealand	1920		Levy based organization (recently joined meat and wool levy orgs.)	Contract research, define research agenda, might conduct some research	Productivity (sheep, livestock) farm productivity environmental management (soil and water conservation), animal health,	Gene sequencing, genomics.
RESEARCH CENTERS						
University of Massey – Institute of Veterinary, Animal and Biomedical Services	1927 (university)	190 staff, 140 postgraduate students (45 PhDs)	Research and education institute within public university	Research projects on animal health; five companies by 2005 (startups and merged companies) (started in 2003)	Offers the only veterinary degree in NZ (one of top ten such degree internationally), and pastoral animal health program	Animal health

[62] The information on this organization is based on a phone conversation and secondary data. For more information see for instance UniServices (2002). Annual Performance Review. Auckland, Auckland University.

Table 5.1. Continued

CRI AgResearch	1992	1,000 staff	Crown research institutes	Research projects, startups		Pastoral research, involving both animal- and plant-based research
CRI Crop and Food Research	1992	370 (around 90 PhDs)				
CRI HortResearch	1992	500			New plant varieties and cultivars; diagnostic kits; firms; services to fruit growers, companies, and other researchers.	Horticulture research

Source: based on interviews, and secondary data[63]

[63] See Appendix III for more details.

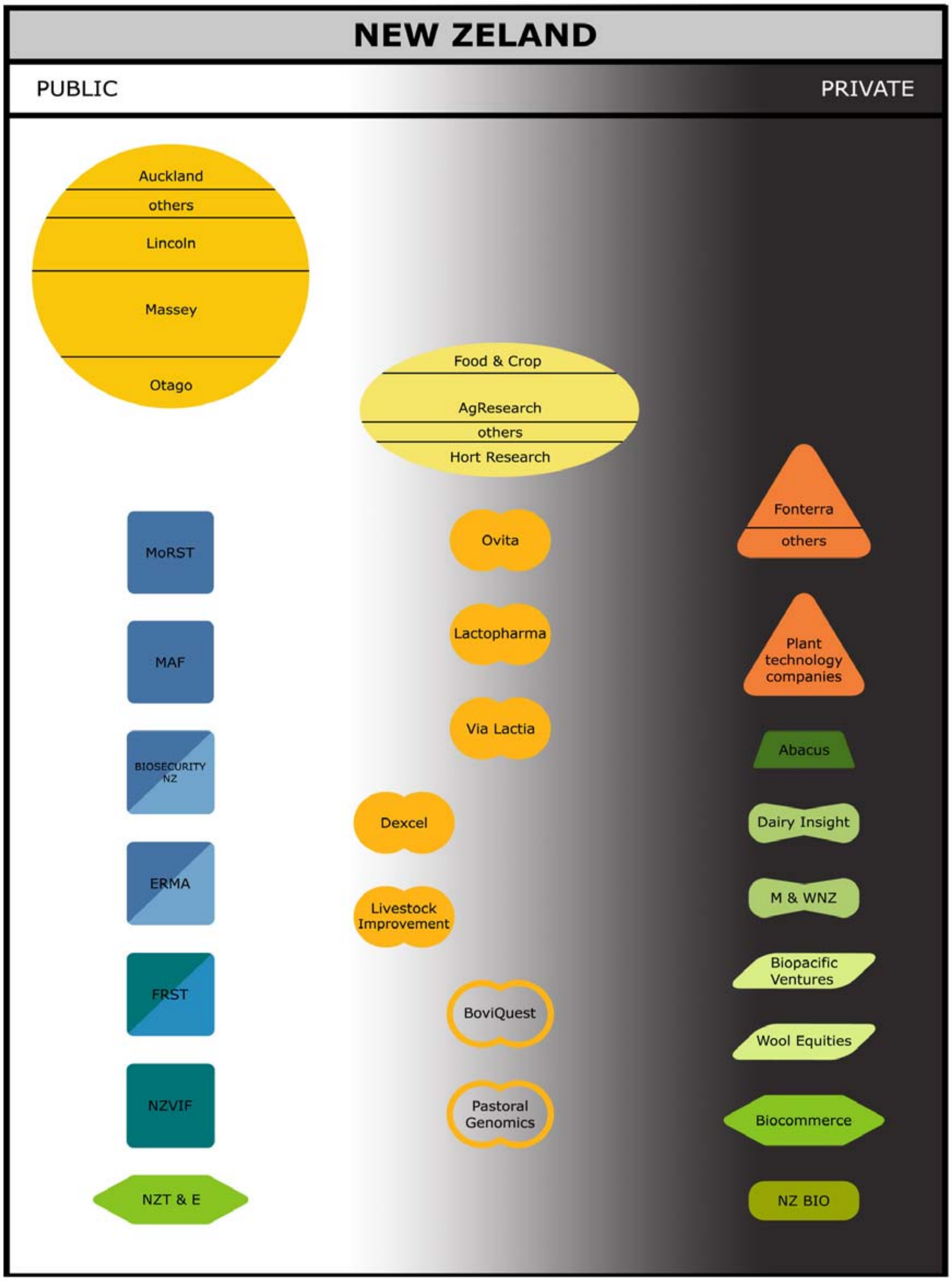

Figure 5.3. New Zealand: Diagram of sectoral related organizations

5.4.2. Interactions and relationships in the sectoral system

(i) Degree of connectedness

Pastoral agro-biotech is a tight sector in New Zealand, with very new and old actors, which have all undergone deep changes in the structure and roles regarding research making, funding, and policy making. Change has been large and has influenced the whole dynamic of the sector. However one of the most crucial factors behind these re-structuring has been the continuity and reliance on previous structures and actors but still letting change and approaching change as an opportunity to re-orient themselves. It constitutes a very dense sector with complementary actors, functions and technologies but set in a very cushioned environment in terms of the number and type of supportive organizations. There are several bridges between one and another types of actors. And all take part, with varying degrees of engagement, and from different functions.

Collaboration between CRIs and universities has not been as close or intense as it was expected and desired. The science-research environment has been trying to cope with limited and overlapped sources of funding, which have led to an over attempt of differentiation over collaboration and complementarity between CRIs and universities. Their variety, multiplicity, and potential for collaboration have been hanging over funding. Funding has been a bottleneck, as it has not accompanied their variety, or supported their supposedly complementary and different niches. They have had to cope with a highly competitive environment. CRIs have concentrated a good part of their effort in becoming self-sustainable, and mainly market-oriented, strongly linked to private companies, and have relied on international collaboration more than in local partnerships with universities. Firms are in close interaction with universities and CRIs.

(ii) Type and purpose of interactions

Linkages and interactions are very dense and complex, with nested organizations, which at the same time are crosscut by several consortia, collective programs, and projects. Organizations engage in different types of interactions, i.e., with different partners, and for different purposes. Fonterra is behind many collaboration efforts. CRIs, levy organizations and biotechnology R&D labs are also involved in those partnerships. Those R&D labs are themselves fruit of collaborative efforts such as consortia or joint ventures. For instance, the reduction of livestock emissions involves the *Pastoral Greenhouse Gas Research Consortium* integrated by several other organizations, like Meat & Wool NZ, Dairy Insight, Deer Research, Fert Research, Fonterra, Wrightson, and AgResearch, as well as a levy-based organization like Dairy Insight.

Another consortium, the *Pasture Genomics Consortia* is aimed at getting higher quality pastures, which apart from Meat &Wool NZ, involves ViaLactia Biosciences, Deer Industry NZ, Fonterra, and AgResearch, as well as funding from FRST. Other consortium partnered by M&WNZ with AgResearch, Massey Industrial Research Limited, and the Meat Industry Association, and partially funded by FRST, is the ‘Meat Biologics Consortium’ oriented to look after new products related to human health and wellbeing.

Livestock Improvement and ViaLactia came together through the *BoviQuest consortium*. Their partnership implies the accumulation of an expertise in bovine genomics, and over 60 years of herd-testing records to identify unique genotypes.

Joint ventures are numerous as previously described. Ovita is a joint venture between Meat & Wool New Zealand, Wool Equities Ltd and AgResearch Ltd to manage an investment of NZ$90million dedicated to biotechnology research on sheep biology, physiology and genome.

Relationships are multilateral, multi-type leading to a structure of nested organizations which participate in different initiatives. Again this description is partial, as not all the sectoral actors are so intensively involved in these relationships. Universities are less involved. It is interesting that farmers are behind many of these hubs through their levy-based organizations. These organizations not only bring together farmers' needs, but also match them with industrial demands, and look to diminish a possible gap between the two. As described by an interviewee at one of these levy-based organization, the process is as follows: "Every year we consult with farmers and industry and prepare a R&D strategic plan, typically of 3 to 5 year window, but we update it on a regular basis. Basically we look at what are farmers' needs and what are farmers' wants, and then we determine from there the research outcomes. So, for example a farmers need might be a healthier livestock so an outcome for us would be to eliminate something like … so then we look into funding research to achieve that outcome, bearing in mind that there might be more than one way of doing it. […] But we also take into account the industry needs because if we produce lot of sheep but the meat processing industry could not sell it then things would not work. So we talk to the main processing industry and sometimes fund research all along the value chain" (Interviewee TW).

5.4.3. Summary of the main characteristics of the institutional environment

The current mapping is the result of a series of drastic changes occurred in the 1990s as a consequence of the government reforms of the 1980s. The government reforms have led to key changes both in structure and practices. The current mapping involves numerous organizations playing different roles in some cases, but in highly competitive environment. Within public academic research organizations, universities have a long and well and world-established trajectory in the field of pastoral agro-biotech. However given the changes in the environment, they are changing too. Semi-public CRIs embody a big part of those driving changes, which have succeeded in finding a niche for their research. CRIs and universities are complementary, and could substantially benefit from their differences. However the environment has hindered their potential collaboration. And the main bottleneck has been funding. CRIs have had to focus too aggressively in seeking funding for their survival, and the sources of funding did not take into account their differences by entailing various mechanisms and types of funding reflective of their different niches and needs. But that has been also recognized as a problem, and some strategies are being implemented to deviate this course of action, as it is discussed in the Policy section below.

CRIs have closely engaged in partnerships with R&D labs and companies such as Fonterra, which in turn are engaged in consortia, shaping a multilayered scenario. Universities also have their spin-offs, which are also involved in some of these partnerships, but to a lesser degree. Farmers levy organizations also nurture the complexity of this sector, not only regarding the functions of the sector, but the many linkages and relationships in which they take part, as well as the ones they foster. By the way of levy organizations farmers have a say and a decision in the research agenda and are direct users of these R&D initiatives. They are actively shaping the orientation of the sector, and not as passive users, but as partial engineering of the knowledge produced.

Policy actors are also multiple, with different responsibilities and scopes. Intermediary organization abound, as it does the types of linkages they hold among them and with other actors. Finally the productive collective is in the hands of also numerous types of businesses in numerous niches, and positions in the 'productive chain'. Public-private amalgamations are part of that mapping.

5.4.4. Institutions

(i) Intellectual Property Rights[64]

In New Zealand the granting of a patent requires fulfillment of two criteria:

- novelty NZ-wise: the description of the invention have not to be published in New Zealand before the filing date of publication. The combination of existing products and/or processes is not sufficient to be a novelty.
- Manufacture type of invention, excluding "…such things as "products of nature", mathematical operations, bare principles, mathematical algorithms, schemes or plans and methods of medical treatment of humans."

Patents are granted for a period of 20 years, starting when the IPONZ receives the complete application. Since January 2004, the Government determined that IP resulting

[64] Some of this information has been accessed at http://www.iponz.govt.nz/pls/web/DBSSITEN.main?p_access_no=E20FFFCDBE1A0EE86965BFCF6EF6A341&p_option=IPONZMISC, and http://www.med.govt.nz/buslt/int_prop/info-sheets/patent-prot.html, July 2005.

from research performed for the Public Service should be used for the greatest national benefit.

Intellectual property is an enduring theme in researchers and firms' discourse and concern, as well as practice. Both universities and CRIs are pursuing IPs, but this trend seems to be coming back to equilibrium after extreme 'patentism'. As noted by a senior University researcher, "New Zealand went through a period of immaturity with relation to IP. Ten years ago nobody knew what it was, did not care about it. We went to the opposite situation, where everybody decided it was so important that they had to show the balance sheets with the intellectual property they had, and they were traded as commodities. That resulted in huge legal expenses. So finally we understand the importance of transferring the technology. We do not care who owns the intellectual property as long as those commercializing the technology in the future share the commercial gains they have. Now we are giving away IPs. In the contract it says, 'you company X now owns this IP, however, should you success commercializing this idea we would receive a commercially acceptable return from our contribution to this idea. The university is not a very good judge to decide what to patent and what not to do." (Interview GV). So, what led to that change? Government rhetoric is the answer, in this interviewees' view, "Government said we are sick of this stupidity. You guys need to have a *New Zealand Inc.* hat on, treat NZ as a single company that we are all working for".

That is one relatively common emphasis in the interviews: R&D labs are not too concerned with owing the IP, as long as the patent remains in New Zealand that is ok. Still secrecy is the most utilized protecting mechanism. A researcher pointed out that: "There is a level from which I cannot go below. I just do not tell you what is that we are working on. But with patents, you spend a lot of time and it is not worth a lot of money, become barriers to communication. We hold confidentiality on everything we do. We have one partner to agree, and as long as it is held within NZ… If Fonterra wants to owe it, the government should be ok with that." (Interviewee DL).

But CRIs are not so relaxed, as it is true that they are required to show self-sustainability and returns to governments' research investment. However, patents might not be always a solution. An interviewee from a CRI pointed out that: "Now that there are so many patents it is so competitive. So much money is required to patent. They block. It is not always attractive. It depends... We have a lot of plants protected. […] The (patent) landscape is too crowded. So [an alternative] is to publish and be the first into the market. For example we did tests for apples, and we released them because we thought we understood them better than anybody else. And then we collaborate with them (Cornell for instance who is interested in it)" (Interviewee MH).

These paragraphs show an ongoing discussion and transitions between an unbalanced intention of getting as much patents as possible, and the search for other alternatives more efficient and suitable. This transition talks about a process of experimenting and reflecting. It refers to the ability to learn based on experience. One aspect of patenting was the excessive competition between CRIs and also, though lesser, between them and universities. So even without knowing what might the alternative, that space of reflection and evaluation is fundamental for the organization's flexibility and ability to adapt and be prepared to change.

(ii) Bio-related regulations

When landing in New Zealand, the visitor gets an immediate sense of the size and intensity of the effort to control and manage biosecurity issues. It is an area of great concern, embodied in a complex regulatory framework under the strong leading role of Biosecurity New Zealand, within MAF.

Some of the R&D efforts include the development of sensor technologies[65] to establish the presence of concealed biological threats in shipping containers. Moreover, an educational package has been elaborated to assist pasture managers regarding pasture quality and production, supported by a software package[66] to enhance the decision-making process to reach production goals and estimate pasture quality (AgResearch 2005).

The 1996 Hazardous Substances and New Organisms Act (HSNO) determines that anyone conducting research that involves GE requires an approval, as it does the release of any living organism not previously existent in the country, including GMOs (Ministry for the Environment 2004). In 2000 the government fostered the creation of a Royal Commission to analyze and advice on the strategy to take regarding genetic modification, and a report was presented in 2001. This commission highlighted the relevance of this technique to the country' but recommended a two-years restricted period for releasing GMOs to determine and establish the necessary mechanisms to ensure a safe approach towards these organisms. Some of the research recommendations were taken over by MoRST in 2003, turning them into a set of actions to be implemented.

The moratorium period expired in October 2003, yet as the HSNO is very restrictive and precautionary, the situation has not changed drastically after that time. The HSNO

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[65] Sniffertech™ is the result of work carried on by AgResearch, together with Syft Technologies Ltd-Canterbury and MAF.

[66] This results from a collaborative effort between AgResearch (software developer and education instructor), Meat & Wool New Zealand (funding source) and Wrightsons and Roundup (sponsors). This software is expected to increase annual income by almost NZ$ 14,000 (average farmer, conservative estimate) AgResearch (2005). Transforming agriculture through innovative science: Annual Report 2004. Hamilton, AgResearch..

together with the report of the Royal Commission have placed GE techniques in a critical spot, while enabling the public discussion about it.

As a counter force to that critical side of biotechnology, a government report launched in February 2002 put modern biotechnology at the core of the country's development strategy. The report known as "Growth and Innovation Framework (GIF)" displayed the relevance of these technologies as a key technological platform for New Zealand's economy, and for its agriculture in particular. Apart from Biotechnology, two other strategic areas were defined to take the country back into the top half of OECD countries: Creative Industries, and Information and Communications Technology. This report constituted a relevant milestone in the setting of biotechnology as a strategic sector. On one hand it drove the creation of new mechanisms and policies aligned towards making biotechnology a core sector. On the other hand, it contributed to the positive visibility of biotechnology that could benefit the national economy. It acted as a counterforce to the taboo around biotechnology, mainly when applied to agriculture. The public perception linked biotechnology to GE in an inextricable way, perceiving it as an end by itself, an ethical matter rather than one other scientific tool among many more.

(iii) Sectoral framing institutions

New Zealand has a wide range of industry bodies and levies applied to agricultural commodities. Some of these bodies are responsible of managing farmers' levies; farmers decide through voting whether to keep these levies or not. Among other tasks, these organizations contract research and as such play a fundamental role as research agenda setters. The Commodity Levies Act 1990 is meant "…to enable an industry organization representing a distinct group of prospective levy payers to impose a levy on a commodity", and involves different commodities such as agricultural, farmed, forestry, horticultural, mineral or wild (MAF 1997). The Act prescribes the type of activities in which the levy funds could be spent on. These include: production and market research, market development, promotion, protecting or improving plant and animal health, quality assurance programs, education and training, and administration of the industry organization (MAF 1997).

The current scientific enterprise is highly competitive. Several and diverse actors are competing for limited resources: CRIs, Universities, Joint ventures and consortia. Science is framed as a public-good, yet it must deliver, be profitable and lead to commercialization. This is particularly the case of CRIs, but also universities are actively into the commercial end of science. Universities' commercial units are determined to spin off as many companies as possible. In some cases, they choose to remain as minor shareholders, so that they do what they know best, and the industry takes the lead in getting those results into marketable products. But performance is currently a key evaluation criterion. Universities are focusing not only on research outputs (publications) but also research outcomes (impact on sectoral/industrial growth and development). Number of start-ups companies is considered an important performance indicator.

As discussed earlier, universities and CRIs, and even among CRIs have not been very collaborative in the past. A highly competitive environment has reinforced their mutual isolation. As pointed out by an academic researcher at Massey University "When I came back to NZ I was not sure why we had CRIs. We had universities and then private companies doing research. But [to have] state-owned research companies was quite a puzzle for me. I think for quite a while there was uncertainty about what was all about. But now am quite comfortable with this situation. The CRIs occupy what they would refer to as ‘a managed-research environment’, where there is a top-down approach to science and the decision is made by the senior people in CRIs in association with government, about research that is particularly important to NZ, and the scientists in the company manage to produce that research; whereas in universities the academic freedom is distinct from that managed research environment. […] University research is more free-willing, is more blue-sky and is less affected by politics and commercial outcomes. We have people pursuing their own interest” (Interviewee GV).

Signals are changing as increasing efforts are put to foster collaboration among CRIs, and between them and universities. One attempt in this sense is the recent decision to re-locate the animal health component of AgResearch, going into Massey University. The idea is that by bringing these two environments together, collaboration and partnership is going to be strengthened. The new Hopkirk research institute is a joint venture between AgResearch and the Institute of Veterinary Animal and Biomedical Science at Massey University attempts to become a world leading animal health research centre, will host 70 research staff in 4,000 square meters located close to Massey University (AgResearch 2005).

5.4.5. Policies

In this section the reader gets some categories related to the broad orientation and characteristics of the policy framework regarding learning and innovation. The categories are: (i) what are the resources (means) put in place related to education and research, what are mechanisms and strategies; (ii) what are the incentives to engage in learning; (iii) what are the education and training system mechanisms to include those who are outside, facility to circulate and move around, and between functions; (iv) what are the mechanisms to access knowledge and to have it flow between universities, and other actors; (v) are there incentives to recycle, forget and remember, and if so, what are those; (vi) what are the mechanisms to stimulate mobility across organizations, and arenas; (vii) what are the mechanisms that policies have to enable changing and redefinition; and, (viii) is there social participation and inclusiveness.

(i) Means to learn

In spite of New Zealand's size, the tertiary education system is extremely diverse and comprises multiple organizations. Apart from the eight universities, there are twenty-three polytechnics, four colleges of education, and four small wananga, which have been are formally able to offer degrees since the 1990s legislation (Education Amendment Act) (Codling and Meek 2003). It comprises all postschool education alternatives, from "…foundation education, such as adult literacy and second chance education for those with low or no qualifications who are looking for employment; certificates and diplomas; bachelors degrees; industry training, including Modern Apprenticeships; Adult and Community Education (ACE); and postgraduate qualifications, many of them requiring students to conduct substantial original research." (Ministry of Education 2006) (p.27).

The tertiary education sector involves public tertiary education organizations, private training organizations, industry training organizations, and Adult and Community Education providers. Furthermore, when decided employers might provide industry-related education and training in the workplace (Ministry of Education 2006).

Universities are one of four actors comprising the tertiary education organizations, together with institutes of technology and polytechnics, colleges of education, and wananga Maori. In 2004 these four employed 28,000 full-time equivalent staff (14,000 were academic/tutorial staff). They have different specializations: (a) technology institutes and polytechnics (20) are more oriented to vocational training, and some applied and technological research areas, and in 2004 they enrolled 214,000 students (78,000 EFTS); (b) colleges of education focus on early childhood and compulsory Education, and also teacher education and some social work training; and (d) Wananga Maori are tertiary centers for all levels based on ahuatanga Maori (Maori tradition) and tikanga Maori (Maori custom). There are 3 of these with 70,000 students or 32,000 EFTS in 2004 (Ministry of Education 2006).

An ongoing change that might affect the existing environment is the new Perform-based Research Funds, managed by TEC. These funds are gradually (2004-2007) replacing the Equivalent full-time students funding for research. The total PBRF funding, which will be about NZ$134 million by 2007 will be divided as follows: (a) reward and encourage the quality of researchers - 60 percent of the fund, (b) reflect research degree completions - 25 percent of the fund, and (c) reflect external research income - 15 percent of fund. This process is in its very early stage. The criteria underlying the new fund will certainly affect the ranking of universities, which until now was mainly based on number of students. It could be expected a process of concentration of universities. This fund meant to replace the previous mechanism based on number of students in the seek of fostering quality and excellence in research, yet it could reinforce a 'Mathew Effect' (Ministry of Education, and Transition Tertiary Education Commission, 2002).

New Zealand total expenditure on education accounts for 15 percent (as % of total government expenditure, 2004). From this the majority concentrates in the secondary level. R&D investment in turn, slightly exceeds 1 percent of GDP (2000-03). While in 1996 R&D accounted for 0.95percent of GDP, in 2002 it become 1.15percent of GDP

(NZ$1,416.2 million). From the total 2002 GERD, applied research and experimental development accounts for the largest spent component (54.2percent), after which comes strategic research (25.5.percent0 and pure basic research (20.2percent). During the same year, NZ government was the major funding source (46.4percent), yet the business sector contributed with around 37.2percent of the funding, and 8percent was in hands of universities. Overseas sources of funding accounted for 6.6percent. It is interesting to note that NZ business supplied by 20percent of the R&D funding in the government sector, and by 5percent of R&D funding in the university sector, while the government contributed with 9percent of the R&D funding in the business sector. Nonetheless, the business contribution is relative as the NZ business category includes state-owned enterprises. In 2002 there were 17,768 full-time equivalent personnel involved in R&D, 13,133 of which were researchers, including post-graduate students (MoRST and Statistics New Zealand 2003).

Biotechnology expenditure was around NZ$430 million, while its income was NZ$675 million in 2004 (financial year). During that year, 117 biotechnology patents were granted, while in 1999 it accounted for 56 patents according to the modern biotechnology survey of that year. For last five years the patents granted to New Zealand biotechnology-related organizations add to 156 patents (Pink 2005).

(ii) Incentives to learn

A government's strategy to foster collaboration and excellence research, has been the creation of the CoREs, Centers of Research Excellence (CoRE), established in 2002-2003 with approved funding until 2008, oriented to "…encourage the development of world-class research in New Zealand, by providing incentives for researchers in the tertiary education sector to conduct research that is excellent, contributes to New Zealand's future development, and incorporates knowledge-transfer activities"[67].

These inter-organizational networks hosted by a university, but including other universities, CRIs, and Maori's Tertiary Education Institutions (Wananga). The hosting university is accountable for the contractual and financial relationship with the Tertiary Education Commission, and must respond for the management, and coordination of the research plan, knowledge transfer activities, etc. (Tertiary Education Commission's website).

CRIs have been set up in a way that makes them very vulnerable. They have not had a core stable budget, and have had to go through contestable processes to get all their funding. The main source of government founding is the Foundation, and there they bid not only with other CRIs but also with universities. As a result this extremely competitive environment has led to the lack of collaboration.

(iii) Capability to learn

Personnel mobility is a fundamental source of innovation. Even further, crossing the boundaries of organization types enhances innovation and learning as mobility of personnel across different types of organizations implies new rationales, conceptual frameworks, routines, practices and habits, time frames, etc. Crossing boundaries between public and private, and within them but among organizations, nurtures creativity and enhances innovation (Hemlin, Allwood et al. 2004).

In NZ, and among CRIs and Universities that is a not yet solved problem (Marsh 2003). However, when looking at boards of public organizations (CRIs, the Foundation,

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[67] Tertiary Education Commission's website, at http://www.tec.govt.nz/funding/research/core/core-profiles.htm, July 2006.

etc.), it is interesting to note the relative diveristy in the backgrounds and work experiences of their members. For instance, the Foundation (FRST) board is not only compounded by academics, but by individuals coming from the private sector. That is also the case of CRIs., but it is not so much the case in universities. It makes sense as the leading positions in universities require the academic type of experience that cannot be achieved in the necessary manner if working outside from it (i.e., number and type of publications for instance). The most noticeable pattern across organization types however, is the strong international experience of leading positions such as board members, CEOs and chairs in the sector, even though it is somehow expected given the country's size, and its strong linkage to Europe, Asia and USA. But still is a key strategy for a small country.

(iv) Access to relevant knowledge

Public universities are open, yet they have a cost that is shared between students, and government. Access to tertiary education is open for domestic students who have met the minimum entry requirements. However there are some populations that still are under-represented: Maori students (at degree level and higher), Pasifika students, students with a disability and for students from lower socioeconomic backgrounds moving from school to tertiary (Ministry of Education 2006).

New Zealand public and private organizations are aware of their reliance on international science and trade. Most organizations in the sector have close ties with international actors. CRIs have appointees overseas to strengthen their business development and research capabilities. The government is also clearly committed to help NZ organizations to find the resources they might need from overseas. In 2004 MoRST has appointed two Science and Technology Counselors overseas, one in Brussels and another in Washington DC. Their role is to support and foster research linkages in their respective areas of influence. They act as windows for the NZ research community, while looking for collaboration opportunities and strengthening the status and awareness of NZ science. The Ministry also supports part-time NZ-based S&T coordinators to enhance the linkages with Germany and Japan from New Zealand (MoRST 2005).

(v) Remembering and forgetting

The education system itself comprises mechanism oriented to the re-skilling of individuals. But beyond the mobility within the sector, in the last few years New Zealand has had an aggressive policy dedicated to bring into the country skilled migration to fulfill their skills shortages. Biotechnology is one of those areas, and they are decided to match their needs with resources from abroad.

(vi) Opportunity to learn

The structure of the system shows numerous hybrid organizations and collaborative instances. It is a highly nested system where organizations interact and intersect. It is also aware of the importance of strategizing. Small countries face the dilemma of having to prioritize and be strategic about how to invest and spend their scarce resources on research in a way that could have a key impact on their production and market niches. Their contribution to the world research is very small, yet their decision of how to invest and spend their resources is critical and could represent the difference between being actors of the international market, or just lagging behind. “Small countries cannot rely exclusively on their own research. 99.87 percent of research is carried out outside from NZ, while only 0.13 percent of world’s research is carried out in NZ. So however good a country is, it cannot rely on its own knowledge. So, the situation for a small country is to be real expert at discovering whatever is being developed in public science and in private science around the world and to try to lift it with its own resources, so its own research should be complementary to the research that is being done elsewhere. I think that is the real strategy of a small country" (Senior policy analyst and adviser). This requires at least two things: strong communication with the outer world, and strategizing and identifying priorities within the country's research efforts. Thus, how do they decide what to focus on, what to invest on, how to articulate their actors and to maximize whatever they have is key.

(vii) Policy learning, and (viii) social learning

Revision, ongoing assessment and mechanisms for policy learning find a place in the system. Several examples could highlight the ongoing policy learning processes (Mytelka and Smith 2002). Davenport, Leitch et al. (2003) analyze the case of the FRST in its search for improving the decision-making process, evaluation criteria and inclusion of related-actors.

Policy definition and implementation entails a reviewing and re-defining character: assessment and evaluation are embedded in the process, as re-definition and change are. It this ability to learn from current and past experience, to be open and alert what makes this case one characterized by a policy learning oriented environment.

Social consultation is punctually used depending on the relevance and social involvement. For the case of GMOs there was an active discussion, and the population was very aware of the importance of the issue.

5.4.6. Bringing back the institutional environment

(i) Institutional coherence

New Zealand is a paradigmatic case of public sector reform since the early 1980s, when it moved from regulation to extreme de-regulation. Their aggressiveness with respect to the scope and scale of the changes into an entrepreneurial path made them extensively known and praised across the world. These reforms are known as an extreme application of the new public management principles, but it was the underlying conceptual rigor and intellectual coherence displayed in a carefully designed and mutually reinforcing agenda what made them successful (Boston, Martin et al. 2002).

Fundamental changes in the structure of science and research making, and in the rationale for framing these activities have pushed the research system to behave business-alike as far as CRIs is concerned. Now the system is showing some degree of dysfunctionalism regarding the functioning of CRIs and their coexistence with universities. CRIs mandate is to serve the national interest, which includes three dimensions (ACRI 2002): 'stickiness' of value to New Zealand, building platforms which enable other value creating activity to be driven from them, and ensuring investment at the right end of the opportunity pipeline. They are expected to pursue research in the benefit of the country, and to commercialize the outputs of their research by collaborating with other actors, including universities and industry. Still, shareholder expectations point out that: "[T]he CRIs are expected to originate and commercialise intellectual property but are owned primarily because of the public-good aspect of their overall capability." (CCMAU n/d).

Thus, CRIs are in between two worlds, and the risk and problem they are facing now is because of being in-between but with an important inconsistency in their mandate and the rules of the game: their need to wildly commercialize to remain in the game. They are research-based organizations with a wide scope: from pursuing world-class science which serves the national interest and benefit the country's economy in a profitable, efficient, private-like manner, to seek the commercialization end of their research outputs. Furthermore, they are expected to be financially viable, and provide an adequate rate of return on shareholders funds (CCMAU n/d). This is a heavy weight to carry on CRIs back, moreover when they have almost no secure budget, and need to go through contestable funding even to keep operating. Lately this has been seen as a problem, because of the uncertainty and lack of minimum stability they face, and there are some attempts to correct for this extreme position. One problem in relation to these many demands and pressures is that they have to be very aggressive with the market end of their research, and this reinforces the lack of collaboration between universities and CRIs that characterizes the sector. Not only resources get dispersed between them, but this situation is also aggravated by the lack of collaboration between universities and CRIs, which rather compete for scarce research funding (Marsh 2003). An important part of the problem is the excessive competition between academic actors for limited resources, reinforced by the overlapping of same sources and types of funds for different organizations, which are expected to collaborate, but collaboration is not rewarded but condemned. The Foundation is aware of this problem and has implemented some mechanisms to attenuate it. MoRST is trying to push up the balance between CRIs core and contestable funding, and thus do not need to compete so aggressively for their core funding. Until now they have had to get contestable funding even to keep their administrative functioning.

This ongoing incoherence provides a chance of looking at the level of institutional responsiveness to experience-based learning, and whether the system enables, accept, and/or stimulates correction and reorientation or not. A paper published from MAF recently states that: “[T]he high dependence of CRIs on contestable and unpredictable funding from FRST has created a strong incentive for them to make themselves more financially independent, including by commercializing their own research. In some cases CRIs are understood to have delayed release of research results to industry in the hope of developing their own intellectual property from it. CRIs have developed their own commercial products and sold technology and services overseas rather than focusing on delivery to the New Zealand sectors. CRIs should be there to do what the market can’t do, not what it can do, and they should be focused on the social returns to the sectors not the private returns to themselves. The excess of social returns over private returns to R&D is, after all, one of the most consistent empirical findings in all of economic literature and is the fundamental rationale for both the creation of CRIs and government funding of them.” (MAF n/d) (p.7)

(ii) Institutional thickness

Thickness is one of the characteristics of the sector. Each one of the four components of this concept are present in this case: it is comprised by multiple organizations of different kinds, which engage in numerous and also varied types of interactions, with changing coalitions and articulating bodies, all of them being aware of the importance of the sector, and sharing a sense of direction of where the sector should head towards.

(iii) Institutional cohesiveness

The intention of changing the development path of the country, from commodities to value-added agricultural products, and more particularly to functional foods is shared across the sector, and is pursued in both directions, bottom-up and top-down. The concept of functional foods underlies the discourse of every related actor in today's New Zealand. It is the goal in dairy and in the meat industries. LactoPharma is focusing on that. AgResearch, the largest CRI, has food and health at the top of its research agenda. AgResearch is also engaged in a joint venture with two other CRIs HortResearch and Crop & Food Research, together with the University of Auckland, to study the impact of foods on gut health at the muscular genetic level. This Nutrigenomics programme, with a NZ$ 19.2 million, aims at tailoring NZ food to match peoples' genes (Digest 2004). Crop & Food Research, in turn, in the same direction, and has dedicated NZ$18.4 million on a six-year program to conduct research on 'next generation' snack foods.

Dairying is also permeated by a common path and a sense of collective direction. Consultation to the interested public combined with a perspective based on strategic goals, long term view and systemicness underlines the strategic framework of the dairy industry. This strategic framework for dairying points out that "[T]he industry has come up with a collective view of where it wants to be in the future –the world's best. After a wide consultation, the Boards of Dairy InSight and Dexcel jointly adopted a strategic framework […] which will: Provide a set of high-level aspirational goals for the dairy industry to achieve over a 10 year period to 2014 [and] Strategically guide the investment of the Industry Good levy through Dairy InSight to providers" This framework includes a concrete set of goals which are organized around four themes that are considered interdependent: (i) farming productivity (feed, animals and systems); (ii) farming business (financial performance, compliance & infrastructure, and human resources); (iii) community interface (community impact, welfare & environment, and biosecurity); and, (iv) operational capabilities (strategic framework, industry, private & public good investment, and capabilities, assets & resources) (Dexcel 2004).

Environmental issues permeate the sector, and influence the set of biotechnologies used. Wastewater treatment and greenhouse gas emissions are key areas in the research agenda of companies such as Fonterra and farmer's levies organizations (Meat & Wool NZ). Soil management, biological control of weeds and pests, and greenhouse gas emissions are some of the concern areas. Some of these attempts include the development of a software[68] to predict the type of soil response to different nutrient applications and conditions to minimize the runoff of nitrate, while helping restore large areas of water and land (AgResearch 2005).

One important feature of the institutional environment is the alignment between the setting of priorities and the policy definition and implementation. In New Zealand, tracing government strategies in biotechnology opens up a large set of recommendations (internal and external), policies, legislation, surveys, etc. that account for an intense and iterative dialogue between the different stages along the process of policy-making (agenda setting, policy definition, policy implementation, assessment and re-evaluation, etc.), and furthermore between actors, including government agencies, industry associations, and to a lesser extent science organizations.

New Zealand presents itself as driven by pragmatism. A biography of a key scientist and policymaker in the national agricultural science and policymaking, Dr.McMeekan, highlights this feature: "In some ways McMeekan was a Super-Kiwi, the

[68] Overseer® is the software developed by AgResearch.

sort of person everyone of his generation wanted to be –a doer rather than a theorist, irreverent of authority, a bit of a larrikin who nevertheless enshrined common sense as a primary virtue, kind and highly likable at a personal level.” (McLauchlan 1982).

(iv) Inertia and rigidity

It has been mentioned over and over again that this sector has changed, and has been able to have combine change with existing structures. The sector could not be seen as rigid in any sense. By different means New Zealand, applies the portrait and guiding principle stating its ability to change and adapt, or in the words of the National Party slogan in 1975, ‘New Zealand the way you want it’.

One risk though is an excess of formality and ‘report’ producing which might misplace efforts and resources, and could risk the flexibility of incremental change as the process goes. Reports are almost never-ending, and get attention and resources dispersed.

(v) Extent and carriers of change, and (vi) Persistence and stability

Change has dominated the country and the specific sector over the last two decades. This chapter has already referred to the extent and implication of that change processes. IT has been at the structural level, as well as in the rationale of framing government’s role and its publicness.

Based on Thelen (2003) typology, these processes of change have entailed a combination of both, change by layering (partial and incremental processes of change), and change by conversion (redirection of existing institutions). These processes of change have been radical in their extent, but their implementation has involved gradual and definite mechanisms, and these processes of change have been carried on from within the system. That is, existing structures were transformed and/or new ones created where there was a gap to be fulfilled. In spite of the radical changes undergone in New Zealand, individuals have responded to these changes in a constructive way, gradually getting involved in the new reformed environment. They reproduce the system, by taking part of it.

5.5. Agro-biotechnology capabilities in New Zealand

This section discusses the set of agro-biotechnology capabilities in New Zealand through the concepts of: skills, processes and resources. Skills refer to: (Sa) what are the educational backgrounds of the individuals behind the sectoral organization, and what have been their trajectories concerning previous work experience and mobility; and (Sb) Areas of application, actors involved and knowledge structure. Processes involve: (Pa) mechanisms and strategies implemented to access and absorb knowledge. Finally, resources have to do with: (Ra) infrastructure; (Rb) R&D investment and funding; and (Rc) future regard: research and productive agendas.

5.5.1. Skills

(Sa) Education and experience background and trajectories

Interviewees' backgrounds include studies in: engineering, veterinary, microbiology, economics, molecular and cell biology, food sciences, political sciences, and business administration. PhDs have also pursued those studies overseas in countries like US, England, as well as in New Zealand. As seen in the next table (Table 5.2.), mobility is an important pattern across interviewees' backgrounds. It is not only mobility between different types of organizations, but also in terms of the area of work, type of job, as well as in geographical scope. Experience in foreign countries is a common denominator of these individuals.

Table 5.2. New Zealand: Interviewees' backgrounds paths

Chemistry (Otago University) → worked at university in UK → researcher at CRI → work at industrial association → work at government agency 1 → director of biotechnology policy at govt. agency 2
Material scientist → researcher at CRI → database programmer → senior policy analyst at government agency (not biotech background)
PhD in Engineering → worked at engineering firm → worked at CRI → Manager of R&D area at levy-based org.
PhD in Innovation Studies (NZ) → worked at research department at government → worked at the Foundation for Research, S&T → strategic advisor at ministry of Agriculture and Forestry
Veterinarian → Worked at firm involved in UK, Europe → worked at government agency in issues related to R,S&T funding → works at Industrial Association
Science, and commerce and administration degrees (NZ) → worked at international auditing company → works at Crown monitoring agency in NZ as sector manager
PhD in Bacterio-genetics → researcher at government research department → researcher at CRI → national advisor at MAF → senior advisor at government agency in NZ
International finance and marketing graduate studies (US) → worked in private company US (IT and biotech related) → works at regional biotechnology fostering organization in NZ
Veterinary → worked in private professional (veterinarian) practice in NZ, UK → PhD in Clinical nutrition (US) → academic researcher in University → head of institute at Massey University in NZ
Food Technology degree → management positions in dairy industry (national and regional scope, Singapore) → chief executive in dairy industry (abroad, Singapore) →CEO of CRI
Botany degree → R&D (plant development) program in company → general manager of firm business development
PhD in Plant breeding and Genetics (US) → Research scientist → director of a division in a government research department→ CEO of CRI → created strategic management consulting company in NZ
PhD in Biochemistry → research career → director of industrial association → general manager CRI division → created consulting firm in NZ
Veterinary clinical practice → senior executive positions in public and private healthcare sectors → CEO university transfer office
Economics degree → worked at dairy industry (manager director in Europe and Russia) → CEO at CRI
Commerce and Management degree → senior management consultant at international consulting firm (Europe, NZ)→ coordinator regional biotech fostering org. in NZ
PhD in Molecular and Cell Biology (US) → researcher at govt. research dept. NZ→ scientist at CRI → science strategist at CRI
Engineer (University of Auckland) → worked in private sector in US → CEO spin-off company biomedicine and plants → CEO university commercialization org.
Management degree → Marketing position in company with international involvement in US, Australia → sector management for biotechnology at government agency in NZ
PhD in Veterinary science → Research career → directing science and product development → management of investment in late state research at CRI → created venture capital org.
PhD in Lactation Biology → Scientist at MAF →scientist at CRI → senior scientist at hybrid organization

Source: Based on interviews

(Sb) Areas of application, actors involved and knowledge structure

Animal- and plant-based biotechnologies are crucial inputs for the country exports. Plant-based biotechnology has a long trajectory and accumulation in research and production, mainly referred to improving the country's grasslands. Plant-based biotechnologies include plant improvement, plant genomics, plant growth, and plant health and protection. Animal-based biotech are also a major and key area of research and production, and mainly involve animal genomics, animal health and nutrition, and animal improvement & reproductive technologies (Partridge and Slim 2005). The identification of bovine gene constitutes one important area aimed at improving their dairy industry.

In New Zealand, plant- and animal-based biotechnologies do not co-exist, rather they constitute an intertwined duet, and their interaction shapes a large extent of the sectoral structure. This is particularly the case of those various hybrid organizations like ViaLactia, Livestock Improvement, AgResearch, and other biotechnology-based firms, joint ventures and other types of merges that characterize the sector. A large driver of these structures and dynamics is Fonterra through its involvement and support on many of these initiatives on dairying in a systemic way. Research and production in agriculture are approached through a systemic framework, within which grass and pastures are seen as a fundamental input for agricultural production at all levels. Biotechnology has been an important part of New Zealand science and has permeated productive applications for as long as agriculture has been in place. The main difference is that, as pointed out by AgResearch's report, nowadays agricultural biotechnology might relate to "simply doing traditional things in new and better ways" (AgResearch 2005).

The structural systemicness is reinforced by strategies and approaches that strengthen the complementarities between organizations and individuals. For instance a top researcher in Livestock Improvement is also working at ViaLactia through a program they have in common on bovine genetics. Thus researchers from both organizations are brought together to focus on a specific area in common. There are many examples of this type in dairying; and to a lesser extent this pattern takes place for sheep and meat.

Beyond these areas, the agro-biotechnology sector is fostering a new framework, with similar integrative approaches. That is on innovative foods and health. Innovative foods and health are being perceived as a strategic niche for the country to take advantage of their accumulated know how on agro-commodities, which have shown to be efficient and productive. Innovative foods and human nutrition constitutes a recent pathway, now strongly embraced as a promising productive niche for the country taking advantage of its strengths around dairying and the leading national dairy company, Fonterra. CRIs, universities, and private companies in the dairy sector together with government agencies are pushing along that path focusing on functional foods, and the overall combination of human health and food.

Animal-based biotechnologies, plant-based biotechnologies, and innovative foods and human nutrition concentrate the majority of full-time equivalent personnel, the funding resources, and the papers and patents, according to a survey conducted in 2004 by MoRST to the CRIs and independent research organizations, excluding universities (Partridge and Slim 2005). Animal- and plant-based biotechnologies have been at the core of the country's competitive advantage. New Zealand has been widely known for its agricultural science along the twentieth century, which has nurtured and relied on the use and application of several biotechnologies. Research on livestock farming, animal breeding and husbandry, together with pasture research have been not only key to the country's development but also have been 'exported' through consultancy services and emulated in other parts of the world. More than half of a century ago, improved seed grasses, drainage techniques and fertilizers led for example, to a grasslands increase of

1.5 million acres, 900,000 more milking cows and 9 million more breeding ewes between 1924 and the mid 1940s (McLauchlan 1982). The same has happened with dairying productivity, in which even though the number of dairy farms has fallen, the farm and herd average have increased, as it has productivity per hectare and per cow (MAF n/d).

5.5.2. Processes

(Pa) Mechanisms and strategies to access knowledge

The first and most broadly utilized mechanism to access codified sources of knowledge is the access to publications, journals, databases, and Internet in general. In New Zealand organizations have regular and unconstrained access to these sources. Researchers can easily seek information and sources of codified knowledge, not only through Internet and databases, but also through research projects in which they actively participate. Furthermore, New Zealand, and AgResearch in particular has participated in fundamental processes of knowledge creation such as the efforts around the bovine genome mapping.

Consortia and programs are created between organizations to reinforce their complementarity and enhance their impact. These strategies become crucial processes to access and absorb knowledge, by having together individuals with different areas of expertise. Collaboration with Australian firms and/or universities serves the same purpose of accessing alternative sets of skills and knowledge.

At the national level, the country attempts to bring into skilled human resources, which is a key mechanism to access and absorb knowledge, particularly tacit knowledge. That skilled immigrant policy has some prioritized areas depending on the sectoral and skills shortages they have. Strategies attempt to fill in their needs on biotechnology for instance because it has been identified as one of those areas in need of skilled individuals.

Participation in congresses, and seminars are regularly established mechanisms for researchers in the public and private sector. Some organizations like levy-based ones and some CRIs have branches or individuals in key market locations. For instance Meat& Wool NZ has implemented a user-producer linkage in China as they import substantial volumes of wool from the country. The levy-based organization has implemented this nexus to show the client how to take the most of the product, while also getting information from users that could be important for producers. CRIs have their partners or representatives in Europe or US but more for a marketing purpose.

5.5.3. Resources

(Ra) Infrastructure

Agro-biotech infrastructure is distributed across the country: research laboratories and centers, training and commercialization infrastructure, etc. Key agricultural-related universities are both in the North and South Islands; and the same pattern applies to CRIs. Sectoral organizations with a commercial interest have their branches in strategic locations across the country. Most infrastructure is embodied in facilities which count with numerous equipment, and individuals with different areas of expertise. There are infrastructural hubs across the country focused on dairying in the North Island, and sheep in the South, for instance. On farm infrastructure has proven to be crucial for the country's increase in milking productivity. Research initiatives are undertaken as programs in which different resources are brought into, as well as actors. For example, once a day milking is an important goal for dairying organizations. Research, training and extension activities are put into this effort by different organizations such as Livestock Improvement, Dexcel, Dairy InSight, etc..

Local suppliers such as Wrightson provide an important part of the existing infrastructure. This company provides a wide array of services, from irrigation, to insurance, real estate, and research and development on new forage. This company was the first one to attempt a GMO field trial in the country. Gene discovery has been part of their R&D program in collaboration with other actors, local and foreign. They had a program in Rye grass in which got between 100 and 200 genes discovered (Interviewee GS).

(Rb) R&D investment and funding

R&D is a critical input in the organizations interviewed. Investment on R&D as well as the set of related activities are performed throughout formal channels. Farmers' levies constitute an important source of R&D investment and funding. Meat & Wool NZ for instance counts on the levy-based budget plus interests of some of its reserves. Levies account for 90% of its income; reserves and interests sum up to NZ$85 million, from which around 60 million is held in case of a major crisis. This organization contracts its research out. It counts on a small R&D team of approx. 6 people and a budget of around NZ$ 20 million. This team overviews the agenda and attempts to match farmers' needs with research outcomes. Contracted research is of two types: annual research projects, and joint venture projects.

Dairy InSight receives 3.4 cent per kilogram of milksolids for industry good activities from dairy farmers' levies. In the 2004/05 season, Dairy InSight's investment accounted NZ$47.8 millions (including GST). From that 3.4 cent paid by farmers, 1 cent goes to Dexcel; levies' account for 60% of Dexcel total revenue, and the rest depends on commercial research and development contracts, and funding from the Foundation for Research, Science & Technology (dexcelink 2005).

Venture capital is available for companies in New Zealand and Australia; mainly directed towards life sciences. More particularly, this capital focuses on health foods: the intersection of novel foods for human health. The specialized focus is attracting requests from offshore companies, from US for instance, which are being considered only as far as they have some connection to New Zealand.

Companies such as Wrightson have their R&D budget and staff dedicated to discovery research around programs considered strategic for the sector.

(Rc) Future regard: research and productive agendas

In 2002 New Zealand government identified modern biotechnology at the core of the country's development strategy. The report known as "Growth and Innovation Framework (GIF)" displayed the relevance of these technologies as a key technological platform for New Zealand's economy, and for its agriculture in particular. Agriculture has been often associated with a backward factor from which to 'get rid of'. Foresight and strategic thinking are inherent to most New Zealand organizations. Both at private, public and hybrid organizations, formal resources and efforts are devoted to future strategies, in terms of research lines, market niches, and potential collaborators and partners. CRIs, private companies and some universities have their abroad offices and/or teams to get first hand information, sell their products/services, and be alert about new projects, products, events, etc.

The processes behind technological capabilities in New Zealand are, to an important extent, based on trial and error, but guided by a direction. A CEO from a CRI clearly points it out: "Originally [2002-03] what we did was we created a pathway, a strategic framework and pathway. The framework was: let's look at the external environment, let's look at the trends, let's look at some uncertainties we do not know about, let's build some future scenarios and then let's figure out how we should shake fork and operate across these scenarios depending which one kind of happens" (Interviewee GH). For that, this organization relied on different actors with whom they have interacted in different ways and for various purposes, such as customers, collaborators, its scientists, and created working groups with all of them to assess how the future would look like for them. From there they established "This is where we want to go, and then we asked how to get there.[…] We only do science where we have a world leading position" (Interviewee HR).

This view and intention to achieve a world leading position is, to an important extent, constructed collectively. Farmers' involvement through levies is crucial to create this future agenda. For instance, Dexcel, which is owned by dairy farmers, aims at leading the goal of improving on-farm productivity by 4 percent, and resources, skills and processes are aligned to achieve that goal.

5.6. Summary

This chapter stresses those features and dynamics that have characterized the sector in New Zealand. The research endeavor has changed dramatically in structure and in its practice (how is done), and rationale (how is framed). The Universities have changed in their process of adjusting and adapting, but have been the more stable actor across these reform processes related to research. Government agricultural research however has changed drastically. These new substituting actors (CRIs) are still finding their way, particularly in terms of financial resources, and the balances between their publicness and public good science, and their business-alike modus of operation. These two actors are also in the process of finding a more cooperative articulation. But the system entails a plethora of other supportive organizations, companies like Fonterra, fundamental driver and trigger of research in the country, by directly demanding it, and by spinning off research projects. These, together with other research demanding organizations such as those levy-based, which closely tie research with farmers, and a dense and responsive policy network have made an overall successful transition from one system (old) to the other (new). The current system has some challenges to overcome, but has the benefit of being inclusive in the extent to which actors are part of it, and share common goals and directions. This facilitates the process of reviewing those problems

CHAPTER 6.

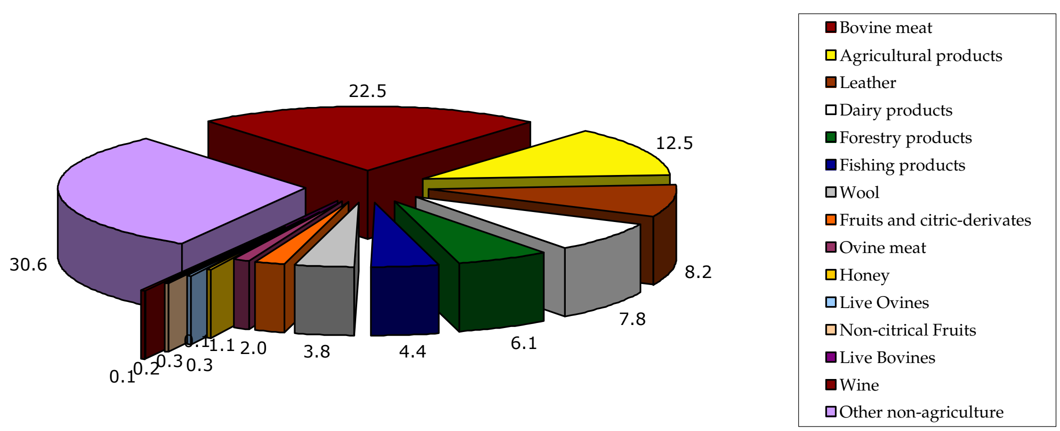
INSTITUTIONAL ENVIRONMENT AND AGRO-BIOTECHNOLOGY CAPABILITIES IN URUGUAY

6.1. Introduction

This chapter presents the institutional environment of the third case study: agro-biotechnology in Uruguay. Following a similar structure than the previous chapters, I start by summarily presenting the country, and then refer to the milestones related to the research endeavor. Third the organizations of the sector are mapped, and then, fourthly, their interactions and relationships. One singularity of this case study regarding the organizational mapping is that it involves fewer organizations than in the two previous cases, only one university, and very few intermediary organizations. The chapter continues with the discussion on the relevant institutions, and policies. For instance in this section one of the characteristics highlighted is the difficulty to process and implement change throughout the institutional environment. Finally the next large section is on the building of technological capabilities in agro-biotechnology in Uruguay: what are the skills, processes and resources in place, and how are they being built. At the end a short summary closes the chapter with some general features of the institutional environment regarding the main characteristics and dynamics.

6.2. Setting the country

Uruguay is a small country with less than 3.5 million people located in the temperate zone of South America. Farming has been at the basis of the country's economy, and also played a key role in shaping society, both cultural- and historically. Agricultural exports account for 43% of total exports, from which the major exports are indigenous cattle meat, cow milk and rice (2002) (FAO 2004). As the next graphic shows (Figure 6.1.), agricultural-based products account for a relevant share of exports: from a total export volume of USD 3,404,501 in 2005, the share of agricultural origin exports represent 69% of them (USD 2,363,435 thousands) (DIEA 2006).



Source: MGAP-DIEA based on the Agricultural Statistical Yearbook

Figure 6.1. Uruguay: Export of selected agricultural-based products, 2005

A characterization of Uruguay could vary significantly depending on what features are highlighted. Different dimensions and realities overlap, leading to different pictures: its current impoverishment previously unknown in the history of the country, with almost 50% of its children being born under the poverty line; while a historic view of the 20th century would point out its high equalitarian society with strong democratic values, and a large well educated middle class, known in the region as 'the Switzerland of South America'; and/or a pioneer country in terms of social legislation, and extended access to education, housing and health (Rama 1987). It could also be described as one of the countries within the group of modern settler economies in temperate South America, together with Argentina and Chile, and then with the larger group of Australia, Canada, New Zealand, and South Africa. According to this approach, these societies have in common a similar economic pattern settled in the 19th century through the combination of European colonization and later large scale migration of Europeans and their culture, temperate climate, abundance of land, and a marginal or sometimes almost eliminated indigenous population (Lloyd and Metzer 2006).

This latter categorization has led to few comparative studies about New Zealand and Uruguay[69]. They share some important historical commonalities, though those have

[69] See Kirby, J. (1975). "On the Viability of Small Countries: Uruguay and New Zealand Compared." Journal of Interamerican Studies and World Affairs **17**(3): 259-280, Alvarez Scanniello, J. and G. Porcile (2006). Institutions, the land market and income distribution in New

blurred in the last half-century. With similar population size, both are heavily reliant on primary production exports, and neighbored by large countries from which depend heavily in terms of trade(Buchanan and Nicholls 2003). As pointed out by Denoon (1983):

"Uruguay invites comparison with New Zealand: they have much the same area of land, rather similar climatic conditions, a roughly parallel demographic history, and occupied comparable niches in the world economy in the late nineteenth century. With a little strain, we may even compare the decisive role of Britain as midwife to their state structures. The British intervention in the Plate estuary in 1806 widened Montevideo's horizons; and British support in the 1820s sustained an independent republic in Uruguay as a solution to Argentine and Brazilian rivalry in the region. […after being under the Brazilian empire] from the 1860s until the Great War Uruguay entered into increasingly close and exclusive dependence upon Britain. One of Uruguay's many presidents described his job as resembling that of the 'manager of a great ranch, whose board of directors is in London'" (Denoon 1983).

But unlike New Zealand, in Uruguay Britain's influence and control was constrained to the productive and economic system: the country had its own social structure which did not resembled the British in any sense, and its social dynamic was mainly based on its Spanish, and Italian immigrations(Buchanan and Nicholls 2003).

The University of the Republic (UR) is the only public university and the single research university in the country: it accounts for more than 60% of the research carried on in Uruguay. This University is more than 150 years old, and very large with its 70,000 students (1999). It's budget is based almost absolutely on government support for

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Zealand and Uruguay, 1870-1940. XIV International Economic History Congress, Helsinki, International Economic History Association (IEHA).

research and training as access is completely free for students, and do not have any type of restricting mechanism for undergraduate inscriptions. It not only has universal free access, but also does not have an exit requirement to push out its students. The student life could last for long periods of time.

The University is completely autonomous; autonomy which is granted by law. It is deeply rooted in the life of the country, as it was born almost at the same time. The law project of the creation of this public University comes only three years later than the first constitution of Uruguay (1930). Its level of autonomy is a distinctive feature compared to other countries. The rector of the University has a comparable status to the Ministry of Education, and to some extent he holds more competences and is more resourceful (Lanzaro 2004). Another distinctive feature of this university, compared to other countries in Latin America, is that its existence and role is established in the Constitution. Until 1984 it had the monopoly of university studies, time when the first private university emerged. Today there are four private universities, but they concentrate on training and education only, leaving the research role almost exclusively to the public university.

Social Sciences and Humanities are the preferred options for students, while Science and Technology, and even the Agrarian areas have captured a small share of graduate enrollment (Figure 6.2.). The trend of the former however, seems to be changing (UdelaR 2005). The University of the Republic has around 500 full time researchers, distributed as follows: 75 in Agronomy (13.8%), 245 in Basic Sciences (45.2%), 37 in Health (6.8), 130 in Social Sciences and Arts (24%), and 55 in the Technological area (10.1%) (UdelaR 2007).

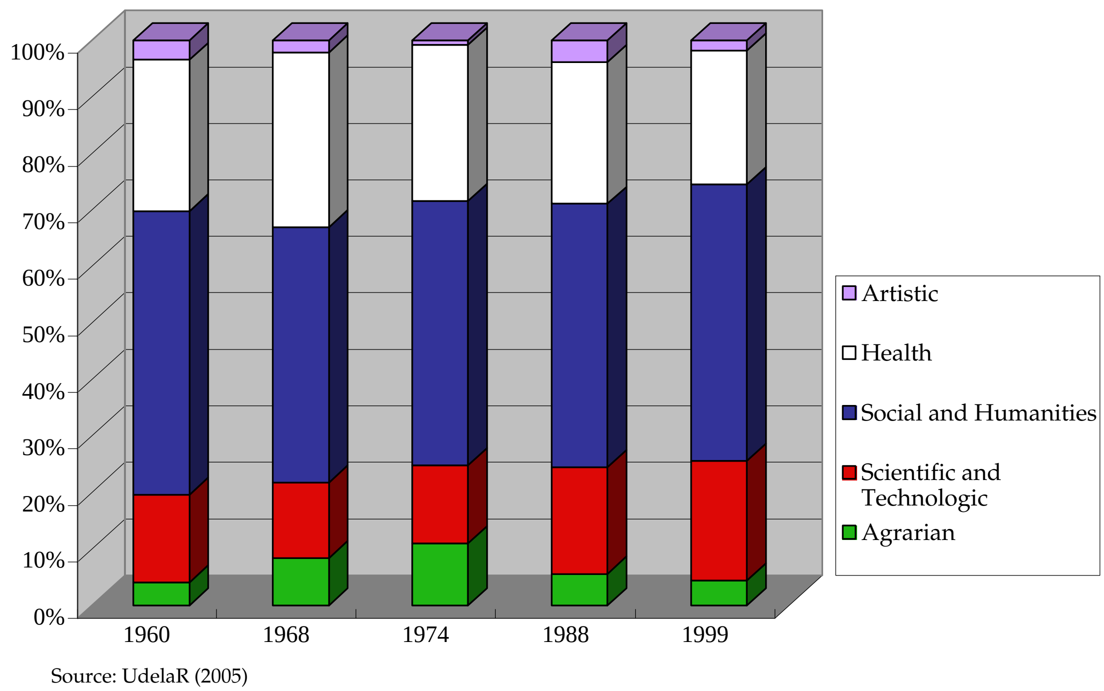

Figure 6.2. University of the Republic: Graduate enrollment by area, 1960-1999

Postgraduate courses have not attracted large number of students, until few years ago. While in 1998 the number of postgraduate enrollment was 404, two years later it doubled (971 enrollment in 2000) (UdelaR 2002). This increase in the rate of postgraduate registrations is in part due to the creation of other postgraduate courses than those supported by PEDECIBA in Basic Sciences (UdelaR 2002).

UR research and tertiary careers concentrate in Montevideo, the capital city where 40% of the total population lives (1.3 million people) (INE 2006). According to the 1999 Census, from a total of 70,156 students, 59.7% had their last year of secondary school in the capital, while 37.6% did it in other cities of Uruguay.

In Montevideo, the University is not located in a single campus rather schools are dispersed throughout the city. This dispersion obstacles collaboration and cross-fertilization between researchers from different schools, and hinders certain research processes that to be completed require equipment and infrastructure also dispersed. Within the university, research takes place in laboratories that in most cases are aligned to disciplines, hierarchically organized within institutes, inside schools.

Apart from the central University offices and schools in Montevideo, there is only one regional branch in the north of the country (*Regional Norte*) where few careers could be completed (Law, and Notary, and Social Sciences), and some could only be started, or finished (first two years of Agronomy, Vet, and last years of Medicine). Overall most students from other parts of the country willing to pursue tertiary studies ought to move to the capital to study a university career. The concentration in the Montevideo is a serious problem, not only because it reinforces the migration problem forcing people to move to the capital city, and generating a process of emptying the countryside in a country that is extremely centralized and concentrated, but also because even in the very shy (existing) attempt of regional decentralization, the programs and careers identically resemble those courses in Montevideo, dismissing the significant contextual differences (i.e., productive systems, demand, economy and markets, etc.).

In Uruguay, 18 percent of the university's investment is on R&D, and that goes for both the overall university's budget on R&D (infrastructure, materials, wages) and to support CSIC. Funding for research projects in the university come part from the university's budget, CSIC funding (contestable) and external funds (contracts or partnerships (Bértola, Bianchi et al. 2005).

6.3. Main milestones in research-related organizations and institutions

Agricultural research has concentrated large national public effort and investment. Yet, this is truer for the past than for the present time when public investment on agricultural research is shrinking, a trend that certainly is not exclusive to Uruguay but an international pattern (James 1996).

The majority of agricultural-related organizations and regulations originate in the first-half of the 20th century, more precisely up to the 1960s. The research organizational map includes the creation of the Vet (1903) and Agronomic (1907) schools, and three agronomic stations in 1911. Three years later, in 1914, the government created a plant breeding station, which became a reference in Latin America in cereal breeding and was directed by a German botanist, Dr. Boerger[70]. In 1932 the Animal Biology Laboratory Dr.Miguel Rubino (animal husbandry) was created, which today constitutes the Directorate of Veterinary Laboratories within the Ministry of Agriculture, Livestock and Fisheries (MGAP).

Later, in 1960 a very ambitious developmental project (CIDE[71]) was initiated to overcome the crisis experienced in the last years of the previous decade. CIDE was a collective effort involving many well-known researchers who collectively committed to design a long-term program for the country’s development with agriculture being a very important chapter of it. In spite of its relevance and the political support to carry it on, it did not become materialized because of the political context undergone in the late 1960s

[70] That institute was restructured in 1961, becoming the Alberto Boerger Agricultural Research Center (CIAAB), and expanding its area of research to other areas such as pasture, beef, sheep, and diary production. Finally in 1989 it went again through a restructure which led to the current National Institute of Agricultural Research (INIA) Beintema, N. M., G. G. Hareau, et al. (2000). Agricultural R&D in Uruguay. Washington, D.C., IFPRI, INIA, FONTAGRO.

[71] For details see Garcé, A. (2002). Ideas y Competencia Política en Uruguay (1960-1973): Revisando el "fracaso" político de la CIDE. Montevideo, TRILCE.

and the incoming military dictatorship that took place in 1973. Yet during the decades of 1950 and1960 many key agriculture-related agencies were created, and several important laws and regulations were designed and implemented, many of which are still ruling today. Furthermore, the overall institutional framework for agricultural issues mainly draws on that time.

Those accumulated capacities were almost dismantled during the dictatorship between 1973 and 1985[72]. In the 1980s the size of Uruguayan professionals and technicians living abroad was very large in relative terms. Some figures about Uruguayans living in Latin America and US during the 1980s show that there were 7,202 Uruguayans in Latin American countries, and 919 in US[73] (Pellegrino and Calvo 2001).

After that long interruption and the consequent large migration of the skilled population, from which scientists were an important universe, several and intense efforts had to be put in place to re-build research capacities in the country. One key driver of this process was the PEDECIBA[74] program, funded by UNDP, complemented with public funds, which operates since 1986 and was explicitly aimed at bringing back the community of exiled scientists who had to migrate during the dictatorship and wanted to return to the country. PEDECIBA focuses on Basic Sciences, including Biology, Chemistry, Information and Computer Sciences, Mathematics, and Physics.

Some features make this program unique in Uruguay. It was born after an agreement between the University of the Republic, and the Ministry of Education and Culture. The University and the Government have never been able to maintain close ties

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[72] For details see Barreiro, A. and L. Velho (1997). "The Uruguayan Basic Scientists' Migrations and Their Academic Articulation around the PEDECIBA." Science, Technology & Society **2**(2): 261-284.
[73] Note that these figures do not include Uruguayans living in European countries which hosted large numbers of exiled families.
[74] Idem previous note.

or anything alike. Furthermore they have ignored each other, with the only difference that the University has to keep approaching the Government for more resources. Many actors worked together to make this possible, including the International Organization for Migrations (OIM), the National Commission for Repatriation (CNR), and the Research Council of the University-UR (CSIC), and then strongly supported by UNESCO. But the exiled scientists themselves were a critical piece of this puzzle. They organized their repatriation and how to go on with the structure of the program.

It is also, and mainly, unique because its structure was developed by scientists themselves and became a space closely tied to the University but outside of it, in which both repatriated scientists and those few who stayed in the country during the dictatorship worked together under their own standards. Working together in Uruguay with those who remained in the country had a fundamental impact not only in terms of the specialized knowledge they brought with them from a different country, but also regarding the experience and practice of working with a different ethos (Barreiro and Velho 1997).

PEDECIBA has played a fundamental role in the building of capabilities in this sector. Not only it has enabled the formation of skilled and specialized human resources in basic sciences, including Biology, but also it has done so by strengthening the creation of postgraduate programs in the country, the research infrastructure (labs, libraries, etc.) (Barreiro and Velho 1997).

Finally, another milestone in this summary must include the major crisis that took place in 2002 after an ongoing recession since 1998, aggravated by a financial crisis result of the Argentinean economic collapse in 2001. The crisis in Uruguay has triggered fundamental changes in the making of science, and research practices. One key outcome of that crisis has to do with the modes of interaction and collaboration among researchers and with the private sector due to the drastic reduction of the research budget, and the process of *pesificación* (transforming US dollars into Uruguayan Pesos) adopted immediately after the crisis.

6.4. Overview of the agro-biotechnology sector

6.4.1. Description of sectoral actors

The agro-biotechnology sector includes: (i) public and semi-public academic research organizations; (ii) private, and semi-public organizations/laboratories which offer biotechnological products and/or services; (iii) intermediate and bridging organizations; (iv) companies-users of biotechnological developments; (v) suppliers; (vi) funding organizations; (vii) policy-advisers, and (viii) regulatory organizations. The following paragraphs describe these actors to then present an overview of the sectoral structure.

(i) Public and semi-public academic research organizations, and (ii) Private, public and semi-public organizations/laboratories that offer biotechnological products/services[75]

With respect to agro-biotechnology in the university, it concentrates in the schools of Sciences, Agronomy, Veterinary, and some in Chemistry. At a lower level, within schools, researchers are organized following the school structure in departments/units and labs. One worth noting feature is that there are not transversal research units. That is in most cases, researchers work in small labs or units within a vertical structure disciplinary-based. There are some crosscutting units, but only for teaching purposes.

[75] In Uruguay these two categories are presented together for meaningful purposes. The first category strictly includes the University (UR) and IIBCE, and the second mainly INIA. It is more meaningful to present them together, but distinguishing their different nature.

The University in general, and this sector in particular have substantially benefited from the PEDECIBA program, already mentioned above. This program is specifically oriented to Basic Sciences, and Biology has concentrated most of its resources. The UR involves around 70% of the total PEDECIBA researchers (500)[76], from which 58% work in the area of Biology (UdelaR 2007).

The school of Sciences accounts for a large share of the research resources related to this field, and particularly to more basic oriented research. The Biotechnology Master is also hosted here. There are different features that have contributed to have concentrated, high quality resources in this school: (i) its scientists have high reputation in their fields, and well connected to international groups mainly because a very large share of them have been exiled and therefore, trained and/or worked outside and still keep some linkages with those groups; (ii) consequently it hosts a large share of PEDECIBA researchers as the program is on basic sciences and many of its areas are in this school (Mathematics, Physics, Biology) and therefore has scientists with extra sources of funding, though very modest by international standards; and, (iii) importantly, it is a new school[77], created as such in 1990, located in a new building of 18,000 m^2 built with a CONICYT/IADB loan, and thus they have new labs, new equipment, etc. This latter feature is not of minor relevance. On the opposite when entering into this school, the difference stands out compared to other schools' old infrastructure. Having new infrastructure matters not only for the everyday research activities, but also for the mindset and frameworks of researchers and non-researchers and the standards they impose over themselves. This school is known for the high standards it has for the

[76] Other organizations hosting PEDECIBA researchers are IIBCE, INIA, LATU, and INAPE.
[77] It is noteworthy that before 1990, the School of Sciences was one with the school of Humanities.

research career and tenure track. Now, the economic crisis of 2002 has led this school to have to build connections and ties with the private sector, which was not really part of the school's short trajectory.

The Agronomy school has a longstanding trajectory in this field, particularly in more traditional biotech. It also has a traditional well-established relationship with the productive sector in the country. It is by far the school with longer and more settled interactions with farmers, and rural-related organizations (including cooperatives, and firms). It is organized around departments[78], and within them around units. Across departments there are very different emphases, and within them there could be more basic- and/or more applied-oriented research.

The school of Veterinary has traditionally shared some of the strengths mentioned in the case of Agronomy, particularly in terms of interaction patterns with the productive sector but with lesser strengths and to a lesser scale. The critical mass related to this sector, as well as the overall state of the school infrastructure and budget are smaller. The infrastructure of the school is notoriously impoverished.

Finally, the school of Chemistry has been very active in strengthening interactions with the private sector and building up an entrepreneurial focus in its programs. However its biotechnological emphasis has been more towards human- than agro-biotech. In the latter it is conducting research on Enology and native yeasts for wine.

INIA is a public entity ruled by the private law, thus it belongs to the second category presented above. INIA, the national agricultural research organization, is another very relevant agro-biotech research actor. It is so because of the quality of its research, and the infrastructure it has, and also because of the mode of research

[78] The School has recently re-structured itself around departments (previously areas), and within these there are units.

production in which its research agenda setting is closely connected with the productive sector. It has kept a relatively good balance between an applied focus and more basic research lines, even though this balance has had its ups and downs. Farmers' representatives within INIA governance have not always agreed on the importance of academic research, and moreover on more basic research efforts. Part of this problem has to do with the overall lack of relevance and consideration to the research endeavor in the country's culture.

Biotechnology crosscuts the different programs being a transversal (technical) unit connected to national initiatives. It is approached as a technological platform enabler of different productions systems and crops, including horticulture and fruits, animal production, and forestry. The biotechnology area supports different programs throughout INIA's five branches located across the country, depending on the characteristics of the local production systems[79].

INIA holds linkages with several actors, including private firms in different sectors such as the meat industry, forestry, wool, dairy, and citrus, and with farmers associations in similar areas (potato, cattle, horticulture, rice, fruit, dairy, and wool). It also has strong linkages with different schools in the University and other research-related actors such as IIBCE. The purposes of these relationships are different including from research collaboration with these latter, to services provider, and technology transfer with the former. Finally a third way of relationship is based on its contestable funding mechanism such as FPTA, and this mechanism enhances the University's research performer role. Apart from this mechanism, another way of interaction but informal one is that researchers from the University as well as from IIBCE count on its

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[79] For more information see http://www.inia.org.uy, accessed in August 2006.

equipment and infrastructure to conduct their projects. Furthermore, several organizations rely on INIA's biotechnology laboratory to conduct some testing and related technical procedures, from the school of Sciences, to the school of Agronomy, INASE and private companies.

Since 1980 INIA takes part of a regional initiative oriented to the agricultural technological development of the Southern Cone (PROCISUR) that includes other similar organizations such as INTA (Argentina), EMBRAPA (Brazil), UPTD (Bolivia), INIA (Chile), DIA (Paraguay), and IICA, supported by the IADB.

There is a third relevant academic research actor, IIBCE, a public research laboratory oriented to biological research. It was created in 1927 by Clemente Estable, an Uruguayan teacher and self-taught researcher whose interest and work on Neurosciences took him to Spain in the 1920s to study at the laboratory of that country's Noble Prize in Medicine (1906), Dr.Ramon y Cajal (IIBCE 2006; Trujillo Cenóz n/d). IIBCE has built an outstanding trajectory in the field of biological sciences, recognized both national and internationally. Traditionally, it has focused on basic research, but recently is expanding its areas and the re-orientating towards agro-biotechnology and collaboration with industry. It has been relatively encapsulated from the rest of the research actors. It belongs to the Ministry of Education and Culture, yet some of its units are associated with the School of Sciences, in the University of the Republic. Its budget is totally dependent on the Ministry. Being part of the Ministry of Education and Culture contributes to its isolation. Its hybrid character and distinct governing rules in some cases makes it difficult to bridge the gap with the rest of the research map. However there are some pluses to their unique condition. They are exclusively oriented towards research, and they do not face the level of administrative tasks that consume so much time of the

University's researchers. They are public servants, and their tenure track is different from the University's one. This institute is very vulnerable as it totally depends on the Ministerial budget.

Within the Ministry of Agriculture three agencies are related to the sector's research-wise, though very punctual and somehow marginally compared to the organizations mentioned previously. They have played an important role, but their very limited and scarce budgets and out-of-date (impoverished) infrastructure has harmed their work. These three agencies are LMSCI, DGSA, and DGSG. LMSCI actively leads research initiatives in the area of inoculants and soil control. Private firms in this area (three firms) heavily rely on this agency to get the approved set of Rhizobiums, which are the micro-organisms utilized for inoculating. DGSA has participated in the certification of some export products such as citrus, and in the elaboration of diagnose kits for diseases also in citrus. DGSG has conducted some work in the detection and diagnose of animal diseases such as Foot and Mouth disease, *Brucella*, etc (INIA-MEC-DINACYT 2001).

(iii) Intermediate and bridging organizations

Biotechnology companies formed an association in 1987 (Uruguayan Association of Biotechnology, AUDEBIO), at a time when biotechnology was part of the government agenda, and a national committee was created. That committee worked for some time and soon it disappeared. To a certain degree something similar happened with AUDEBIO, which even though still exists, it does so at the formal level, and does not operate regularly only on a punctual basis when some special circumstances call for its participation. The last time it had some visibility was in 2002 that played an important role for planning the BIOLATINA Congress held in Montevideo with the participation of biotechnology firms and research labs from different Latin American countries.

In spite of the overall absence of farmers associations, there are some farmers' pushing and demanding for biotechnological solutions to their problems. Rice is one of them. The production of rice constitutes one of the more vertically integrated productive chains, from farming to agro-industry. It has become a strong product for export in a relatively short time span, and their vertical integration favors their ability to articulate themselves and their demands. They have pushed for technological developments in rice varieties and industrial processes, and INIA has been an important partner in searching for varieties' improvement.

(iv) User/producer companies of biotechnological developments

This category includes biotechnology-related firms with products and/or services already into the market. There are few relatively old, and small firms producing either plant-based, or animal health-based biotechnologies. One first group is comprised of three relatively old firms producers of inoculants for legumes. Inoculants are bio-fertilizers that have been applied to the country pastures since the 1950s based on the Australian and New Zealand experiences (See chapter 3). Within this group, the eldest firm was created in the late 1940s (Firm A), the second in the late 1970s as such, even though it existed since the late 1950s as part of a private lab (Firm B), and the third one in 1984 (Firm C). The first two were started by chemists while the latter was done by agronomists.

For these firms, inoculants have been at the core of their production until recently, but for two of them this trend is changing as they have had to introduce agrochemicals in their product portfolio (Firms A and C). They are following an inverse path compared to the expected trajectory along the current 'biotechnological paradigm'. They started with biological products but now have introduced agrochemicals to expand their products as a strategy to satisfy demand and increase profit, as the demand for biofertilizers is not growing.

Few firms are in the area of in vitro micropropagation. Two are producing seeds for their own cultures and plantations of potato. Other firms are oriented to the micropropagation of seeds for commercial purposes. The leading firm in this category has a remarkable trajectory in the production of high quality horticulture, fruit plants and seeds (Firm D). In 1980 a couple of Italian professionals decided to move to Uruguay and install a laboratory dedicated to offer R&D services to firms from the North. They installed the main lab facilities with greenhouses and experimental fields outside the capital city in the countryside, and only the administrative office is in Montevideo. The decision of moving to Uruguay and starting this business here lies on some competitive advantages. First, Uruguay provided a counter-season to complement and contrast to Italian researching and production. Second, it has an interesting pool of highly skilled scientists and technicians working at much lower salaries than those in Italy. Third, Uruguay has tight ties with Italy, and a strong Italian culture given the high immigration from that country that Uruguay had in the 19th and (beginning of) the 20th centuries. Fourth, Uruguay is well connected to the region, is safe and has good infrastructure. These reasons set a good platform for them to take advantages of their linkages and relationships with companies and universities in Italy. Since then they have worked constantly on their R&D services 'for export', and expanded the portfolio of products for the domestic market. This firm is an outlier compared to the rest, for at least two reasons. First, because of the scope of its production varying between different types of berries, peaches, apples, olives, and many more. And second, because apart from that multi-product dimension, its client portfolio, and services provided is also extremely large and closely tied to the Northern hemisphere.

The other firms are producing plants and seeds for themselves in some cases, or growing in vitro plants for others. Customers vary, but they are mainly either in horticulture (potato, sweet potato) and fruit (strawberry), in some cases wine, or in others larger forestry companies. Since these forest companies do not have their own R&D laboratories, they contract out the micropropagation of trees (Eucalyptus mainly) to either these private firms, or INIA, or foreign labs (INIA-MEC-DINACYT 2001).

INIA also takes part of this group, both with products and processes. It produces seeds and some technological packages, which franchises to few (three) seed companies. Until now the experience is on blueberries. “They receive the mother material and must follow the protocols we give to them. They commercialize their products with a certification of compliance with certain quality norms, and products become then differentiated by this process. So, we provide the technology (AR-VITRO®), and they go on with the next phase” (Interviewee IF). In this case, the varieties are public, so the added value is in the process of production.

Another area is plant certification via molecular biology, an incipient area of interest for the youngest firm in the sector, the one specialized in molecular biology. Its orientation to this area is new, as until recently it has only focused on human biotech. As part of its intention to move towards agro-biotech, and plant-based biotech it is getting in touch with the Uruguayan Seeds Chamber in an attempt to trace and control intellectually protected seeds.

During the 1950s few companies were started by researchers and professionals from the University, both in the vegetal and animal health areas. These companies are still running today with interesting outputs. The one in the animal health area was created in 1957 by a group of veterinarians committed to combat the Foot and Mouth disease. With their ups and downs, the second generation took over, later in the 1980s, and oriented it to an innovative project around a vaccine against the same disease. They were successful and contributed to eradicate that problem from the country. That achievement turned them into a serious crisis given a regulation from the 1950s that prevented from manipulating the live virus of that disease once it was eliminated as such. Even though their laboratory was biosecure by international standards there was not political will to modify and modernize the law and let biosecure laboratories manipulate live virus to produce vaccine for export. That situation took them almost to bankrupt but again they re-structured the firm and introduced new projects around which almost start over again[80]. Up to 60 if the firm's revenue comes from biological products. This firm sells in the region through various channels of distribution. This firm sells in Paraguay, Mexico, Bolivia, Ecuador, Colombia, and Argentina. In most of them products are sold with their brand. Only for Mexico they have sold to third parties without branding their products. In Brazil they have their own company.

The Vet school provides services of embryo-transfer of bovine, and ovine to individuals and firms. There are also private firms providing this and related services.

Within the private sector, GENIA is one of few firms dedicated to molecular biology in the country. Even though it was created in 1993, only few years ago turned

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[80] For more information see Bortagaray, I. (2004). La relación entre tecnología y política en la erradicación de la fiebre aftosa [The relationship between Politics and Technology in the eradication of the Foot and Mouth Disease in Uruguay]. Trabajo e Innovación en Uruguay. E. Massera. Montevideo, Trilce.

into agricultural biotechnology. For a decade, GENIA has focused on the application of molecular tools to human medicine, and other issues like paternity analysis. The process of moving into agro-biotechnology started in 2002, when GENIA received support from CND to expand its area of application from human health to agriculture. The strategy to build capacity on agro-biotechnology has relied on collaboration and partnerships with different organizations, beginning with LATU, the national certification organization. The same year, in 2002, it signed an agreement with LATU to complement and reinforce each other's capacities and access to networks. A first important step in this partnership has been an agreement with a private farm, *Bayucuá*, with a hundred years tradition in growing pedigree cattle in Uruguay (Aberdeen Angus). They agreed that GENIA-LATU would perform a biological identity certificate of cattle, which includes a wide range of genetic information such as meat's tenderness, marbling (intra-muscle amount of fat), tracing, etc., as well as genealogic data that is stored for 30 years at a DNA bank in LATU. Now they have signed similar agreements with other farms.

INIA is an important player in conducting molecular diagnosis. It has an accumulated trajectory in this area. Its relevance is also because of the fundamental resource it has become for other actors in the local community due to the equipment and infrastructure it has. Researchers within the University count on INIA's equipment to conduct their work, as most university labs do not have their equipment as updated as INIA's.

(v) Suppliers

Agro-biotechnology suppliers are foreign companies. Supplies are critical for biotechnology, and getting them into the country constitutes an odyssey and a bottleneck. Costs, rules and procedures for importing supplies are very heavy obstacles difficult to overcome. Bureaucracy is very slow and heavy, increasing substantially theirs costs and delaying the process very much. And scale makes the problem harder. Sometimes a company has to wait until there are others who need the same input so that the volume is large enough to make the import worth.

One way of solving this problem could be by having something like a bio-techno-duct: a pilot project with external support to cover one fright per week for two years to get inputs flowing constantly into local laboratories. This was a suggestion of the manager of the molecular firm in the context of a prospective exercise carried out few years ago (INIA-MEC-DINACYT 2001; Pagliano, Mazzolla et al. 2002)

(vi) Funding organizations

Funding is scarce and concentrates on the public side: government is the major and almost only funding source. Few organizations are in charge of managing and distributing those funds. There is not a specific ministry of science and technology or a coordinating agency within the public sector. Traditionally government funding for S&T was channeled by the national S&T council (CONICYT), dependent upon the Ministry of Education and Culture (MEC). But that has changed based on some reforms in the formal level triggered by a second IADB loan and evaluation of the previous structure. IADB then required to set the change to have a second loan. Change concentrated on the formal level. Since 2001 this Council acts more as a policy adviser, and the Ministry has two other funding arms: the National Directorate of Science, Technology and Innovation (DINACYT), and the Program of Technological Development (PDT). This program operates based on an IADB loan. Its funds are distributed through a contestable process open to firms and research groups. It entails three subprograms, one oriented to promote and enhance firms' competitiveness (USD 11 million), (b) a second one oriented to research teams (USD 8.4 million); and (c) a third one for coordination and linkages (USD 1.48 million) (PDT 2006). PDT funding budget is USD 26.67 million for five years, from which USD 20 million are an IADB loan, and the rest is local investment.

DINACYT in turn, deals with two funds. One is the National Fund of Researchers (FNI), and a second one is the Fund *Professor Clemente Estable*.

The University's Research Council (CSIC) is an internal unit oriented to finance research projects through contestable processes directed exclusively to University's researchers. Within CSIC there are four lines of funding: (a) one to promote researchers-productive sector collaboration, (b) one for Human Resources (scholarships, participation in events, etc.), (c) another on Special projects (for instance, research for social emergence as a response to the economic crisis of 2002), and (d) one dedicated to R&D. CSIC funding for the period 2001-2003 represented about 14% of the University investment on S&T, which this in turn accounts for about 15% of its total budget (US$ 47.251.671 and its total budget for the same period was US$ 312,572,146) (Pittaluga and Vigorito 2005).

Other sources of funding for more applied research are INIA, and the S&T council (CONICYT). INIA funds agricultural research conducted both intramural and conducted outside it, through the Agricultural Technology Promotion Fund[81] (FPTA). During the period 1991-2004 UR accounted for 48% of funded projects through INIA's funds FPTA and LIA. The schools involved were Agronomy, Vet, Chemistry, Sciences, Engineering, Medicine, Architecture and the North Branch of the University (UdelaR 2007).

[81] For more details see Hobbs, H., C. Valverde, et al. (1998). The Agricultural Technology Development Fund For Contract Research: An INIA (Uruguay) Initiative. ISNAR Briefing Paper. The Hague, International Service for National Agricultural Research.

This organization is at the core of the sector, and plays a fundamental role not only because of the funding per se, but also because the other research labs count on it as it has some of the more modern infrastructure concentrated in one. INIA's resources come from: (i) 0.4% taxes of agricultural-based goods; (b) at least an equal counterpart provided by the Executive; and (c) resources from international cooperation, and (d) the sale of products and services (Bértola, Bianchi et al. 2005).

Private sources for funding innovation projects in general, and biotechnological developments in particular are totally missing both in the private and public sectors. Banks are not an option, as there are not any credit options suitable for innovation, nor any type of venture or seed capital. In all cases private companies rely on their own resources. Only one company had support from a public corporation, CND, which operates since 1985 aimed at stimulating the creation of companies, acting as a shareholder. In theory it could have acted as a venture capitalist and fill part of that gap, but in reality it did not, at least for knowledge-based firms. Difficulty to access has been one of the problems, and the uncertain length of the evaluation processes and delivery of resources. That has been a criticism about CONICYT as well, where the only certainty is the application deadline.

The overall funding mechanisms of research labs and organizations are of two types: (i) based on taxes, and complemented by public funds, and (ii) direct government funding. The former entails few advantages compared to the latter. First it necessarily ought to involve taxpayers in the governing structure. This is positive at least in two senses. First because private commitment to R&D is one of the critical problems of the country, also common to the Latin American region, and engaging them in the decision-making process of research organizations could be a starting point for a (slow) process of change in attitudes and values. Second, because they are the end users of research tools and results, and it is key to have them actively involved and committed. This is the case of INIA for instance, where the governance structure includes representatives from the Executive and farmers organizations. (ii) IIBCE's funding is totally dependent on government. Some of its units/labs are associated to the Sciences school, in which case they can apply for CSIC funding. But those that are not, then rely on the Institute's budget, and whatever extra funding they get from external sources. This is very problematic for them given the small budget the Institute has, and the related uncertainty and vulnerability associated to this source of funding, and very small commitment to R&D (Bértola, Bianchi et al. 2005). As an example of the budget problems that this organization faces, 30% of IIBCE researchers are honorarium (IIBCE 2006).

(vii) Policy advisers

CONICYT plays an advisor role in issues related to science, technology and innovation. In 2001 after an attempt of reforming the organization, and based on a new loan from IADB and their own requirements and demands, biotechnology was defined as one of the prioritized areas for support. However, this was mainly a rhetoric definition, not clearly aligned with strategic actions, or funding prioritization.

The MGAP is the policy reference for agriculture. However, biotechnology is relatively in a policy vacuum and has not been appropriated by any particular actor. It is in a grey zone between agriculture and innovation, and is not a policy issue within the broader policy agenda. Even innovation issues are slowly becoming part of the political and, to a less extent, the policy discourses, but only at the discourse level. Agriculture however is strongly institutionalized, both at the policy and public agendas.

In Uruguay science and policy have gone through very different paths, in general opposite ones. The University and the government have not hold good relationships, and the latter has ignored the former as an advisor in for instance, controversial issues. This has been the pattern during the 20th century. This distance and conflict is reinforced by the fact that government is critical for the university's survival as provider of its budget. The relationship is then connoted with a soliciting character: the University approaches government claiming and begging for more money. The government dismisses its relevance, the importance of knowledge for social and economic development, and the return from knowledge that is beneficial to the country. It is an asymmetrical relationship, disrespectful with static roles of giving and asking.

(viii) Regulatory organizations

The Ministry of Livestock, Agriculture and Fishery (MGAP) plays a regulatory role through different dependencies. In terms of plant biotechnology the organizational mapping includes mainly DGSA, though LMSCI is a player for the control of inoculants. There is one agency in the area of animal health, DGSG).

LMSCI - The Laboratory of Soil Microbiology and Inoculants Control was created in 1961 for the following purposes: research and quality control; selection and approval of Rhizobium samples, as it is the only agent able of determining and approving what samples could be used by commercial inoculant manufacturers; and maintenance of the national collection of Rhizobiums and other micro-organisms.

This laboratory plays a double, potentially conflictive, role: on one hand it carries on research activities, identifies and defines the set of approved bacteria to be used by private firms; and on the other hand it controls that industry and its production of inoculants. It is also a regional referent for storing the selected samples, conducting genetic control, quality certification of commercial inoculants, and study of legal and commercial aspects of the countries of the region(INIA-MEC-DINACYT 2001).

DGSA - This organization is in charge of protecting the country's phyto-sanitary situation. It is the responsible agency for sanitary certification of propagation materials, and exported products. It plays a fundamental vigilant role, but with a small budget, and scarce resources. Another role it has is the policy definition and implementation of sanitary and quality conditions of agriculture inputs and derivates.

DGSG - is the sister organization of DGSA, but for the animal sector. It is in charge of controlling and implementing the policy arena of animal related issues. The same comment applies regarding the contradiction between the scope of its functions and the assigned budget. Uruguay has a very complex situation as far as sanitary protection because of the smuggling that goes in Uruguay from Brazil, Argentina and also Paraguay, where lack of controls and regulations are well known. Finally another dimension of its function is providing services as a diagnose laboratory.

Then another regulatory institute is INASE, the National Institute of Seeds, a public non-governmental[82] institute oriented to promote, and contribute to the development of the seed industry by assessing on and controlling the seeds' quality and identity within the country. It is the official responsible entity for taking care of the intellectual property of vegetal varieties[83]. It also has the ability to authorize firms to certify seeds by auditing and controlling their processes quality. Its budget is based on government support, complemented with resources from selling services to private

[82] The public non-governmental character refers to type of legislation ruling this organization. It is public only that for personnel contracting it acts as a private organization.
[83] The IP of vegetal varieties is granted based on their differentiability, uniformity, and stability.

companies[84]. Its governance structure includes a Directorate Board with five members representing the MGAP (President), seeds producers and commercializers, as well as users. It also includes an Executive Board, a national council of seeds integrated by representative of different groups (public and private, and professional ones such as the Association of Agronomists), and a Commission of Users with representatives of second order farmers associations.

INASE and INIA collaborate in the registration of cultivars since 1998 when the signed an agreement through which INIA would conduct the field trials and any other technical requirement for cultivars registration. This institute relies on third parties to accomplish some if its mandatory tasks, as it is the case of the evaluation of marketable vegetal varieties, which is contracted out to INIA for conducting the agronomic evaluation of those varieties in the field.

They relate to the School of Agronomics, and to the General Directorate of Agriculture Services (DGSA) within the Ministry of Agriculture. INASE also participates in the Commission of Risk Evaluation of Genetically Modified Vegetables representing the Ministry of Agriculture, together with the Ministries of Economics and Finances (MEF), Public Health (MSP) and Housing, Territory ordering and Environment (MVOTMA).

[84] The budget is approximately USD 500 thousand/year, from which 25% is provided by the Ministry according to the interview realized in 2004.

Table 6.1. Uruguay: Snapshot of interviewed firms and research centers

	Year of origin	Number of employees		Ownership	Outputs and markets	Area of application	Main techniques utilized
		Current	At beginning				
FIRMS							
Firm A – Inoculants	1947	26	10	2 partners-family (originally 3 only 1 alive, one sold its share)	Biofertilizers (part of wider portfolio) Markets: national and regional		
Firm B – Inoculants	1984	14	6	2 partners (originally 3, Agronomists). (2 current partners) Spin off from a seed company	biofertilizers, national and regional	Vegetal: Legumes	Inoculants: fixing nitrogen for legume
Firm C – Inoculants	1978	20	7	Family business, now 30% of Argentinean capital	Products (biofertilizers), national and regional		
Firm D – seeds and plants, R&D services for export	1980		Approx.30	Family business	Products (Seeds and plants) and services (R&D consultancy, contracted research projects)	Fruits, olives	In-vitro culture
Firm E – Seeds-related, Agronomic projects	1982	1 (re-structuring)	3 (2 part-time)	1 Agronomist	Local	Seeds quality control (sanitary and seeds), wage management, integrated management for different products (organics for example)	Research projects, consultancy services (assess and test seeds)
Firm F – potato plants	1980		5 Agronomists + production and harvesting personnel (200)	Familiar business	Local	Potatoes (1,500 has of potatoes)	Propagation of potatoes for self consumption (plant potatoes)
Firm G – Wine	1975 (1930)	35	15	Family business	local and exports	High quality wine	fermentation

Table 6.1. Continued

Firm H – Molecular biology	1993	9		3 partners (Vet. Studied in France)	local market (punctual exports)	Human biotechnology (+++), and only recently agriculture	PCR: extract DNA, apply PCR, typify amplified products through electrophoresis. This technological package could be applied to many different things. In the case of bovines instead of electrophoresis they apply an automatic sequenator (borrowed from INIA)
Firm I – Animal health	1957	70	7	70% 0wn capital 30% outside (Uruguayan living abroad)	Domestic and exports (through distribution and 1 MNE in Brazil)	Vaccines	
RESEARCH CENTERS							
UR- Agronomic school Vegetal Biology Biochemistry unit	1975	7 professors + 4 interns	5	Public university		Two areas: greenhouse gas emissions (Chemistry) and plant biochemistry (Sciences)	
UR – Agronomic school Horticulture unit-culture technology	N/d	1 (7 in the broader level)				Soil management, intensive horticulture systems	
UR – Sciences school Biochemistry Molecular biology	2000	7 (3 budgeted, 2 projects-based)		Public university		Stress in plants produced by diseases (pathogens), lack of water and low temperatures	
UR – Sciences school Biotechnology Master	1998	(50 enrolled, 12 graduated) (do not have funding for the master)				Training program in biotechnology (2 years)	
UR – Sciences school Biochemistry -	1987	5 (2 budgeted)				Folding of Proteins in vivo	
UR – Vet school Genetic analysis in companion animals	1985	7 (budget)		Public university		Genetic variation in *Criollo* bovine	immunogenetic molecular and chromosomic markers
IIBCE neurochemistry	1983	12	6	Public research institute			

Table 6.1. Continued

IIBCE Microbiology lab.	1988	10 (2 budget + honoraries and others)				Recently oriented towards animal health (previously human health)	PCR analysis, characterization of autochthonous cepa characterization
PUBLIC AND SEMI-PUBLIC LABS							
INIA-Biotechnology Lab	1991 (biotech lab)	6	6	National agricultural research institute (mixed system of funding)		Crops, animal production, forestry, horticulture and fruit culture	
INASE	1997 (Seeds Law)	33, 18 technicians (agronomists)		National institute of seeds (mixed system of funding)		Quality control, regulation and certification	
LMSCI – MGAP	1960	10 (research role: 7 students and junior researchers) and 2 (controlling role)		Ministry's laboratory (public funding)		Microbiology of soil and inoculants control	

Source: based on interviews and secondary data (Appendix III).

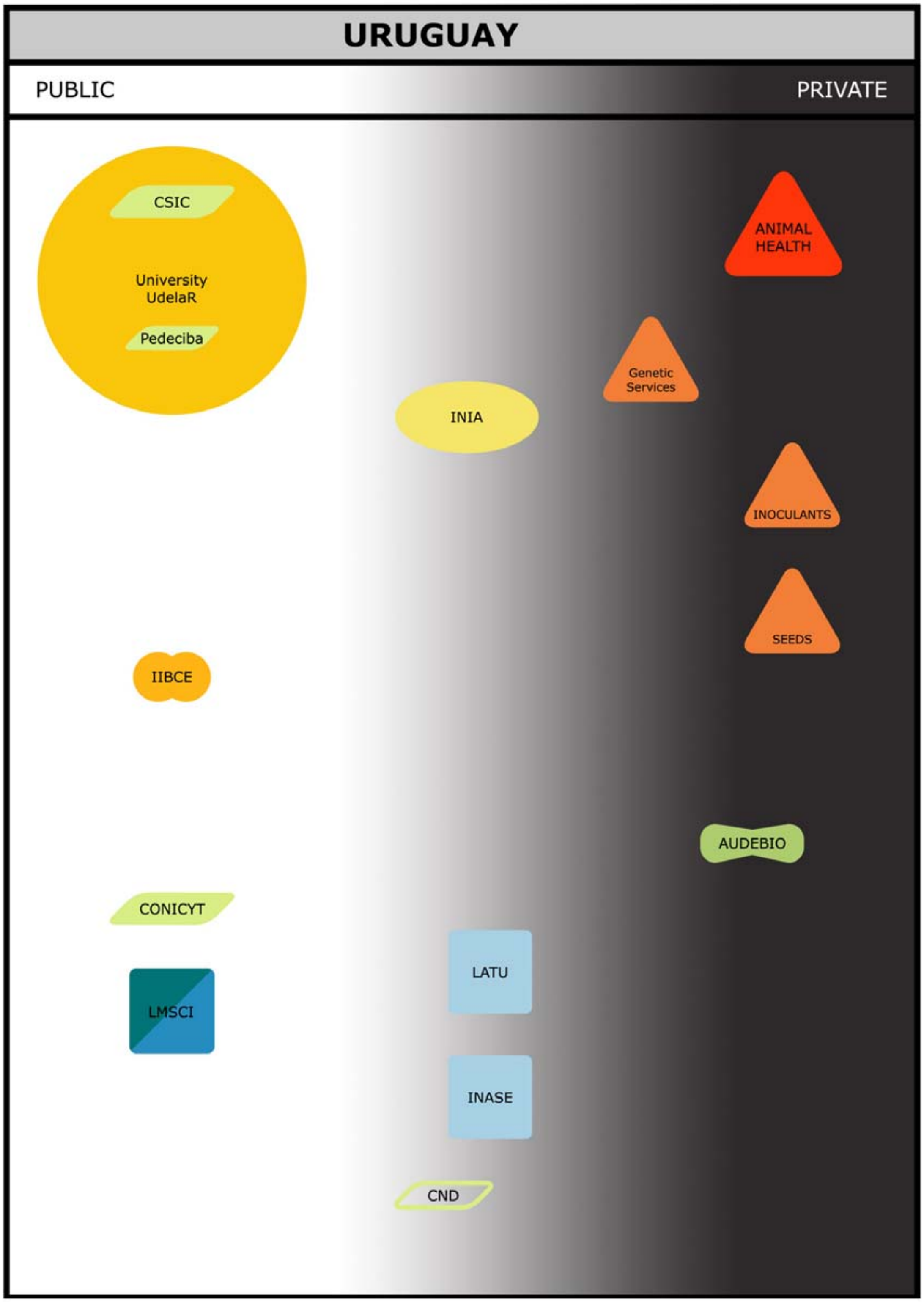

Figure 6.3. Uruguay: Diagram of sectoral related organizations

6.4.2. Interactions and relationships in the sectoral system

(i) Degree of connectedness

Up to this point, I have described the actors structuring the sector. In these paragraphs I am presenting broader aspects of the organizational dynamics. A first approach to the agro-biotech sector indicates a rather disconnected and disarticulated sector with scattered linkages, mainly based on personal interactions.

The level of institutionalization of these linkages is rather low. Personal ties dominate the interactions between actors, but they are on a punctual basis and oriented by necessity in most cases. Linkages are strictly bilateral, functionally oriented to accomplish punctual goals, thus transitory, and mainly informally held.

This atomized sector is shaped by few actors at the academic research end, and small and relatively old firms with narrow bilateral paths between them. Within these two types of actors there is some variation, but within linkages are also very weak. If represented in a 3-D diagram, we would see those actors as dots, and the connecting paths would be twinkling with varying intensity depending on the particular (short term) need in question, personal ties, and on the specific situation/context that goes on (i.e., economic crisis).

Sectoral actors only develop particularistic, sporadic linkages developed to serve specific interests. Linkages and interactions are not institutionalized, nor rooted in the very dynamics of these individual actors. Most of the times they do not translate into relationships. They do depend on their connections to perform elemental research activities, but these are informally held, on a punctual basis and for a specific utilitarian purpose; once the specific goal is accomplished the interaction ends, and there are no further linkages, least sustained collaboration. The typical case is when researchers at schools or firms need some specific reagents to go over with their work, a phone call to a known colleague is what takes to get a small dose of the reagent, and that's it. But these linkages do not translate into further commitments with a sustained character, neither among firms, nor between researchers within schools or between them.

Research concentrates in few organizations, which are not very much integrated into the rest of the socio-economic fabric. Science and academic research have not been considered motors of the country's development. This lack of relevance and consideration of research and science gets aggravated by a combination of loneliness and isolation.[85] The production of knowledge takes place in isolation not only from the outside but also within the walls of the University, and public research organizations. This also applies even at the level of schools and labs. Researchers work in small units in their labs within schools, which are already physically dispersed across the capital city. Dispersion is not only at the location level, but also in terms of efforts and resources. Researchers are working in isolation in their labs, in part because of structure, which reinforces that pattern by being so fragmented while at the same time does not have mechanisms nor promotes their embeddedness into larger and broader collaborative spaces within the University. Another part of it has to do with the dominating work rationale that does not stimulate crosscutting efforts, and the logic has to work alone and perceive other groups as competitors rather than as collaborators. As mentioned by a researcher in the public sector: "For 25 years I have been in contact with that group with whom I was trained and still today they keep supporting us. We have excellent connections with groups outside the country, very few here inside. The level of entropy

[85] This problem is not exclusive the University in Uruguay, but common to other universities in the Latin America region Arocena, R. and J. Sutz (2001). "Changing knowledge production and Latin American Universities." Research Policy **30**: 1221-1234..

here is horrible, the thematic jealousy, the small *chacra*s, each one has its own theme and themes are protected as if they would be property of individuals. We do not have critical mass and even worst we do not try to build it. Each one is a potential competitor. In the whole world science is a collective enterprise. Here is far from that. ” (Interviewee JI)

Migration of trained students and junior researchers is a problem mentioned by researchers. It happens after the dedicated work of senior researchers to conform a group, and then they cannot keep them in a stable contract because the project through which were paid ends and there are not any extra sources. However this problem has a twisted angle as for researchers in Uruguay the connections to those local resources but located abroad become tools to cope with deficits and scarcity. A professor and researcher who has suffered the problem of training and investing on junior researchers who then have had to leave because did not find opportunities in the country comments the following: “To do things here we need collaborators from abroad. So we are collaborating with people that have left the country and are working abroad. With them is that we are doing things in bioinformatics for instance. That is our reality” (Interviewee AV).

(ii) Type and purpose of interactions

A first categorization indicates two main types of interactions depending on their nature. First, one in which interactions are oriented to get access into an asset based on very short term needs, which is owned/managed by the other party engaged in it. This is the case of interactions for regulatory purposes of firms approaching public actors to get approvals, certifications, and/or rules compliance. Funding support is also part of this mode of interaction as actors approach donors/supporters to get financial resources.

These are held in a formal context, and are asymmetric: ‘producers’ approach the regulatory/financial entity, and the exchange entails a control process that leads to a regulatory output or funding. Apart from the asymmetric engagement, roles are somehow static: there is one who provides and one who asks for.

On the other hand, a second type of interactions takes place on the basis of knowledge, and/or information exchange. Interactions are more symmetric with higher levels of reciprocity, informal but still are set around short-term and transitory patterns, only for specific purposes.

Collaboration has been left to the informal side, in which personal ties are used to get specific resources, but sustained, synergistic collective efforts have been avoided. This is changing, and an important trigger for this change has been the economic crisis undergone in 2002. This pattern is extensive to all research actors.

Researchers cross over organizational boundaries in their punctual need for resources such as information, inputs, and services. When university researchers need something in particular they ask for it, but the lack of resources, combined with the multiple tasks they face beyond research and lectures, together with the lack of flexible resources that could be used to support even the minimum cost of transportation to a different school, strongly disincentive collaboration and interaction. The result reinforces the vicious circle of research isolation and duplication of efforts.

The school of sciences shows a slightly different trend in terms of its relationships with other academic research actors. It holds more linkages, and with more actors. Their relationships with firms are new, as before this school did not have a tradition in that sense. Linkages are more about providing services, running tests that are routinely performed at labs. “It is like applying routine techniques for us and it does not represent any intellectual effort or challenge” (Interviewee SM).

They have also had punctual links with NGOs: “yes a NGO came to us asking to determine the presence of transgenic elements in food. With a colleague in Chemistry we oriented two students to update the methods of inspection, but they [NGO] did not have money. What the NGO brought was two bottles of corn oil and three packages of corn meal for us to detect and assess them. [Do you charge for that?] No, nothing. Because we can do it [have the faculty to do it], yes we can; it is like a social commitment, people want to know if they are eating a trans-gene, it is a right people have to know what they consume” (Interviewee SM).

Until recently IIBCE was rather distant from the private sector. That has changed again triggered by the economic crisis in the year 2002. Some of its units are associated to the School of Sciences and for them that is very important, as a mechanism for accessing the university resources. Students are key connectors for IIBCE as they take part of research initiatives there for thesis work. In both cases, the university and IIBCE, as well as in the case of INIA, the Diaspora of Uruguayans living abroad is crucial resource with which they interact on a more sustained basis. These strong linkages provide with valuable resources that enable scientists in Uruguay to conduct their work.

LMSCI holds close linkages with the three existing firms in the area of inoculants production. Yet it is art and part: it supplies them with the required set of microorganisms for the inoculants production, and then controls their product. LMSCI strongly relies on field trials, thus it works in close connection with private farmers who agree to be part of field trials, and with INIA.

Firms have traditionally worked in isolation, disconnected from other firms. And only recently have started to approach the University. The case of the animal health company is paradigmatic in this sense. By 2004 this firm was by far the one with higher and deeper collaborative research efforts with academic groups, particularly in the University, but that same firm in 1997 held very few linkages with research organizations in the country, and heavily relied on researchers from abroad, particularly it largely counted, and still does, on a satellite of Uruguayan researchers living abroad.

Consortia of firms are missing. There is one formed by the group of firms dedicated to inoculants, which few years ago decided to create a consortium to reach export volume. This consortium only operates for marketing and commercialization in Brazil, and each firm supplies it with similar production volumes. It is not without difficulties however, that these firms face the dual process of being competitors inside the country with problems of market size, and collaborators outside. Their level of involvement and satisfaction with this joint effort slightly differs, but overall it is seen as necessity, and not much of an option.

6.4.3. Summary of the main characteristics of the institutional environment

Academic research boundaries are tight, and constrained to the smaller unit of reference. For researchers in the university and the same happens at IIBCE is that their unit of reference is the immediate division. For instance the department of Vegetal Biology in the school of Agronomy involves four units (Biochemistry, Vegetal Physiology, Microbiology, and Genetics) and one laboratory (previously called Biotechnology, now Molecular Genetics). Sometimes a single unit has more than one emphasis, still researchers tend to focus on a specific area within the unit. As an example the unit of Biochemistry, created in 1975 and comprised of seven researchers and four interns and students, has two main focuses: emission of greenhouse gases, and biochemistry of plants. Two of these researchers work on the former research focus, while the others do it on the latter. Therefore within the larger department, the only clear overlapping between units are the techniques they might have in common, rather than research goals or problems. Thus, the relevant functioning unit is the smaller one.

This level of concentration entails a problem. The problem is not the deep level of focus within the organizational structure alone, but that in the context of an already vertical structure, with low levels of inter-unit/lab fertilization. Thus the everyday life of research-making takes place in extreme disconnection from larger levels or from other units in parallel departments, and chances of cross-fertilization, synergy or even having critical mass are lost in that deepening of the way research is practice without broader/horizontal roots in the larger structure. This causes dispersion of efforts, resources and expertise. The synergy within departments is very small, and at the end efforts are duplicated, and outputs diminished, not to mention the multiplied dimension of these problems at the larger level of the university between schools.

For the most part, linkages tend to be more towards the outside, than between and/or within. For instance, researchers within a school say to engage more in linkages with actors of other (different) organizations (firms, INIA, government) more than with peers. But this applies at the sectoral level, because at the international level linkages are stronger than with any other sectoral actor, and in that case those linkages are fundamentally with peers. Within the sector, university researchers' linkages tend to be with the 'other', other in terms of the type of organization. But once the boundaries of the sector are crossed, then linkages with academic peers are strong.

Some of these problems are recognized as such and there are some attempts to implement alternatives to improve this. For instance some schools are creating a commission at the department level to overview the research proposals and look for complementarities within the organization. Beyond the intention, one common problem is that often the intention do not translate into effective strategies, and the resulting change only takes place at the formal/structural level. If before they were organized around 'majors' (*cátedras*) now it is through departments. In terms of content, and even more, in terms of dynamics, there is not any substantive change.

Firms are slowly turning to research organizations. INIA has traditionally had linkages with agro-industries and firms, and the school of Agronomy, too because both played an important role as sources of technology transfer of agronomic packages into farmers. The rest of the schools in the sector, are slowly engaging in more linkages with firms. But this are very short term, most of the times, as service-providers, and stronger, bilateral, and more symmetric research linkages are rare exceptions. Firms are also rather isolated, and do not engage in mutual collaborative efforts.

6.4.4. Institutions

The following paragraphs present the set of institutions - rules of the game- that by the way of presence or absence, configure the overall environment. IPRs are present as a law, are receiving some attention (the University has a commission on it), but are not utilized as a mechanism for protecting intellectual property. Regarding biosecurity issues, the country is also very immature in terms of regulations. But besides their weaknesses, the underlying theme is enforcement. What is the purpose of having regulations if enforcement is missing or very weak? How do actors react about these problems, and then in the next section, the focus is on how the overall environment acts and reacts particularly in terms of change.

(i) Intellectual Property Rights

Regarding the legislation about intellectual property rights in Uruguay, plant varieties are patentable, since it is a member state of the Union for Protection of New Varieties of Plants (UPOV) (Blakeney, Cohen, and Crespi, 1999). Nevertheless, the current legislation about intellectual property rights is considered insufficient (Delpiazzo and Cousillas 1998). It has vacuums that lead to ambivalences in terms of the invention's beneficiary. In some public organizations, the legal framework dismisses the role of the inventor, and only considers the ones of the organization. But beyond the written law, patents are not utilized in the sector. Researchers are not familiar with the legislation, and in many cases do not consider the possibility of protecting the intellectual property (Delpiazzo and Cousillas 1998). It is important to note that the issue of IPRs is totally marginal in the overall public discussion, as well as in these interviews. The practice of patenting is not internalized, nor exercised by researchers and firms. For agro-biotech firms, patenting is not really an attractive alternative. They lack incentives for different reasons: market size, competition rules, and associated costs and benefits.

Patents are not utilized, and in those few actors who have thought about it, or experienced it the judgment and/or opinion is quite negative. Patents are seen as obstacles for development. One firm that holds a patent in Uruguay and started the process in US but decided to cancel it posits that: "for us the issue of patents is quite disappointing. It happened to us that having patented this anti-fungi it was not a good strategy. It would have been better not to have it patented. Because [potentially buyer] firms would have rather see and then decide whether they wanted to patent it or not" (Interviewee VF).

In the case of biological systems, patents are not attractive nor they serve as protecting tools. “They are more arguable, you will loose always, they will modify three minor things and get it into use, and then go and defend that is non-defendable, it is extremely expensive, and unaffordable. It is always better to have the product made, hide the information, and have some details that make them original, and then if there is a big firm interested in that, they will patent it.” (Interviewee VF).

The most utilized protecting tool for vegetal cultivars is the registration of varieties. In Uruguay, the responsible entity is INASE. In the case of inoculants, the registration and control takes place at LMSCI. Even secrecy is not mentioned in the interviews as a utilized mechanism for protection. It was however, in the other two case studies.

(ii) Bio-related regulations

In 2000 a commission dedicated to assess the risk associated with GMOs was created (CERV). It involved representatives of three ministries (MGAP for agriculture, MVOTMA for environment, and MSP for Public Health), and from INASE, and INIA and played an advising role. The University has not been part of it, and this commission’s role has been somehow controversial. By 2006 Uruguay was in the tenth position in the ranking of GMOs planted area, and had three events approved for commercialization: Soy MON 40-3-2, and Corn BT11 and MON 810. Until 2005 the list of carried on events included Corn (two types, MON 810 in 2003 and BT11 in 2004), Soy (RR in 1998), Eucalyptus and Rice (INIA-MEC-DINACYT 2001)

In 2004 UNDP was fostering a project to establish, assess, and review the national framework on biosecurity, according to the Cartagena Biosecurity Protocols, to which Uruguay subscribed in 2001 (UNDP 2004).

Higher levels of informality in the economy, and problems like smuggling are cause of severe problems related to biosecurity. The lack of seriousness to tackle the latter problem crushes with an attempt to establish biosecurity in the country. The smuggling of animals and other types of products have already caused bio-insecurity in the country. In 2002 Uruguay got infected with the Foot and mouth disease, which was eradicated, because of smuggled pigs. The sanitary barriers are very fuzzy and not seriously protected. No clear and efficient mechanisms have been put in place to eradicate this problem. An agronomist explains the extent of this issue and the lack of protecting measures: "Any country protects itself legally from incoming germplasm. We do not have a legal protection that says that incoming seeds should be proved clean and healthy. Anything can be brought into the country. And in fact many times has happened. We only have a structure of quarantine, new in the country, that requires taking samples and then testing them. But because at the same time the country is poor and we do not have availability of all the set of necessary reagents to do the testing, there are escapes and problems, and still there are things that are not tested. If we would get an incoming pest, and multiply something that is sick, we do not have legal tools to blame the counterpart for that. We are very unprotected" (Interviewee RF).

(iii) Sectoral framing institutions

Game rules not always follow the written script. The gap between de facto situations and the norm is often large in Uruguay. Rules are very inadequate, obsolete and unfeasible to follow given their outdated character. It could be expected to have some groups actively demanding rule change, exercising their *voice*. However, small firms do not have lobbying apparatus, and tend to have a low profile and act quietly: be as invisible as possible, and adjust towards the lower end, avoid being different, furthermore avoid showing signs of success. Keeping a low profile is a survival strategy: it is better to avoid being under somebody's eye, particularly as a strategy to avoid being too visible for government and thus interfere. The strategy is then to be as invisible as possible, and remain at the margin to avoid potential harm.

In Uruguay, rules are not clear, and the limits of what is and is not allowed are unknown. An academic researcher at the University states: "There is total lack of support for providing information. For instance a firm comes and we [researchers] do not how to do for it to make the donation, or what type of agreement we can sign, we do not have legal support. We do not know anything. For instance they come asking how much do we charge for doing X, I ask ten people around, from the dean to my colleagues and we do not know how to value it, nobody has any idea." (Interviewee MB).

The co-existence of dual, contradictory roles is also problematic. This is the case of LMSCI which faces a conflictive dual role: between controlling and researching. They are not equally important in terms of the number of dedicated personnel to each one of these tasks. For the research role, it faces some difficulties because of its belonging to the Ministry of Agriculture. Its research is applied and requires to be closely tied to field trials. "A very interesting new area we want to pursue is that of endophytes (bacteria that fixes Nitrogen and lives within the plant). But we cannot study rice endophytes if it is not in rice fields, under real conditions of rice growing and farming. We are not part of an organization compatible with this work, maybe with the controlling role, but not with the research one." (Interviewee ML).

6.4.5. Policies

The next paragraphs discuss the characteristics of the policy component regarding the following categories: (i) what are the resources (means) put in place related to education and research, what are mechanisms and strategies; (ii) what are the incentives to engage in learning; (iii) what are the education and training system mechanisms to include those who are outside, facility to circulate and move around, and between functions; (iv) what are the mechanisms to access knowledge and to have it flow between universities, and other actors; (v) are there incentives to recycle, forget and remember, and if so, what are those; (vi) what are the mechanisms to stimulate mobility across organizations, and arenas; (vii) what are the mechanisms that policies have to enable changing and redefinition; and, (viii) is there social participation and inclusiveness.

(i) Means to learn

Innovation has not been an institutional pattern of the Uruguayan society, as mentioned above. There have been successful innovative stories but that remain at the individual, anecdotic level, without becoming an institutionalized routine. Government investment on S&T has been extremely low (0.3 percent of GERD, 2000-03), and private investment has been even lower[86] (RICYT 2006). The lack of policies has contributed to this invisibility, and there has not been a policy actor willing to take this issue into action, nor anything like policy entrepreneurs that could bring this issue into the policy agenda. These issues have fell into total vacuum. Lack of policy has ruled, and this domain has

[86] Private investment in 2002 accounted for 46.7 percent, while government was 17.1 and higher education was 31.4 percent. These figures are tricky because in Uruguay government and higher education is almost the same thing in terms of the source of final investment, which is government. And also the private component is misleading, because these are mainly public enterprises, which are the largest companies in Uruguay in terms of R&D.

been dominated by spontaneous emergences in the best case, with some events of short-term *reactions* to already ongoing situations.

The overall S, T&I policy arena in Uruguay has been characterized by the absence of policies rather than by their presence, or sometimes by their destructive presence. Beyond the financial support for the University, which is a never-ending battle, the policy arena only entails individual organizations acting on their own. There is still a long way to go to have researchers taking strong part of firms in this field.

As in many other Latin American countries, Uruguay has its S&T council, created in 1961 oriented to manage and allocate funds, mainly those from IADB loans to enhance science and technology in the country. Even though this council has pertained to the orbit of the Education and Culture Ministry, one main feature of the education system as a whole, from primary to tertiary levels, has been its disarticulation and fragmentation.

Even evaluations of ongoing programs in public organizations such as CONICYT have only existed because of donor requirements (IADB). The same has happened with the restructuring attempt of this organization at the beginning of the 21st century, but again it was due to IADB requirements. The erratic attempts are so large, that DINACYT which was supposed to be the policy entity for S, T & I policy did not involve a single person trained in an innovation policy related field (Bértola, Bianchi et al. 2005). CONICYT lines of funding include: (a) research projects and researchers re-insertion; (b) promotion of scientific vocation and awards; (c) postgraduates and renovations; (d) internships, courses, workshops, events, and conferences; (e) scientific associations; and (f) research projects linked to the productive sector.

Agro-biotechnology is not a policy issue nor has it been appropriated by any policy actor. Initiatives are internal to organizations such as UR or INIA. Funding mechanisms for this area were formally settled in the restructuring of CONICYT in 2002, but the crisis undergone at that time impeded any substantial change in this sense.

The traditional breadth of the knowledge bases of the Uruguayan education system is what enables the bridging with modern techniques. Because researchers have the good fundamental bases, they are able to overcome the scarcity and outdated techniques and rapidly catch up with modern ones. An interviewee describes the issue in the following words: “The truth is that the humanist education we used to have in Uruguay has given us a wide knowledge breadth that enables us to think ‘why cannot we apply this into that problem’. If we would have access to information, even if the amount of ‘kilos’ would not be there, and would not have to chase and be running behind money so intensively, which is exclusively for the people who works not for those who coordinate the project, then things would be really different” (Interviewee PQ).

(ii) Incentives to learn

Incentives to learn are largely missing at the sectoral and national levels. There are no scholarships or any other type of incentive to learn, and to complete learning processes. Even though university access is unrestricted and free, students have to work while studying to generate an income.

(iii) Capability to learn

Education and training constitute a rigid funnel-type of structure. Formal education and training is hierarchical. There are broadly three cycles of education: primary with six years of education; the secondary level which includes four elementary years, and then either two more years with a diversified structure and alternative disciplines, or the technical-professional level. The higher level of education includes two main options: the tertiary education (Teaching and Technical Careers) and the University education, which involves the single public university and the four private ones. Mobility between these two options is not possible.

The whole education structure functions as a funnel, in which once a path is taken it is not possible to move or change without going back to the beginning. This funnel type of process starts at the end of the fourth year of secondary in which the first choice is between the technical-professional, and the formal cycle. Within the latter the student must choose between three alternatives (Humanities, Biological, or Scientific) that in the next year (last year of secondary level) become six (each one opens up in two). In turn these different alternatives connect with distinct university careers. That is, at the age of 16 (average) the student begins a process of decisions regarding the future studies and career that do not inter-connect horizontally, and furthermore open up into branches that each time enlarge the distance from the original trunk.

This lack of flexibility also applies to the university careers where there is not much flexibility or horizontal programs and interdisciplinary programs. In spite of criticisms and acknowledgement of the problems associated to this structure education reforms are largely resisted across the education spectrum.

(iv) Access to relevant knowledge

Access to public university is open and formally un-restricted, given the absolute free character of the university and that there is no tuition or payment of any kind. That is at the formal level, though it is subject of discussion because of the informal filters put in place in some schools.

(v) Remembering and forgetting

Remembering and forgetting are not fostered nor considered positive mechanisms for learning. Technical education is fundamentally in the formal system. The university does have some short courses for graduates on specific issues (professional courses). Change is not a priori stimulated, on the opposite change is condemned in many cases. As illustrated above the formal education system does not facilitate change and mobility across alternatives, nor the university does it.

(vi) Opportunity to learn

For the most part encounter is missing, and part of it has to do with the difficulty to see each other. These actors do not constitute collectives. There are not intermediary organizations helping them out with bridges and synergies. The University does not have a functional technology transfer office, or something alike. Some schools have it. But firms find it difficult to know who does what, or what is being done in the university, and the university is not contributing to make it clearer.

(vii) Policy and (viii) social learning

Policies rarely include mechanisms for ongoing revisions and feedbacks. Again here it is not clear that this is perceived as an important mechanism for learning. Social participation is very punctual depending on the matter. Ex post evaluation is carried on particularly for the policies and programs involving international donors or funding. IADB loans for instance frequently generate evaluations about programs in CONICYT for instance. But they remain part of the organizational memory and reports evaluations are not brought into changes at further levels of practices and habits of the organization/policy. At CONICYT for instance most changes are driven by IADB requirements. Local demand for mechanisms leading to larger evaluation efforts and ongoing change, transparency and accountability is still very low. In any case, social participation is absent from sectoral discussions.

6.4.6. Bringing back the institutional environment

(i) Institutional coherence

The system entails some institutional inconsistencies that are hanging over and hindering a more flexible, synergistic sector. One of these inconsistencies is the problem of funding. Public research funding is reduced to three main sources, one within and for the university, another managed by CONICYT based on IADB loans, and a third one coming from INIA. The former is for researchers within the university, and some of that funding is to promote linkages with the productive sector. CONICYT also has lines of funding dedicated to same purposes, and firms could apply to these funding. However, the experience with and the opinion about these funds have not been positive. On one hand, the outputs of these investments are not evident, and those investments have not followed a strategic plan to enhance the country's capabilities. Several interviewees have pointed out this issue of incoherence between where/what are the needs for more resources and the actual investments. The reasoning behind the criticism is that there are resources being spent but in areas or issues that do not seem to solve the problem or to enable accumulation of any sort. So for instance, there is the problem of junior researchers leaving the country because of the lack of money to retain them, and at the same time there are resources spent here and there in a scattered way and it is not clear what are the results and benefits of that spending. "How much has the country spent.

How much did it spend with the CONICYT-IADB projects? And where are the outputs? Before spending we need to think what are the outputs and outcomes to be achieved. That should be thought before spending. In Uruguay there has been a lot of money invested, but there are no clear results to be shown." (Interviewee AV).

Furthermore, the incentives to present a proposal are negative for small firms considering the time frame that these processes involve. The management of time, both for assessing proposals and for delivering the funds, has been troublesome. An evaluation and selection of proposals could take close to a semester, and then the delivering of funds is totally unknown. But also the evaluation criteria do not seem to be too clear for firms. One interviewed firm illustrated part of this problem. A group of firms came together to apply for a project in the context of a call for research funding by PDT. They proposed to scale up the level of exports which conform a consortium. Their proposal was not selected, because according to the evaluating committee it did not fit with the innovation requirement of the call. "[T]he call had as one of its items, the scaling up and repositioning of firms and productive processes. We presented a proposal within that context, to scale up the consortium production and increase the export volume. The technical evaluator response was that he did not understand where was the technological innovation in our proposal given that those products were already in the market. I think he never understood what was that component of the call about. His response made us realize that it was so distant from what we thought was the call about, that we did not want to even argue about it." (Interviewee CA). Time is a very scarce and costly resource for these firms, and in the country it is a key element in the process of applying for contestable funding. Funding and public contestable calls are generally seen by firms as negative incentives: benefits are unclear, and unattractive compared to the pain and high costs associated to participate in the process.

Furthermore firms do not count with suitable credit lines or seed capital or any type of innovation suitable form of capital. Besides, there are not clear incentives for firms to invest in R&D. The only mechanism, a donation law, is sub-utilized by firms in part because it is largely ignored as a resource and/or because it is perceived as too complicated and time consuming.

For researchers it is an ordeal to have many tiny national sources of funding is extremely low by all standards. The effort of getting one extra source is marginal in benefits but significant in terms of time and workload. Moreover, resources are small *and* extremely uncertain. As explained by a researcher: "We try to keep going with small collaborations. With a Swedish collaboration we get some reagents. With a project we won with PDT we get other reagents. Then the PEDECIBA aliquot is another small resource. I also do technical advice to Firm I and that also adds. [That is strictly regulated, and] I personally do not get anything [money] from that. It comes through the general accountant and then we use it in the laboratory. Once I asked for permission to get funds from some technical advice I did, but apart from having it evaluated here and there at different decision levels, it took me from July 2002 to March 2003 to get US$400 which already were in the system. Never again." (Interviewee MB).

Researchers cope with a meager budget that hardly covers salaries of senior researchers, no new positions are opened, and junior researchers can only be contracted based on resources got from research projects, which are often short-term, for concrete and constrained goals, and with uncertain continuity. Upgrading infrastructure also depends on projects. International projects, donations and/or loans account for most of the existing equipment and infrastructure. External funding is what makes the difference between short term and mid term research lines, and between keeping equipment updated or out of date. But even in that front, it is getting more complicated because urgencies and priority setting has changed in the agenda of international donors, and now is not so clear that Uruguay classifies for them. The focus is now either on poorer and the poorest countries, or in Eastern European ones, which have come as ‘substitutes’ in the donors’ agendas. A crucial issue here is that all those resources that used to be useful and valuable are becoming out of date. But if these resources are not constantly updated then the cost of getting them functional is higher as time goes by. And research groups are very vulnerable in their reliance on international funding for research infrastructure.

Another source of inconsistency is related to import requirements and procedures. They do not fit with what an agro-biotech sector would require to dynamically operate. Molecular biology, and other biotechnological techniques require different reagents that are imported from US or Europe. A firm in this area would typically need small amounts of several reagents. In Uruguay, red tape is a crucial constraint at the time of importing. An interviewee points out the existing difficulties: “Here there is a problem. For example for something that originally costs US$ 50 and needs to be transported in dry ice, has to pay a freight that costs 300, has to pay a custom procedure that costs 150, and taxes for 100. The final cost is instead of 50, US$650. And because nobody likes to pay 650 for something that costs 50, we say let’s wait until I need other things and then bring them together, because the transport costs are similar. But the problem is that the decision of waiting makes the whole process slower. And this applies to us or to our supplier here, who would do the same and add our purchase to other customers’ requests. So he must wait and in two months we will get the enzyme we need. If we have to wait two months for that enzyme, and another month for another input, our life as firms is gone like that" (Interviewee GC). Five years ago there was a prospective study on biotechnology. At that time one suggestion was to create a 'bio-techno-tube': a mechanism that would enable 'in time' and 'in price' access to inputs without suffering those differential obstacles of being located in a small country in the South. The alternative suggested consisted of having "…custom procedures facilitated, and taxes (tax free), and 52 freights per year paid (once a week). It is very important to have the first two years supported by some project. So that mechanism would cost US$ 15,000 x 2 years. And then after two years of having that practice already set, if all the laboratories in the country pay a yearly fee, we keep the mechanism going. This would substantially increase the potentiality of the sector"[87] (Interviewee GC).

Biotechnology firms play in a foggy environment. Competition rules are unclear and uncertain. And lack enforcement. The grey zone of ignorance between what is and is not allowed, what are the rules, and under whose responsibility they are is large. What are the limits between public and private, how to balance what public entities such as the University does as service provider, and the private sector? Who is in charge of controlling these issues? Information is not considered a universal right. Acquaintanceship is a very valuable asset that could make the difference between getting the right information/signal or not. Many *de facto* situations are reproduced by the way of practice, but do not undergo a debate or evaluation. It is not clear what are the rules, their extent, and who takes care of enforcing them. Private and public are fuzzy concepts for

[87] According to the interviewee this mechanism was already suggested in the context of a prospective study about the biotechnology sector, conducted in 2002 by INIA, UNIDO and the Presidential Unit Pagliano, D., M. Mazzolla, et al. (2002). Biotecnología en el Sistema Agroalimentario [Biotechnology in the Agro-food system]. Montevideo, INIA-Presidencia de la República-ONUDI., and was accepted as an attractive tool, but it has not been implemented

competition. The public sphere predominates and by far concentrates research efforts and resources as well as the demand for research in the hands of the public productive sector, i.e. public enterprises such as telecommunications, water, etc, which are not directly related to this sector. The university is public, and most of its budget provides from government funding. IIBCE is also public and relies on ministerial budget. INIA in turn, is a mixed organization with public and private funding (levy-based). The competition arena is fuzzy; it involves organizations of very different nature which compete under different rules and to some extent, in the limits of legality. There private sector *per se* is small, firms are few and competition is scarce. Within this area of study there are not so many firms doing the same things. However this description is different if the criterion is more flexible, involving public entities which also offer biotechnology services. The school of Veterinary for instance, offers some services regarding embryo-transfer. The National Institute of Seeds is the public organization committed to controlling the seed industry, at the national level. That is its main mission. Nevertheless, it also sells testing services for seed companies. This dual role of being the national controlling agency, and a competing lab in the market of testing services, is somehow conflicting. Competition of this type, in a small market, goes against those small private laboratories, which apart from competing in this unclear and distorted market have no financial support (public or private).

How to keep a private sector in a small market in 'competition' with a public sector, but under differential conditions? At the same time, how to keep the public sector, which needs alternative resources and funding, benefit with some (marginal) involvement in an area they have capacity and naturally work on? As pointed out by an interviewee: "the University budget is small and scarce, in an attempt to increase its budget the Vet school offers some services that distort the market. Their wages are paid by the central University budget, their equipment is often purchased through research projects, so the fees they charge for their services are lower than those from the private sector who has to cover larger fixed costs. There is also a problem of business ethic which has to be respected and taken care." (Interviewee GC). In this person's view, the solution is to have different sources of capital, and funds to create businesses. This should be the main policy, to stimulate the creation of firms, so that all play with the same rules. "It is easy to compete if you are protected by a university or incubator, where you do not really have to pay all the costs. It is different if we are all outside without protection" (Interviewee GC).

(ii) Institutional thickness

The variety of organizations is constrained in type and reduced in number. One research university, one semi public research agricultural organization, and one public research centre conform the research side of it. Then the sector involves a group of firms, around a dozen of them, which for the most part, have their already established trajectory. They concentrate in the area of plant- and animal-based biotech. Few of them have changed the scope of their products, but most of them keep doing what they have been doing since their foundation. Interactions are scarce, punctual, and bilateral. In general, firms are weakly tied between them, and with other actors.

Regarding the emergence of coalitions or guiding bodies, the sector had an association of biotech firms, which after an intense initial impulse, has remained almost inactive, unless a particular event calls for it. AUDEBIO, the association of biotech firms, has neither played a role of interlocutor with government.

In Uruguay the private sector has been very weak as a collective, rather disarticulated with also loose corporate interests, which have traditionally been co-opted by political parties (Caetano, Rilla et al. 1985; Caetano 1991). Furthermore, the business community in Uruguay has been opaque, rather invisible and as a collective has not characterized by pushing forward modernization and development. Rather that has been the traditional role of the State. These patterns fit into Evans's (1996) and Hirschman's (1958) characterization of the institutional environment of countries with late capitalist regimes (Evans 1996). According to these authors, they lack institutions able to absorb or distribute risk, and individual capitalists do not want nor can assume it. Then it is the State that must respond and act as a substitute entrepreneur. The lacking ingredient for Hirschman (1958) is not capital, but the entrepreneurial capacity that is the willingness to risk the extra surplus in productive activities (Hirschman 1958).

Farmers associations are not collectively engaged in participating or demanding agro-biotechnological developments. In Uruguay, farmers' behavior characterizes by risk aversion, and short-term rationale with a rather passive attitude in terms of innovation, and strongly reliant on government support, as it has been the attitude of the productive sector in general. The agricultural trajectory has been dominated by commodities production, high vulnerability, uncertain prices and markets, lack of suitable credit and financial support, reinforced by the absence of innovation policies which have in turn, prevented higher commitment to technological development. Agriculture has been concerned with commercialization, diseases, adoption of some technological packages and credit lines. Innovation has not been part of default view and frame about agriculture in the country. The institutionalized undervaluation of domestic innovation and technological development is reinforced by a traditional pattern of a 'ready to import' technological attitude, starting by government procurement that has systematically prioritized foreign suppliers over local sources. This environment has seriously harmed national technological developments, not only because of the absence of stimuli to local innovations but also because of existing obstacles that some projects have had to overcome to make innovation happen[88].

(iii) Institutional cohesiveness

The list of failures and aborted innovations because of the difficulty to change and adapt existing regulations is significant in Uruguay, not so much because of the number of cases, but because of the impact of those cases on the broad environment and attitudes towards risk and innovation. The current regulatory framework related to agriculture is based on laws and regulations developed during the 1950s and 1960s. At that time those were very innovative and led to fundamental achievements in different respects, an important one was sanitary. During the decade of the 1960s there were some clear and almost consensual policies on agriculture. Beyond the specific achievements, what was clear was that there were some main issues that should be solved (sanitary, and regulatory) and then efforts were oriented to those. That sense of shared visions on some elementary issues has been lacking in the overall policy environment.

That phase corresponds to a time in which visions were shared as well as the common and articulated efforts between policies, legislations, enforcement, innovative professionals and firms, and responsive farmers. At that time Uruguay decisively introduces sanitary legislation, makes vaccination for some animal diseases compulsory, as well as sanitary certificates, and a set of campaigns against those diseases are implemented, particularly those that were key to access export markets. Also, the individuals behind these different spheres (policy, business, government enforcement agencies) were colleagues and peers from the university. They belonged to a generation

[88] See Bortagaray (2004).

that had tight ties with professors, who were respectable professionals, well connected inside and outside the country and who had the advantage of having those positive records in their resume. They were carrying on those changes, and were doing so because of a very favorable and supportive context with visible positive results. They were able to make a difference in terms of the values transmitted to students. They could tell about successes and the importance of professional responsibility, respect, and collaboration for those achievements.

Associations are weak, and reactive: when there is a specific event or need then they attempt to express a shared voice, which does not translate into a collective. This reactive-based character on a discontinued basis prevents any chance of building a collective-based trajectory at the sectoral level. But this reactive feature is common to the broad institutional environment. There are not plans, nor programs and efforts are erratic and punctual, mainly reactive to already existing problems. The following quote illustrates part of this issue: "In this country we do not plan, we do not know how to plan, I'm not saying only a 5 years plan, but even for next year. Did you see what has happened with meat? We work hard to get rid of diseases that prevent market access like the foot and mouth disease, and to get access to new important markets. Once we get access, then what happens is that the next year we do not have enough volume of meat to reach the quota because there is not enough cattle prepared for that" (Interviewee RF).

(iv) Inertia and rigidity

The 'system' is characterized by persisting structures and institutions, even if they seem to be dysfunctional. This is not only key feature of the agro-biotech sector in particular, but of Uruguay in general. Since its foundation, Uruguay has been tied to a buffering role, not only towards the neighboring countries but also as a distinctive feature of its society (Real de Azúa 1984). Continuity and invariability are embedded in the societal and institutional functioning. Change is conceived more as aggregation and adjunction to existing elements rather than as replacement or elimination. Change at the formal level is incremental and cumulative. It hardly occurs that one organization is substituted by another one; change takes place only by adding up appendices that grow around existing structures. Furthermore, within the public arena change tends to occur at the formal level, while change is resisted at the more functional level. No new shapes appear in this diagram, and old ones survive, even if only at the formal level more than at the functional.

Rules and regulations have also been kept, even if in practice they are obsolete or obstacle further development. There are few cases in which reality has had to adapt to an outdated law, leading to the abortion of an innovative and successful product[89]. Inertia often becomes rigidity. Bypassing the law is a regular routine in the system. Difficulty to change is such that even if it is a shouted secret, laws and regulations tend to persist without formal change. Therefore the gap between the formal and the concrete appropriation and put in practice is considerable. The lack of an enforcement system reinforces and makes this practice possible.

The University is a very large and heavy structure. Democratic negotiation and decision-making has been one of the pillars of the university. Decisions often go through different instances and levels, within schools and in many cases through the hierarchical system up to the rector. To make it more difficult, decision bodies are also large, heavy and centralized structures, which prioritize details and procedural democracy over efficiency and expedited results.

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[89] See Bortagaray (2004).

In the University changes in practices and structures are very difficult even to discuss, much more to reach the implementation loci. Overall there are negative incentives to open new positions, make openings and calls because of these processes, and it is much more difficult when the issue at question is new and have no precedents. These structures are resilient, and in general against change and novelty. Change and transformation are seen as disruptions questioning their permanence and tasks. They are rooted on principles of procedural democracy rather than on substantial ones.

(v) Extent and carriers of change

Change follows a peculiar path in this sector. On one hand, many regulations and institutions are old, and belong to a different country. Still they might entail some useful approaches, but require revision. Crucial definition on issues such as S&T&Innovation have not permeated the public agenda, less any course of action. The policy has been the lack of one. When change takes place is more procedural than substantial as the first reaction is to change name, or structure, or even better to create a new one, but not to change patterns of action. There is rarely a second instance: rather there is a new wave of change that leads to a different area, or policy issue. In the early 2000 CONICYT was restructured based on a new loan of IADB, but fundamental change was not attempted. Change takes place by attempting a duplicative approach: create a new one is less costly than re-orienting an old organization with its own dynamics, vices, ways of doing things, etc. To avoid negotiation, new structures are added to existing ones. But they are not really combined nor converted. They are set in an adjunct way. One outcome of this in-between way out is a unclear state which might act as an exit to avoid the cost of substantial change. Something similar has happened with the education reform of the last decade (only primary and secondary-wise). Many of the institutional drivers of the reform were carried on through parallel structures, not from within existing structures and institutions, but in parallel ones (Filgueira, Moraes et al. 1999).

(vi) Persistence and stability

Biotechnology companies became associated in 1987 through AUDEBIO. This association emerged in a context when government itself was actively recognizing the importance of biotechnology: in 1986 a national committee of biotechnology was created by the Executive, coordinated by the Ministry of Education (MEC), and fostered by a group of scientists, business firms and government agents. They defined a set of areas of interest, including agricultural production; food-related technology; human, animal, and vegetal health; chemical industry; environment; and energy. Within agricultural biotechnology they identified different areas of specialization: vegetal, animal, human, bioprocesses, and agroindustry-related biotechnologies (INIA-MEC-DINACYT 2001). But those efforts did not persist, and the committee disappeared and did not operate after those first couple of years. Somehow similar was the destiny of AUDEBIO, though to a different extent. AUDEBIO started with active involvement, and an important associational role, in that context of government attention and recognition to the field. Few years later in the early 1990s some agro-biotech related companies were recognized among the hundred innovative firms in IberoAmerica coordinated by the IberoAmerican Program for S&T Development (CYTED). But gradually AUDEBIO remained more of a formal instance, only active when there were instances that required its emergence. It never disappeared, and its members refer to it as an alive, but there is no content besides its name. One of those instances in which it left the nominal stage was in 2001 for organizing a professional congress on biotechnology in Uruguay.

6.5. Agro-biotechnology capabilities in Uruguay

This section analyzes technological capabilities through: skills, processes and resources. With regard to skills, the focus is on: (Sa) what are the educational backgrounds of the individuals behind the sectoral organization, and what have been their trajectories concerning previous work experience and mobility; and, (Sb) Areas of application, actors involved and knowledge structure. Processes refer to: (Pa) mechanisms and strategies implemented to access knowledge. And resources in turn, have to do with: (Ra) infrastructure; (Rb) R&D investment and funding; and (Rc) future regard: research and productive agendas.

6.5.1. Skills

(Sa) Education and experience background and trajectories

In Uruguay studies' backgrounds include: agronomy, quality control of seeds, plant biology, biology, microbiology, veterinary, biochemistry and neurochemistry. In Uruguay researchers in the sector have pursued their postgraduate studied in countries like Sweden, Denmark, France. Firms in that country's sector involve agronomists, biochemists, microbiologists, biologists, virologists, and molecular biologists.

For the most part researchers' experience is constrained to the academic area. Geographic mobility takes place mainly for postgraduate training of scientists. A serious current problem for the country is the loss of skilled human resources. Individuals are trained and when they are skilled and starting to contribute to the group they leave the country looking for better opportunities. A researcher who has trained several groups highlights the problem as follows: "This might be the fourth trained group that leaves. This seems to be a more stable group that wants to stay, but I have had whole groups gone abroad. In 1993 I had a whole group gone after 10 years of training. Because the worst thing is that those who leave are the most prepared and trained individuals. We are throwing away our resources. Each one is a potential Einstein in a way.[…] They help us in whatever they can but then time passes and the ties get loosen" (Interviewee JI).

The next table illustrates the interviewees' backgrounds.

Table 6.2. Uruguay: Interviewees' backgrounds paths

Veterinary (Argentina and UR) → work at family firm and created new initiatives within same firm
Agronomy → work at local government (support to farmers) → part time work at firm S→ started PhD (Scotland) while working and supported by firm S→ continue to work at firm S (full time as technical advisor)
Biology (UR) → working at family firm → PhD in Chemistry (Uruguay/Australia) → work at family firm and part time researcher and professor at Chemistry School (UR)
Engineer → manager of family firm → studies Business administration → continues to manage family firm
Chemical Engineer (UR) → technical director of R&D department at a firm
PhD in Plant Biology (Sweden) → Researcher at laboratory of Molecular Vegetal Biology and professor at Sciences School (since 2000)
Agronomy (UR) → professional work at seed production and commercialization company → decided to create own firm with two more partners (since 1984)
Master in Biology Sciences (UR) → researcher in Neurochemistry at Public Research Institute
PhD in Neurochemistry (Sweden) → Neurochemistry department at Public Research Institute (since 1983)
Agronomy (UR) → Master in Soil Sciences (Brazil) → researcher and professor at horticulture area, Agronomy school
PhD in Biochemistry (France) → researcher and professor at area of Biochemistry, School of sciences (since 1986)
Master in Agronomy Seed quality control (Denmark) → part time professor at Agronomy school → created own firm
PhD in Molecular Biology (Uruguay/Spain) → researcher and professor at department of Vegetal biology, Agronomy school (since 1975)
PhD in Biology Sciences (UR) → researcher and professor at Vet School
PhD in Microbiology (UK) → Researcher at public research institute (since 1988)
Agronomy (UR) → board president of national seed institute since 2003
PhD in Biotechnology (US) → researcher at INIA
PhD in (Italy) → worked as researcher in Italian company → moved to Uruguay and created own agrobiotech firm in Uruguay (since 1980) → in parallel has participated in many consulting initiatives in Europe and in the region

Source: based on interviews

(Sb)Areas of application, actors involved and knowledge structure

Plant-based biotechnology is a very relevant common research and production area in the three countries In Uruguay the sectoral area of application involves plant-based biotech, but shares the importance with animal-based biotechnology, also fundamental to the sector. They both co-exist and have their own references in terms of research groups, resources, and skills.

In Uruguay agro-biotechnology concentrates on plant biotech, and animal health, though there are some (very) incipient attempts related to agro-food and environmental management. Uruguay, together with Australia and New Zealand, is one of few countries where leguminous plants are massively inoculated with bacteria found in the soil (Rhizobium), which capture the nitrogen from the air, fixating it to the plant and soil, which in turn interact with leguminous plants in a symbiotic way[90]. The original interest on and application of inoculants emerged to improve cattle production due to the lack of nitrogen and phosphorus of the country's pastures. This technology, adopted from Australia and New Zealand, was aimed at improving the quality of fodder leguminous plants, yet it went beyond that original field of application and became successfully adopted in crops like rice or, more recently, in soy, which are grown in a mixed system of rotation between crops and cattle.

Three firms supply the domestic needs of inoculants, while also export to the region. LMSCI, a lab within the Ministry of Agriculture and Livestock, is in charge of controlling the quality of their products for both the domestic and export markets. That same organization is responsible for defining and providing the accepted micro-organisms to use for their production.

Another area of plant-based biotech is the micropropagation of plants and seeds. There are few firms dedicated to propagate fruits, potatoes, and horticulture. There are around a handful of them. In some case they do it to satisfy their own needs (two potato

[90] For an analysis of this technology in another developing country, see Hall, A. and N. Clark (1995). "Coping with Change, Complexity and Diversity in Agriculture -The case of Rhizobium Inoculants in Thailand." World Development **23**(9): 1601-1614.

firms), while the rest reproduce plants and/or seeds and then sell them to nurseries or directly to farmers. In this case the controlling organization is DGSA within the Ministry of Agriculture and Livestock. For seeds registration, control and certification, and for the assessment of cultivars needed for their later registration, the agency in charge is INASE, the national seeds institute. In this area the main research actor is INIA. It is so in terms of its visibility among the interviewees, because of the updated resources it has in terms of funding, infrastructure, and specialized and trained researchers while concentrating in one (large) organization research on a wide spectrum of crops studied. Biotechnology is approached and framed as a horizontal platform potentially enabler of all the research areas, particularly in the context of INIA's research organization around crops. The Agronomy school is a very relevant research actor, not lesser important but playing with different attributes. It has very different type and organization of resources. These are dispersed across departments and labs; less modern equipment, but a totally different scale and depth of knowledge resources, and areas. It conducts more basic research that INIA does not to the same extent, while also entailing very applied research areas, with an important agro-extension role in issues like soil management, and agronomic practices of different crops. The school of Sciences is also a key player, but at a different level. It has broader and deeper cognitive tools and resources compared to the other actors, but they are less applied, and lack critical mass with experience on applied research problems. They constitute a reference for all other actors, in terms of knowledge bases, international resources.

In Uruguay animal health is one of the leading areas of agro-biotechnology. The production of vaccines and medicines to combat animal diseases such as Foot and Mouth disease and Brucellosis has been a key industry in the country. Few firms but with longstanding respected trajectory are given the merits of quality and responsibility in combating those diseases with key implications both in terms of productivity and for penetration of international markets of cattle, meat and dairy products. Biotech has also been a key input for the dairy and wine industries mainly around fermentation techniques. Overall agro-biotechnologies are mainly utilized for research and development in the areas mentioned above. The production of agro-biotechnological goods and services is more marginal and constrained to more traditional products like inoculants, micropropagated seeds and plants, transferred embryos but also to newer ones like diagnosis kits.

Only few of the interviewed firms had a positive response to the question on whether they were exploring new areas of research and development, or were thinking of doing. These are the more dynamic firms, which are looking at biotechnology as an investment in their future. These relate to animal health, wine, and micropropagation of non-traditional plants (blueberries, strawberries, olives, etc), and the one providing services in molecular biology. Nonetheless, if looking at one of these firms simultaneously with two of the firms in the area of inoculants it is noteworthy their opposite paths regarding the focus on biotechnology. Inoculants are biotechnology, second-generation biotech, and these firms have been doing that since they were established. They started doing that, and that was their core strength. In the case of the firm in the field of animal health, biotechnology is increasingly attractive for them: “what we are building is a firm oriented to the biological area and not so much pharmacological. There are two main markets: one the biological (with vaccines, reagents, diagnostic kits, and all that set of things relying on a biological product), and the other is pharmacal, that is an active principle that is combined with different solvents, and is an anti-parasite. We said let's do innovative formulations for punctual needs that do not exist in the market, because in the other [pharmacal] we compete with all the international companies, and the group of national firms that appear and disappear." (Interviewee EL).

However, two of the firms in the inoculants industry consider that they need to follow the opposite path, from inoculants which are biofertilizers, they have had to move into agrochemicals. They are following an inverse path compared to the expected trajectory along the current 'biotechnological paradigm'.

Thus, comparing these two types of firms, the former is more dynamic, and has shown an incredible ability to re-position itself after some devastating initiatives[91]. For a third time they have had to reposition themselves and widen their portfolio and knowledge base. While in 1993 they were totally dedicated to foot and mouth disease, now they have no resource dedicated to that disease, but have new research areas, including a project on (human) Anthrax. For the first time they are going into a human health issue. So, what have been some of the decisive factors for that change. They have always been heavily counting on a satellite group of Uruguayan researchers in the world. Their associational capabilities have anchored them in broader research agendas, and have led to the emergence of new opportunities that in turn enabled them to materialize their skills, resources and processes. The lack of flexibility of the sectoral institutional environment led them to an almost bankrupt situation from which they have recovered without counting on any financial resource other than their own.

The latter firms have specialized in those biofertilizers and have been successful at that, but have constrained their production area and have been relatively isolated from

[91] See Bortagaray, I. (2004). La relación entre tecnología y política en la erradicación de la fiebre aftosa [The relationship between Politics and Technology in the eradication of the Foot and Mouth Disease in Uruguay]. Trabajo e Innovación en Uruguay. E. Massera. Montevideo, Trilce.

researchers and hybrid organizations. According to the interviewees, it is difficult to think what new areas or initiatives they could work on. An interviewee refers to the problem as follows: “When we started it was only biotechnology. Around 2001 we started with agrochemicals. My father, who started the firm and was a chemist, did not want to know about selling agrochemicals. Today it is 60% biological products, 40% agrochemicals, and if this trend continues it will be 10% biological and 90% agrochemicals. Besides we used to produce an artisan product in some cases, and today cannot compete with that. The problem is that people do not trust biological products because results are not as clearly and rapidly seen, and we do not have any State support, there are no regulations. Here you do not have how to register a biotechnological product. We worked on the research institute to register a Trichoderma as a fungicide with a native cepa. Few years ago (around three) we presented it to the Ministry, and there it has been ‘sailing’ around the cloudy offices because there is not a normative that allows you to register a biological product. But if it is not registered people does not want to buy it, and then in the meantime other researchers came to the same organization and did not know about the previous work we did with them, and started working on that and all our work was lost. Here it is a continuous fight with wind mills” (Interviewee IL).

6.5.2. Processes

(Pa) Mechanisms and strategies to access knowledge

Mechanisms to access information and knowledge are relatively similar for firms and academic researchers. One difference though is that researchers in the country have close ties to a large number of Uruguayans researchers living abroad, as many of those have been trained and worked with the researchers who stay in the country. So the community of researchers living abroad is an important source of knowledge and learning for colleagues in the country.

Firms access knowledge through Internet, participation in seminars and workshops in the country and abroad, and through training. Firms have tended to search for knowledge outside the country. Foreign contacts have been crucial, both foreigners and for few firms, the Uruguayan *Diaspora*. One mechanism is just sending questions to experts abroad, waiting for their reply. One firm had a very good experience of consultation and collaboration with a Canadian firm. The process started by sending a fax with a question. “One day, around ten years ago, I consulted an institute in Hawaii, asking for some information about a production process. They suggested me to get in contact with a company in Canada. So I wrote a fax and ten minutes later I got a response from this person who seemed as if we would be acquaintances for long time. So ten minutes later a long fax came, they told me to go to talk to them. I went to visit them. We had a system of consultation via fax that worked very well for long time. We partnered in a part of the production system. But then it got interrupted because the person with whom we had the contact who was a very interesting and kind old Australian man retired. The company was sold, the structure changed and that program of collaboration died (around 1998)” (Interviewee CA).

For some firms the latter has been a crucial resource. This is also the case of most researchers in the academic sector who have serious difficulties to access articles and publications. In Uruguay the universities does not have access to full articles. The processes for accessing full articles are difficult and time consuming. Again, the enabler is personal contacts and mechanisms developed to cope with the conditions of scarcity. “When the articles that we are interested on are identified, then the search of how to access them starts. And you have to either start looking for each one in different places, or bother friends to see if they have it. It might take time for them to respond to the request" (Interviewee PQ). One way to access these publications is through a restricted network that involves a web group of Uruguayans living abroad with access to full databases that facilitate articles on a requested basis, but with several constraints and restrictions.

Researchers rely on foreign sources of knowledge. Training courses, short research stays in foreign laboratories and co-participation in research projects are some of the mechanisms to access that knowledge. The gains of those experiences are very valuable. But sometimes researchers have to undertake a process of translation between what they learn and see outside, and the local conditions and applicability of those tools in their environment. One researcher describes her experience as follows: "In the year 1990 I had the opportunity to go to Sweden and learn some techniques about sexing of embryos. It was very important not only for the laboratory but for the School. At the time I went they were applying very modern techniques, and it was a nice timing for me to be there. At that time we thought it was very important because we imagined that it would be very useful for exports of animals in the country as it happened in Europe. But in Uruguay it did not happen like that. Sometimes we forget the market constraints. I then learnt that technologies that may seem crucial according to the bibliography might not work in the local market with the local constraints" (Interviewee AV).

Within familiar firms, knowledge is transmitted between generations. One interviewee that works both in the familiar firm and in the University states that: "Many of the things we apply and know today have been transmitted through generations. We value that knowledge because there are some things that you cannot learn in four years in the University" (Interviewee VF).

6.5.3. Resources

The following paragraphs present the resources available in the sector, distinguished in: (Ra) infrastructure, (Rb) R&D investment and funding, and (Rc) future regard: research and productive agendas.

(Ra) Infrastructure

In Uruguay the university concentrates in Montevideo, but schools and labs are dispersed across the city, which concentrates half of the country's population but represents a less than one percent of the country's area. There are two other locations of the university in the north of the country, but one of them is more for training, and the second is an agronomic station for students' practice. Most related infrastructure is located in schools' laboratories within the university. These laboratories have a hard time in renewing and updating the infrastructure, as there are not institutional resources for that. They depend upon international funded research projects which enable the purchasing of equipment. An important part of researchers work is how to be creative and efficient with the scarcity of resources they have. A researcher points out the problem: "The equipment we have here was purchased in 1994, ten years ago; after then I have not been able to get new equipment. That is our reality. We have a PCR from the year 1990. But we keep going, trying to look for things we can do, and we keep advancing knowledge, because you do not have to pay for that. We do not have a sequenator, so we go to other labs to do that. But it is costly, we have to pay" (Interviewee AV). Still the volume and relevance of this group's research results are very considerable and recognized outside the country.

At the country level there are some isolated regional research units from INIA, even though most biotechnology-related infrastructure is in one of the regional branches.

Firms have some essential infrastructure and when more complex technologies are needed they rely on either university labs or INIA's. A free trade zone located in the outskirts of Montevideo has recently established a biotechnology plaza with laboratories and infrastructure that is rented to firms and laboratories. It is a very recent initiative, and as for now very few firms have installed their facilities there.

(Rb) R&D Investment and funding

In Uruguay funding sources for research are scarce, and unpredictable in terms of timing. Many labs are recovering from the crisis of 2002, time when they did not get funding even for those contestable projects that were selected.

Firms engage in R&D informally. For the most part of the firms interviewed, there are not strategic plans put into place to decide what to invest on in the long run, and how to get there. Research related personnel are often involved on a part-time basis, or partially dedicated to it while playing other roles in the firm. As discussed in chapter 3, R&D departments are very important, as the R&D team within a firm plays a key role to internalize and absorb the knowledge accessed elsewhere (Cohen and Levinthal 1990; Senker 1998). This pattern of informality is slowing starting to change within firms due to the need to fulfill quality certification requirements. Firms that are looking for certification are facing the need to undergo an internal restructure that includes the creation of a design department, for instance. Very few firms are the exception to this pattern, having mid-term goals, and actively seeking for resources and pushing knowledge frontiers in a more dynamic way. However, these are just two firms.

When asked about R&D investment, most firms' interviewees could not tell with certainty the size of their budget on R&D. Part of the reason of why this is happening is that these small agro-biotechnology firms do not have formal R&D departments or budgets, and re-investment varies depending on performance and concrete requirements. In most cases they have not relied on external funding, nor have even thought of the possibility of counting on external capital. As illustrated by a firm manager in Uruguay: "When we faced ISO Certification in 2003, it was the first time that we've had a balance sheet. An output of that process was the restructuring of the firm, and an improved organization of resources. Because we never borrowed money from the bank uuntil two years ago we did not have a balance sheet, and my father, who is a chemist, knew that the firm was going fine if he had money in his pocket. But now we know that that is not right and the firm needs an accountant, a laboratory manager, etc." (Interviewee FL). Most firms do not count on, nor even consider, borrowing money from banks to engage in innovative activities.

In Uruguay all firms interviewed, except one, use their own private resources to invest on R&D. The only exception is one of the youngest firms (more than 10 years old) dedicated to molecular genetics. In this context, firms avoid to engage in longer-term research projects unless they have a clear return from them. In Uruguay, as in the rest of the region, private commitment to R&D is very small. A look at R&D indicators by funding sector shows that the private sector does not even constitute a category within it. Higher-education is the most important source of funding, with about 50% of total funding (50.3% in 1995, and 47.1% in 1999), then it was the public non-governmental sector, which accounts for around 25% (25.4 in 1995, 29.6 in 1999); foreign funding in the third place (12.5% in 1995, 7.9% in 1999); fourth government, which accounted for 6% in 1995, and 9.4% in 1999; and finally, government companies represented 5.7% in 1995 and 6.1% in 1999 (MEC 2000).

(Rc) Future regard: research and productive agendas

Uruguay does not have nor has it had a strategic plan or program for biotechnology. Around 2002 CONICYT defined three main areas for the commitment of their resources: biology, ICTs, and materials. However this focus did not translate into clear goals and strategies, and then the economic crisis came, and that attempt was not followed up. In 2001 a prospective study was carried on about biotechnology. But apart from the report which presents a picture of the current resources, there have not been outputs or strategies coming after that effort. That bioprospective study was fostered by UNIDO (Pagliano, Mazzolla et al. 2002). Prospective strategic thinking sometimes is perceived as a quixotic task as it entails much fighting against shadows. The University does not have any formal unit/department/agency dedicated to fulfill this area of study, nor the government does.

In Uruguay, agro-biotechnology largely concentrates in public sector research (PSR) organizations: the University (Agronomic, Sciences, and Veterinary schools), the national agricultural research organization INIA, and the Ministry of Cattle, Agriculture and Fisheries (MGAP). Another important PSR player is a public research lab which depends from the Ministry of Education (IIBCE). Within INIA, biotechnology involvement is more towards plant-based compared to animal for instance. Skills and resources in Uruguay have been seriously undermined due to more than a decade of dismantlement of the scientific resources (human and physical) in the context of a military dictatorship in the 1970s. Hundreds of scientists were exiled, and academic research was reduced to a minimum expression during that lost decade.

Firms engaged in agro-biotech are few, and most of them are old small firms. In the area of plant-based biotechnologies, these are either oriented to inoculants or seeds, while in the case of animal-based biotechnology, firms are mainly oriented towards animal health. Within the private sector, the inoculants industry has had an interesting trajectory. To some extent, it has followed an inverse path moving from biological products, its core strength at its origins, to agro-chemicals, a current attempt, because the market as it is has reached its ceiling, and therefore this new product line is a source of flexibility for the firm which was too focused on inoculants. It is not only market demand what constraints their expansion into other biological products, but to some extent, it is also knowledge limitations. The inoculant’s industry is closely linked with the regulatory entity within the Ministry of Cattle, Agriculture and Fisheries, but it is not connected with academic research organizations, including the University nor INIA.

At the university each team concentrates on their own interests and specializations. This is common to all case studies, though there are some differences. One is in terms of the type of problems that guide the agenda. As the levels of engagement with outsider actors is very different in the three sectors, the extent of support for themes differs, as it does whether these themes are developed in a more extensive base, with more actors involved, and draw on more complex approaches and dimensions, depending on the backgrounds of the actors involved and their trajectories.

“In Uruguay, the process of learning and moving forward builds on the old, and we walk by giving baby steps; we are moving, but very gradually” (Interviewee PQ). Whether these are baby steps or Gulliver steps, is not the decisive factor. Because in part if instead of baby steps those are giant ones, there might not be a demand for such peace of change. However, if those baby steps are small ones, but ever step has a wider breadth of knowledge, and of actors involved, and the walk is every time more inclusive than before, so instead of having these two same approaches from these two researchers with whom we have always worked, we are introducing somebody else, and complementing the approach with not only academic researchers' views, then the path is wider and more associational.

6.6. Summary

This chapter attempted to display the institutional environment of agro-biotechnology in Uruguay, and then point out some of the interacting dynamics of these environmental factors. Agro-biotechnology is a sector with few actors, concentrated academic research efforts in public ones, and few firms. They do not engage in sustained, synergistic linkages. These are based on punctual exchanges of information, services, or procedures. The institutional environment is not helping much. There are many problems but there is not any actor pushing to change them. Change is at the margins, more cosmetic change. Substantial change is very difficult, and avoided, and part of it could be the cost of negotiation involved in a sector with no clear leading players. Knowledge production is an isolated and lonely endeavor in Uruguay.

CHAPTER 7.

CROSS-CASE STUDY COMPARISON: INSTITUTIONAL ENVIRONMENTS AND AGRO-BIOTECHNOLOGY CAPABILITIES IN COSTA RICA, NEW ZEALAND AND URUGUAY

7.1. Introduction

After presenting the three case studies with regard to their institutional environments and technological capabilities, this chapter highlights the main commonalities and differences across case studies. The institutional environment has been analyzed based on the web of organizations, institutions and policies; while technological capabilities were characterized by the set of existing and gained abilities both at the firm and/or sectoral levels, which require a wide range of skills, processes, and resources for their enhancement and development, along a scale of increasingly complex tasks (productive, and associational) demanding different orders of involvement, commitment, appropriation and mastering throughout various dimensions that are considered relevant for agro-biotechnology.

The next paragraphs are structured in two main sections: one on the institutional environments in the three cases, and another on technological capabilities. The first section summarily reviews the main similarities and differences in the institutional environments of the three cases, distinguished in organizations, policies and institutions. The second sections focuses on the technological capabilities, and starts by presenting an overview of the position of these three countries regarding academic publications. That section then opens up in three: skills, processes, and resources. Finally the chapter closes with the analysis of capabilities and opportunities. A brief summary is presented at the end of the chapter.

7.2. Institutional environments across case studies

The organizational mapping of the sector varies across cases. Most differences arise in the type and variety of organizations in place, and their dynamics and functions played. Universities are fundamental actors in the three cases, though differences are large in terms of the number of universities, the configuration and dynamics of laboratories and centers within them, their patterns of connectedness, and the extent of their multidisciplinary bases. Uruguay is by far the case with less variation and number of research organizations: it has one research university, and few hybrid research actors. The single (public) research university is located in the capital city, where half of the country's population lives, but far from a good extent of the productive fabric. Two other organizations share the research arena, a public research center and the national agricultural research organization, which is of a hybrid type as farmers contribute to INIA's income through a tax to agricultural exports together with public funding.

In Costa Rica the research role is distributed among more actors: three public universities, and hybrid research organizations. Universities main campuses are concentrated in the vicinity of the capital city, though they have some branches in other locations. Hybrid organizations have specialized profiles: bioprospection and biodiversity, tropical agriculture, and others like CORBANA which is only about banana production.

Firms in Costa Rica and Uruguay share some similarities: they are relatively old firms which have been utilizing biotechnologies from second generation, for the most part. They hold linkages with other actors, but mainly isolated and punctual. Very few are attempting to walk in a more complex biotechnological path.

In New Zealand, the sectoral mapping is even more complex as it involves several universities, and hybrid organizations that are located across the country. It is a complex setting with quite many actors, and of various types. According to one interviewee “there are too many players”. These players include universities, crown research institutes, firms, joint ventures, levy-based organizations, etc.

Within academic research organizations, horizontal structures fed by different disciplines and tied to different schools are important as they contribute to that variety and complementarity of approaches, rationales, and epistemic tools to understand research problems. Hierarchical research structures reinforce isolation: small labs part of a hierarchical structure are often too specialized and concentrated on bounded research areas, in which mobility and openness to the rest of the academic community is partial, fragmented and punctual. Not only linkages are harmed, but also the very mechanisms and processes of knowledge production and utilization get fragmented and isolated. Critical mass is even more constrained and weakened.

In New Zealand their variety is very large. Firms are also key drivers of capabilities in the three cases, yet they largely differ in type and relative position within the sectors. In Costa Rica and Uruguay firms are small, and relatively old but they are very different: in the former they are closely related to multinational companies, and dedicated mainly to plant-based biotechnology. In Uruguay they are small local firms in both areas, plant- and animal-based biotechnology. In New Zealand they resemble more the type of knowledge-based firms described and analyzed in the literature. There are several spin-offs and joint ventures, dedicated to niche knowledge areas, and closely connected to academic research.

7.3. Agro-biotechnology capabilities in Costa Rica, New Zealand and Uruguay

7.3.1. Overview of the loci and focus of academic research

Bibliometric indicators help to provide a first general picture of the situation of academic research, though it might be a constrained and biased picture given these indicators' limitations[92]. New Zealand is far ahead Costa Rica and Uruguay in publication terms[93], as it is already expected based on the country's investment on R&D, the number of scientists, and institutional environment with which science interacts (SCI Expanded). For the period 1989-2005[94], New Zealand had 68,872 publications while Costa Rica had 3,797 and Uruguay 4,581.

The next graphs illustrate the distribution of each country's total publications[95] indexed in *SCI Expanded*, 1989-2005, by subject category (Figures 7.1. to 7.3.), and by organization name (Figures 7.4. to 7.6.). Both in Costa Rica and New Zealand, plant

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[92] For a discussion see Velho, L. (1986). "The meaning of citation in the context of a scientifically peripheral country." Scientometrics **9**: 71-89, Cozzens, S. E. (1989). "What Do Citations Count? The Rhetoric-First Model." Scientometrics **15**(5-6): 437-447.
[93] Total publications involve all publications with at least one author from the country specified.
[94] It is important to note that Costa Rica has one national journal indexed in SCI related to Tropical Biology (Revista de Biología Tropical). Its first articles indexed are from 1997. Uruguay has also one journal indexed in SCI in the area of Chemistry Engineering (Ingeniería Química, created in 1962), and its first articles indexed are from 1998. New Zealand in turn, has 23 journals indexed in SCI.
[95] The results shown in each category do not add to 100% as I have included in the graphs only those >= 2% to avoid the enormous list of categories and make results more visible in the graph. The rest of the categories are added into 'others'. Note that as I have worked with the online version of SCI Expanded only displays the top 500 records (i.e., the top 500 subject categories, organizations names, etc.).

sciences hold, in relative terms, higher shares within the total publications. In Uruguay however, the relative majority of publications are human health related. But more importantly, and regarding the organizational loci of those publications, it is clear that fin the three countries are universities, and furthermore public universities the main academic actors. The University of Costa Rica is the one that holds the larger share of publications[96] in that country, while in New Zealand[97] they are distributed among the main universities. Uruguay is a case apart as it only has one (public) research university, which accounts for most publications.

[96] The relevance of University of Costa Rica in the country's publications has been analyzed by Lomonte, B. and S. Ainsworth (2002). "Publicaciones científicas de Costa Rica en el Science Citation Index: análisis bibliométricos del trienio 1999-2001 [Costa Rica Scientific Publications in the Science Citation Index: Bibliometric Analysis for the period 1999-2001]." Revista Biología Tropical **50**(3/4): 951-962.

[97] In New Zealand publications by organization name it is important to note that CRIs, i.e. AgResearch, are relatively new players (1992) and came to substitute DSIR, which was an important research department within the Ministry of Agriculture and Fisheries. Both organizations are included in the NZ diagram (as seen in the list of organizations names). To take into account the young existence of CRIs I also performed a search for the period 1992-2005 and 1993-2005, but the distribution did not change substantially in neither cases.

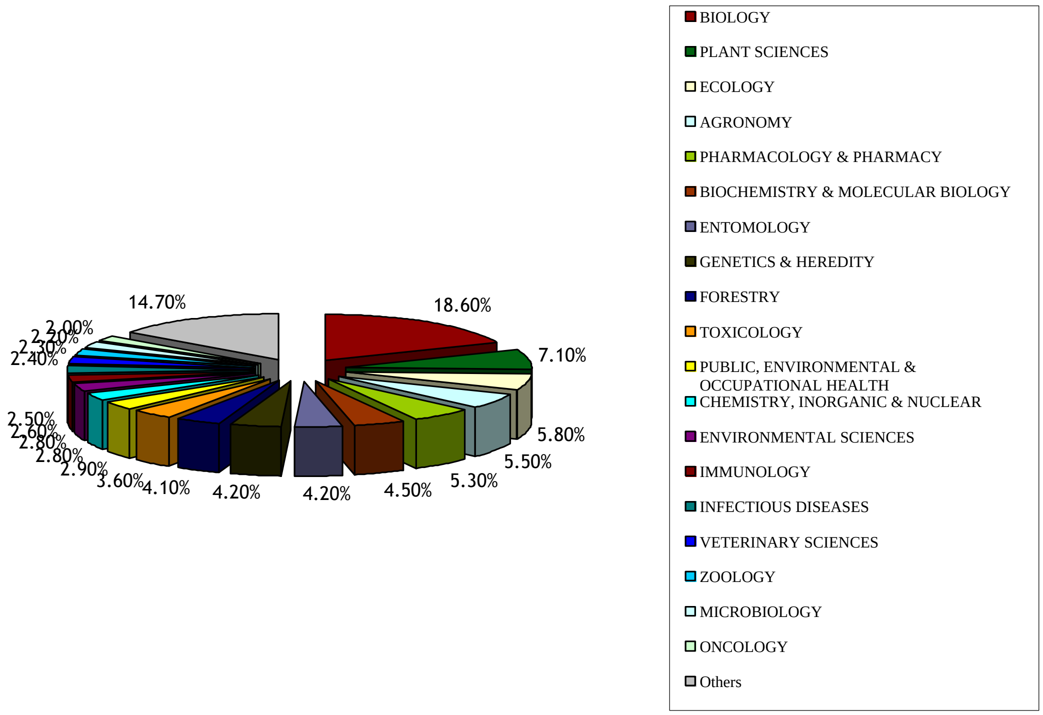

Figure 7.1. Costa Rica: Total publications by subject category, 1989-2005 (SCI Expanded) (Total 3,797)

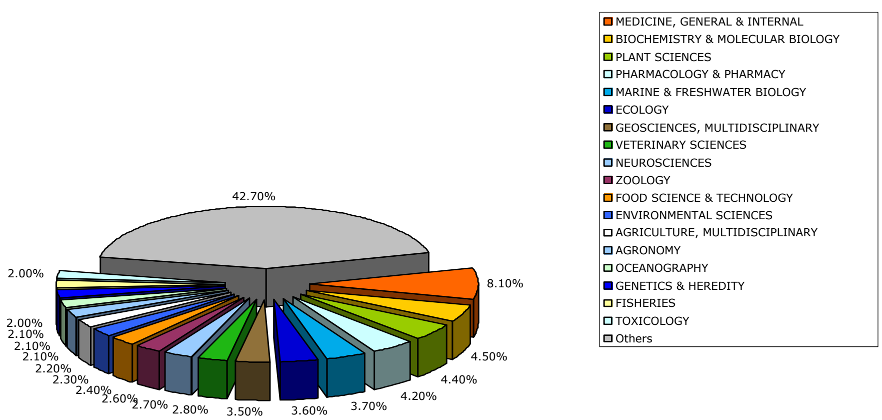

Figure 7.2. New Zealand: Total publications by subject category, 1989-2005 (SCI Expanded), (Total 68,872)

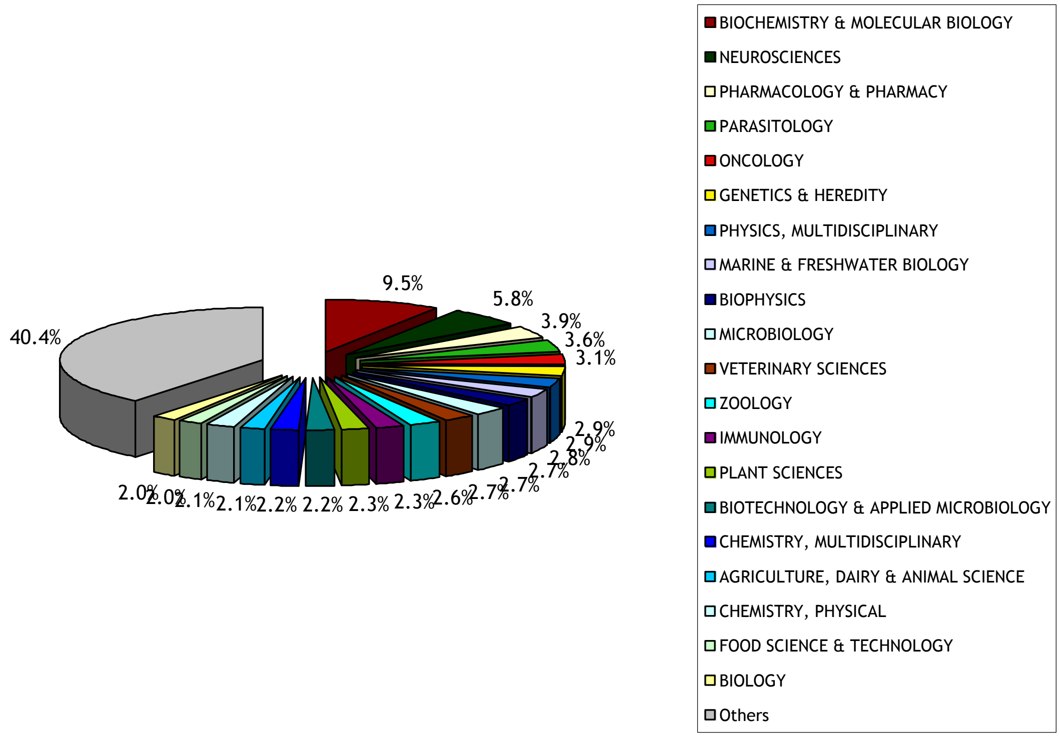

Figure 7.3. Uruguay: Total publications by subject category, (SCI Expanded) (Total 4,581)

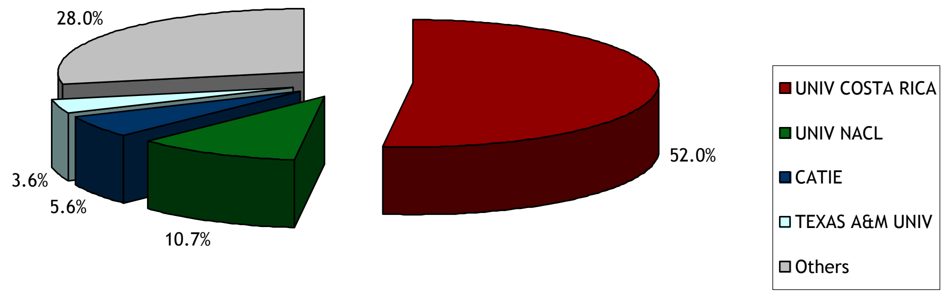

Figure 7.4. Costa Rica: Total publications by organization, 1989-2005 (SCI Expanded) (Total 3,797)

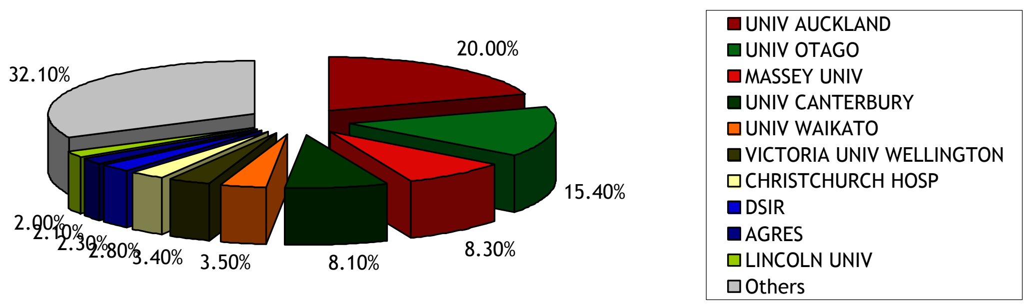

Figure 7.5. New Zealand: Total publications by organization, 1989-2005 (SCI Expanded) (Total 68,872)

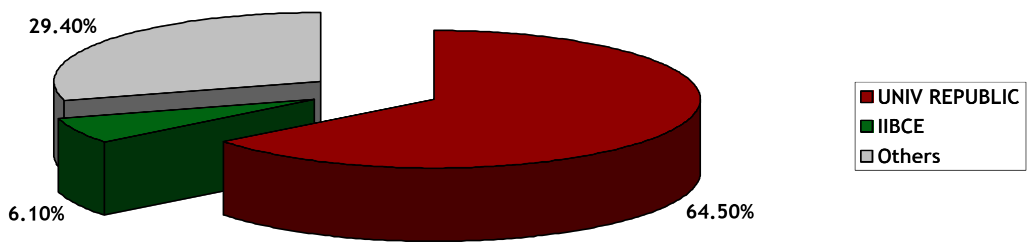

Figure 7.6. Uruguay: Total publications by organization, 1989-2005 (SCI Expanded) (Total 4,581)

7.3.2. Skills, processes and resources

Technological capabilities are decomposed in skills: (Sa) educational and experience backgrounds, and trajectories; and, (Sb) areas of application, actors involved and knowledge structures; processes: (Pa) the mechanisms and strategies implemented to access and absorb knowledge. For resources, I focus on: (Ra) infrastructure in terms of buildings, equipment, and access to databases, particularly of publications; (Rb) R&D investment and funding; and (Rc) future regard: research and productive agendas. In the case of investment efforts, the discussion centers on the general orientation of those investments: what items are being prioritized at the time of investing.

7.3.2.1. Skills in Costa Rica, New Zealand and Uruguay

This section analyzes the skills in each case study regarding: (Sa) what are the educational backgrounds of the individuals behind the sectoral organization, and what have been their trajectories concerning previous work experience and mobility; (Sb) what are the types of knowledge, and (Sc) what are the research/productive areas and outputs. These outputs involve enduring projects/products/processes that are visible, and identified from the outside, as distinctive features of the organization.

(Sa) Education and experience background and trajectories

Interviewees' formal education backgrounds vary between case studies but not in any specific manner. However, large differences arise in terms of individual paths of non-academic researchers, both place- and job-wise. Academic researchers in Costa Rica, New Zealand and Uruguay have for the most part been abroad to pursue postgraduate studies, but have rarely worked outside academia in that context. However, differences arise in terms of managers and CEOs of hybrid research organizations and intermediary organizations: in New Zealand working abroad and crossing sectoral boundaries is part of the background of several interviewees, as well as having foreign on hand experience.

The patterns of mobility of individuals vary between the three case studies. Differences are large between the three cases, and within each one, depending on the organizational loci: universities, and firms. A common pattern between the three cases is the trajectory of academic researchers from universities: after undergraduate studies, they go abroad to pursue postgraduate training, and then they return to the university where they currently work. Among academic researchers geographical mobility is the most important type of mobility.

In spite of this common pattern, there are important differences regarding scientists' participation in other type of activities, i.e., policy-making. In Costa Rica, scientists participate and are asked to participate of broader policy making instances, public hearings, and advisory functions. On the other extreme, in Uruguay these two bodies have traditionally been disconnected. This is particularly interesting because for the most part policy makers have studied in that same university. Still university and government have traditionally been at the antipodes. The only time in which they get closer, but not with aligned interests thought, is when university budget gets defined and discussed every five years. In New Zealand like in Costa Rica scientists' participation in policy-making instances do take place.

The trajectories of firms' managers are largely different across case studies. Managers in most cases hold bachelor studies in disciplines like Agronomy, Veterinary, and Chemistry. In most cases current managers have either started the firm or are the family second generation, particularly in Uruguay, and a large share of them have traveled to study a diploma or master, or doctorate in a couple of cases. Personnel mobility between firms is very scarce in Costa Rica and Uruguay. In both countries firms' managers do not move either. In Uruguay managers are also owners or larger shareholders in firms that often have a family root. In Costa Rica, it could be either that, or firms are subsidiaries of MNCs.

In New Zealand the pattern is totally different, and managers' mobility is very strong. CEOs from CRIs often combine industrial and agro-industrial backgrounds, with overseas experience, and sometimes, research exposure[98]. But it is not exclusive to CRIs. Levy-based organizations, and other intermediary players are led by individuals who have worked abroad, or in close connection to foreign markets, and have moved around either in terms of work place, countries, or industries. A typical trajectory of a manager

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[98] Based on the interviews, website and reports information.

from one of these organizations would be very much like the following: "I grew up on a farm in New Zealand, and I lived there until I was seventeen, then I moved to study university and I studied engineering [and did the] PhD. Then I went to work for a large engineering firm in NZ, and there I worked in the medical products division, then I moved to a CRI and worked for the automation team. My area of work was in meat processing automation. That is how I got involved in the primary industries we basically developed robots. I did work in New Zealand, Australia, US and Europe. So after moving from hands on research to be general manager of a team in automation. And then I came to this organization" (Interviewee CS).

It is also noteworthy that the question on background led to very different responses regarding the way interviewees identified their background. In Costa Rica or Uruguay, interviewees would identify themselves first by the discipline they studied. In New Zealand the response was different. Interviewees tend to introduce their background based on broader labels such as having a 'research career', or a background in 'research science', or in 'food technologies'. These ways of referring to their own backgrounds are tuned with trajectories that involve two distinctive features in New Zealand, as compared to Costa Rica and Uruguay: first the extent of their exposure to a broader spectrum than the own working unit of reference. These individuals are surrounded by many others, from many other loci with whom they interact for different purposes. They identify themselves as part of broader units, and broader frameworks because they are embedded in structures that involve few more than one type of organization, and many of which are 'in between' pure organizational types: they are not pure research-oriented centers, nor pure businesses, nor only lobbying associations. A scientist or a manager within one of these organizations have to deal with various actors of very different types, and has to articulate maybe scientists with business developers, who in turn are also in close interaction. So a scientist in a CRI has also had to learn how to integrate approaches and interests, beyond the specifics of the research field that he/she is working on. The same would happen to a R&D manager from a levy-based organization. Individuals in organizations that are embedded in wider structures need to have integrative approaches.

(Sb)Areas of application, actors involved and knowledge structure

Plant-based biotechnology is a very relevant common research and production area in the three countries. In Uruguay the sectoral area of application involves plant-based biotech, but shares the importance with animal-based biotechnology, also fundamental to the sector. They both co-exist and have their own references in terms of research groups, resources, and skills. In New Zealand in turn, animal- and plant-based biotechnologies are crucial inputs for the country exports. Plant-based biotechnology has a long trajectory and accumulation in research and production, mainly referred to improving the country's grasslands. Plant-based biotechnologies include plant improvement, plant genomics, plant growth, and plant health and protection. Animal-based biotech are also a major and key area of research and production, and mainly involve animal genomics, animal health and nutrition, and animal improvement & reproductive technologies (Partridge and Slim 2005). The identification of bovine gene constitutes one important area aimed at improving their dairy industry.

New Zealand thus shares with Uruguay the two-focus agro-biotechnology. But differences are several and large ones. Uruguay's exports also relies on cattle and has a relevant dairy industry, and there are huge differences in their market niches, industry's strategies and approaches to innovation and risk behavior. Differences loom large and deep particularly in their dynamics and structure.

The next table presents in a schematic way the set of utilized biotechnologies in the three countries, though it does not reflect the specificities of each country. At the broader level, utilization of DNA-based techniques, Cell and Tissue Culture, and Proteins and Molecules-based techniques are common across them. Differences appear however, with regard to the scale of application, and the diversity of application purposes of these techniques across the countries. Furthermore, larger differences emerge when considering the scope and variety of actors engaged in their utilization, as it has been discussed above.

Table 7.1. List of utilized agro-biotechnologies by country

	Costa Rica		New Zealand		Uruguay	
DNA –THE CODING						
Genomics	X	Characterization of useful genes/banana	X	Bovine gene discovery/forestry/ Dairy/meat/sheep/clover & rye grass improvement	X	Generic research/ (services) Diagnosis/rice
Pharmo-genetics						
Gene probes	X	Variety identification	X	Genetic testing/diagnosis/disease resistance, superior traits/	X	Variety identification
DNA sequencing synthesis and amplification	X	Genetic of populations/diseases/ Cacao/mutation/molecular taxonomy/enzyme searching/diagnosis	X	Gene-typing/forestry/ Dairy/meat/sheep/clover	X	Generic/ Meat quality diagnosis (services)/rice/ Assisted selection through molecular markers
Genetic engineering	X	Genetic transformation of plantain	X		X	Animal vaccine (bacteria-Footrot)
PROTEINS & MOLECULES –THE FUNCTIONAL BLOCKS						
Protein/peptide sequencing/synthesis			X		X	Inoculants and soil control/vaccine (yeast)
Lipid/protein engineering						
Proteomics			X	Milk analysis		
Hormones, growth factors	X	Micropropagation	X	Milk analysis/animal reproduction	X	Inoculants for leguminous
Cell receptors signaling	X	Genetic of populations /genetic diversity/banana	X		X	Birds sexing/
Pheromones	X	Insect attractors	X	Biocontrol/animal behavior		
CELL AND TISSUE CULTURE, AND ENGINEERING						
Cell/tissue culture	X	Micropropagation/ somatic embryogenesis /germ plasm conservation /tiquisque/potato improvement/services	X	Gene function testing/forestry/ Agriculture/virology	X	Plants/in vitro conservation and propagation/ Virus vaccine
Tissue engineering						
Hybridization	X	Flowers	X		X	Research on plants and rice
Cellular fusion	X	Tiquisque/potato	X	Animal		
Vaccine/immune stimulants			X	Animal health	X	Adjuvant
Embryo manipulation	X	Somatic embryogenesis	X	Embryotransfer/animal-Sheep cloning		
PROCESS BIOTECHNOLOGIES						
Bioreactors	X	Micropropagation/banana/ Fermentation/enzymatic maceration	X		X	Wine/inoculants/ Plant tissue propagation/ Vaccine/enzyme
Fermentation	X		X	Dairy/wine	X	Inoculants/ Vaccine
Bioprocessing	X		X	Harvesting specific milk components/dairy-meat-, plant-waste/nutriceuticals	X	Inoculants/vaccine/waste processing
Bioleaching	X					
Bio-pulping						
Biobleaching						
Biodesulphurization						
Bioremediation			X			
Biofiltration	x				X	Inoculants

Table 7.1. Continued

SUB-CELLULAR ORGANISMS						
Gene therapy			X	Future animal health		
Viral vectors			X		X	
OTHER						
Bioinformatics			X	Lab services/animal tracing/quantitative genetics/gene sequencing	X	
Nanobiotechnologies						
Other						
Gene silencing					X	
Cleaning of local materials					X	Tannat variety (wine)
Evaluation and risk analysis of GMOs	X					

Source: Data based on interviews[99]

This list of biotechnologies illustrates some of the differences in terms of the levels of complexity involved. The table above reflects one of these differences. In New Zealand there is spiral type of structure in terms of the areas of research application. The spiral gets thinner as it goes up in a convergence type of processes: plant research and biotechnology on rye grass, and milk proteins, and farming systems, and environmental concerns on greenhouses emissions from cattle manoeuvre, and sheep and cattle genetic research, all is crosscut by organizations and by a systemic approach, in which farming and productions system are fairly integrative going from farmers' quality of life, to water and soil management, passing through all the life subsystems. At the end, explicitly by pursued interaction or tacitly by coexisting the areas of research are interconnected, and all add to the larger goal of moving from producing commodities to having agricultural-based value added products.

[99] The list of biotechnologies is based on Canada Statistics. (1997, August 2005). "Biotechnology Firm Survey 1997." Retrieved March, 2004, from http://www.oecd.org/document/55/0,2340,en_2649_37437_1950135_1_1_1_37437,00.html., available at http://www.oecd.org/document/55/0,2340,en_2649_34537_1950135_1_1_1_37417,00.html accessed on March 2004

Costa Rica and Uruguay rely on external sources to strengthen and build their capabilities at the research level. For skilling the research core these countries totally depend upon interactions and relationships with the outer environment. In Uruguay the most dynamic firms also entail this same pattern, as its main strategy has been to closely connect to the Uruguayan Diaspora who signpost what to focus on in terms of attractive and applicable strategies, or where to look for resources.

7.3.2.2. Processes in Costa Rica, New Zealand, and Uruguay

(Pa) Mechanisms and strategies implemented to access and absorb knowledge

The next paragraphs discuss the strategies and mechanisms utilized in the three countries to access knowledge. The set of strategies implemented to access new knowledge do not vary drastically among actors, both within and between countries, except for an important qualitative difference. When new information and skills are needed, actors follow different paths, with varying degrees of commitment, and effort, from more passive to more active strategies, with also varying costs. These mechanisms are about how do these actors soak up new information and knowledge. Responses across actors and countries are more or less the same: participating in seminars, congresses, accessing publications through the internet, linkages to colleagues in foreign countries, and having students and researchers trained and have internships abroad. But at a more detailed level, there are important differences in the extent of utilization of and access to these mechanisms.

The most common and elementary strategy is to search for resources in the Internet from publications, patents, and firms specific disclosures. Whatever is of public access entails no major challenge as far as access is concerned. However access to tacit knowledge by the way publications is not obvious. In Uruguay there is not institutionalized access to publications in international databases, for the most part. University libraries have constrained access to international databases, and most of the time getting the article is a challenge. Researchers in Costa Rica and New Zealand do not face this level of constrained access to publications. Researchers who have studied abroad are still closely connected to their laboratories of reference. The Uruguayan Diaspora is in many senses one of the most crucial vehicles for accessing knowledge and information in the country, and in this sector in particular.

A second mechanism is to access new information and knowledge has to do with participating in seminars and congress. This is also varies depending on the country. Uruguay's geographical position makes it harder to travel overseas because of the low frequency of flights and thus, expensive tickets. Academic researchers at the University count on the university research council to get funding to participate in seminars. Firms could request funds to CONICYT to participate in events, but it is a very time consuming task. International agencies have small funds for them, and LATU, the Technological laboratory of Uruguay dedicated to certification has some small funds too. Costa Rica has the advantage of location, and New Zealand has much wider variety of doors to knock on seeking for funds.

A third strategy is the training of their human resources. This could be achieved in different ways. They could be trained in house with local resources. They could be sent abroad for internships, or courses; and they could also be trained by individuals coming from abroad. In Uruguay a single organization can hardly afford to bring somebody from abroad. Very few firms have in house courses based on local expertise. In the university they do bring in professors from abroad; also a chamber such as rice farmers association might invite somebody to focus on some issue related to rice.

However, in Costa Rica, INBIO for instance builds its own capacity strongly relying on collaborative projects, and they use those partnerships to get in-house training.

Bringing skilled human resources into the sector is another form of accessing and absorbing knowledge. One strong difference between countries is respect to their ability to capture foreign scientists and technologists. In one extreme it is New Zealand, which has succeeded in implementing this mechanism that is part of an aggressive migration policy of skilled resources across the country. It goes beyond attracting foreign skilled personnel but it is also decided to bring back New Zealanders who have settled abroad. To a lesser extent Costa Rica has also been able to attract foreign scientists who find in the country an attractive environment.

A fourth mechanism has to do with relying on acquaintances living abroad that can facilitate the access to resources. This is the case of the interaction between researchers and firms in Uruguay and the country's Diaspora. This mechanism is a publicly recognized problem not yet solved nor attempted to do it. The migration of scientists, and skilled labor in general, is part of a structural problem the country has facing for the last few years. Research teams are disintegrated quite often; senior researchers are seeing the consequences of loosing their junior colleagues, and their training and investing efforts are somehow dismantled when these young researchers are offered jobs outside of the country. The problem is that in many cases they would stay if only some stability and continuity was given to them. Based on the interviews, what is more frustrating is that it is not so much a migration for getting higher salaries, which counts, but because they are offered a perspective, a career which they do not easily see in Uruguay. There, they are working for free in some cases, or in the best situation, working for very low salaries on a (short term) project basis. Regular projects are often short term (two years) and once the project is finished they have to be on their own until some other project is funded. Research teams do not have buffer resources to retain those researchers. This problem has not been given a solution yet. But as a counter-effect is that the Uruguayan Diaspora is an extremely utilized and valuable resource for knowledge access and absorption.

An important way of acquiring and absorbing technological capabilities is through having scientific organizations managed by people with industrial background, who have lived and worked abroad. That is common practice within CRIs in New Zealand.

In Uruguay during the 1960s agricultural research capabilities were developed based on a strategy of attraction of foreign researchers to lead the research programs in the public organizations. That path has not been sustained over time. Still several processes are put in place to cope with difficulties and shortages. Updating and producing knowledge in constrained contexts follows some specific paths and criteria. Limited resources have led researchers to develop highly creative solutions to keep their programs, machines and initiatives going on. Researchers develop a set of resources driven by difficulties and limitations that enable them to create alternative paths to carry on with the making of science in the sector[100]. For example, that has been part of the success of Uruguayan researchers outside the country, when they have migrated. One researcher perceives the process as follows: “I do not waste more time in meetings. I concentrate on my work doing original research. [So how do you cope with the scarcity

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[100] Srinivas and Sutz (2006) analyze how science-making in the context of Southern countries share some characteristics related to that constrained environment Srinivas, S. and J. Sutz (2006). Economic Development and Innovation: Problem-solving in Scarcity Conditions. CID Graduate Student and Postdoctoral Fellow Working Paper. Cambridge, Center for International Development - Harvard University.

of resources to work on original research?] The thing is that if you set a goal you can develop a more creative methodology without so many competitive techniques. Because using those competitive techniques is what makes research expensive. When an academic research finds something original, and you think that this could serve as a model to study something new and original, that is an achievement. For us, that is more interesting than optimizing a technique expecting it to useful and applied into the local context, and then it clashes with producers not adopting it. That is really frustrating for us, maybe not for a technician but it is for a researcher. It might make sense for a technician who is here today and tomorrow creates his own private lab. We have tried to develop and adjust techniques that serve the two purposes: that could be interesting for the local context, but also that serve our interest in academic research. Because you are not going to have a design for experimental research based on nothing; the design has to be based on things you count on in the surrounding environment. You will not develop an impossible design, or one that requires to go to another country to conduct it" (Interviewee AV).

7.3.2.3. Resources in Costa Rica, New Zealand, and Uruguay

(Ra) Infrastructure

The difference in infrastructure in the three sectors is incommensurable. The quality of infrastructure is totally different beginning by the existing facilities in terms of the conditions of the buildings, the resources with which they are loaded (electronic, hitting/AC, etc.), their maintenance, and the equipment they have. That is a first order difference between them. A second order difference is the way the infrastructure is organized. In both Costa Rica and New Zealand there are university campuses around the country. Schools and labs are co-located within these campuses, and many of them are multidisciplinary. At those places, local production systems interact with university resources, with varying degrees of involvement and articulation. In New Zealand, on the other hand, there are hubs of research facilities throughout the whole country, with at least two different types of organizations in each local community, such as a CRI and a university.

Second generation biotechnology can be utilized and developed with inputs that do not require large investments. One of the equipments that make a difference in terms of the level of preciseness of the results and use is known as quantitative PCR. In Costa Rica and Uruguay there is one real time PCR, a technology related to molecular microbiology. In spite of the scarce resources, and cost of infrastructure, many research labs would like to have their own equipment. This happens both in Costa Rica and in Uruguay, with the difference that while in the former there is physical proximity between them, in the latter researchers from different schools and laboratories are dispersed across the capital city.

Studies in biotechnology also conform the available infrastructure at the sectoral level. In Costa Rica and Uruguay there are programs on biotechnology studies. In the former it is taught as part of the Engineering school at ITCR since 1997, and it is exclusively dedicated to plant-based biotechnology. An engineer in biotechnology in Costa Rica knows how to deal with tools related to plant-based biotechnology. At the end of the studies that person will be able to deal with the needs of most firms in the area regarding laboratory protocols and practices. Students have laboratory training in tissue culture and molecular biology, apart from physiology, botany, among others. They will also have had a course on entrepreneurship, and an elective one on bioinformatics. In Uruguay the program offered is at the level of Master, it takes two years and is taught in the Sciences school. It is directed to B.S. in Biochemistry, Biology, Clinical Biochemistry or pass some courses to get the required level. In New Zealand there are also programs on biotechnology at the three levels, undergraduate, master and doctoral offered by more than one university (University of Canterbury, University of Waikato).

(Rb) R&D investment and funding

Funding is scarce almost by definition; there is always need for more funding. Compared to pharmaceutical biotechnology, agro-biotechnology does not need a large upfront investment. Availability of funding varies in quantity but even more it does so in terms of variety of sources. Costa Rica and Uruguay entail similar patterns in this sense, but New Zealand is further up in the alternatives for funding.

In Latin American countries, the private sector is almost left to its own. Firms' abilities to invest in new lines of research are seriously undermined due to the lack of adequate funding for innovative activities. The only private capital available is from the banking system, which does not have any special credit line that contemplates innovation requirements, such as risk and long term. The only (scarce) sources of funding are public, these are small, and in Uruguay they face legitimation problems given the past difficulties in complying with delivery schedules (review and evaluation, and delivery of funds).

However, based on the interviews most problems do not have to do with having more or less resources, but to framing issues and approaches. The lack of planning, the short-term predominance, inefficiency, and the obscurity of some criteria are emphasized over volume of resources. A comment mentioned more than once across interviews in Uruguay states that: "The serious problem is when things are half way through (*medias tintas*) because money is spent but results are not achieved. There has to be a plan to get results, and in Uruguay that is not the case. Money is spent but results are not there. What happened with the money that was spent based on loans in the last years, for instance?" (Interviewee AV).

(Rc) Future regard: research and productive agendas

In New Zealand and Uruguay there is a common ground in terms of the focus on plant (mainly pastoral) and animal health. A qualitative difference however is that in New Zealand the organizational setting is more complex, and integrated both from the technological standpoint and from the actors involved and their integration, and linkages. The dairy industry is a fundamental trigger of this setting and particularly of the biotechnological arrays. New Zealand, at one end of the spectrum, has built a trajectory on pastoral biotechnologies and animal health through a sustained and cumulative learning path. It is not only the type of capabilities they have built, and their ability to learn technically and at the organizational and policy level what characterizes them, but also the underlying systemic approach embedded within the organizations and at the sectoral level. The building of capabilities is embedded both at the sectoral and firm levels, in a setting characterized by clear visions about the strategic areas to be pursued, the existing strengths and weaknesses, reinforced by mid- to long-term thinking. In this context, the building of capabilities constitute a trajectory, nonlinear but cumulative. Cumulativeness is possible because of the institutional environment and because of the opportunities emerged by the encounter of problem and solution, of complementary layers. Complementarity is a driver of knowledge and innovation in the country's agro-biotech in the sector.

7.4. Opportunities and capabilities

The building of capabilities largely depends on the opportunities carried on by institutional environments. These three case studies show different levels of capabilities and propensities of encounter. If capabilities are there but are not matched by environments that carry them along a cumulative path, in which actors are articulated in various and sustained ways, and knowledge and productive structures do not become intertwined, then capabilities are sterile, constrained to single purpose, single actor, punctual basis output.

Agro-biotechnology draws on and embodies different but interacting types of knowledge. First it entails the knowledge about the core content of the subject matter, which in agro-biotechnology involves the fundamentals of genetics, molecular biology, virology, cell biology, and others. A second type of knowledge relates to the instruments and techniques that enable to either produce biotechnologies such as vaccines, GMOs, fermentations, or to use biotechnologies for further applications: to use a genetically modified organism to study its reaction against a pathogen, for instance. There is a third type of knowledge, and has to do with the problem area towards which biotechnologies are applied. For example, the research interest could be to look for genes that are in charge of milk fat in dairy cattle, so research would be driven by the interest of changing milk composition. Or to identify genes that regulate particular traits like milk production. Thus the technologies underlying these areas are relatively common, but they are utilized and framed for different purposes, though closely intertwined in the broad industrial view of dairy production for instance. For instance a specific tool like QTL analysis enables the identification of pieces of chromosome that hold the gene that regulates milk composition. Or it could be applied to analyze genes that do other things, like regulate the milk yield loss. Same technique could be used in the search of solutions for different problems, and that too might relate to different sets of disciplinary knowledge. Thus, biotechnologies could be utilized for different problems, and they are crosscut by different knowledge disciplines. The articulation of these knowledge types stands on associated actors of multiple and of different kind, which mutually complement and to some extent compete with others. Complementary skills are then required: biotechnology draws on multidisciplinary bases, and associational settings that enable the articulation of necessary skills, resources and process to develop them. Tight organizational boundaries, or disciplinary vertical structures do not facilitate the biotechnology knowledge structure. Within that type of arrangement, capabilities get encapsulated, constrained to a marginal and punctual character.

Capabilities concentrate in the academic research community in Costa Rica and Uruguay. Firms are very isolated, more in Costa Rica than in Uruguay. Uruguayan capabilities are more disperse: it is an archipelago type sector.

New Zealand, at one end of the spectrum, has built an intertwined trajectory on pastoral biotechnologies and animal health through a sustained and cumulative path. Thus, animal- and plant- based biotechnologies reinforce each other. It is not only the type of capabilities they have built, and their ability to learn technically and at the organizational and policy level what characterizes them, but also the underlying systemic approach embedded within organizations and at the sectoral level. In this context, the building of capabilities constitute a trajectory, nonlinear but cumulative. Cumulativeness is possible because of the institutional environment and because of the opportunities emerged by the encounter of problem and solution, of complementary layers.

Complementarity is a driver of knowledge and innovation in the country's agro-biotech sector.

7.5. Summary

This chapter analyzed the institutional environments and technological capabilities of agro-biotechnology in Costa Rica, New Zealand and Uruguay. As for capabilities, and particularly regarding skills including background and trajectories, they loom large in terms of the high mobility of R&D managers and CEOs in New Zealand compared to Costa Rica and Uruguay. These organizational actors entail deep differences along almost any criteria. Firms are isolated in Costa Rica, and in Uruguay, though it is slowly changing, while they are more interconnected in New Zealand. Academic researchers in the three countries share many commonalities, reinforcing the relatively universal character of universities. Still their embeddedness differs in the three countries. Knowing the techniques, disciplinary foundations, and what to apply on the knowledge involved in agro-biotechnology do not translate in being more capable at the sectoral level. Associated actors carrying on different approaches and strengths, from different settings are necessary to build sustained paths of capabilities that reach the instance of becoming cumulative achievements.

CHAPTER 8.

CONCLUSIONS AND POLICY IMPLICATIONS

8.1. Introduction

This chapter reviews the main issues arisen from this dissertation analyzed in previous chapters, while also highlighting the most important theory and policy implications of these findings. The dissertation has examined how institutional environments interact with processes of building agro-biotechnology capabilities in small countries: *how* is that capabilities are built, what are the important dynamics and settings that have lead to more sustained and integrated sectoral trajectories or more disarticulated ones. This thesis aimed at contributing to the field of policy studies, and more particularly to science, technology and innovation policy studies by better understanding the underlying dynamics and interactions of organizational actors, institutions and policies, and how these shape the capabilities at both, levels firms and sectoral in the context of agro-biotechnology in small countries.

8.2. General observations and findings

For the most part, variations among the three cases have to do with: (i) institutional thickness: number and type of existing organizations and institutions; (ii) their sense of purpose (cohesiveness); (iii) the extent of institutional responsiveness; and, (iv) the level of systemicness.

With respect to (i) institutional thickness and (ii) cohesiveness, the institutional environment in Uruguay is for the most part thin, with few organizations of limited types, with high levels of contradictory rules and practices. It lacks cohesiveness, and a leading role for identifying this strategic purpose.

The institutional environment in Costa Rica characterizes by a combination of thick and thinness, or thin-ck (thicker than Uruguay) because of the number and the varying character of the set of related organizations. Niches of institutional coherence predominate at the institutional level, though with some incoherence, and low ongoing levels of cohesiveness. One feature distinguishing this case study however is that it during the next decade it has shown readiness to establish it.

In New Zealand the institutional environment involves several organizations of varying types, configuring a complex environment which shares a strategic purpose, and is largely coherent, though it has very limited incoherence particularly regarding the situation of CRIs, and their mandate to conduct science for the public interest, but are required to turn into the market very heavily, and are going into excessive competition with universities. Excessive competition without oriented types of funds is constraining their synergy and reinforcement. Still they have managed to shape differential profiles to contribute into the articulation of different research areas, and related to different, but complementary, productive problems. In New Zealand the institutional environment is oriented by pragmatism.

(iii) The level of responsiveness of institutions and policies to changing demands and obstacles constitute one of those dimensions. When institutions and policies embody mechanisms that connect them and make them opener to the system, their ability to correct for problems and re-orient their direction improves. Openness and responsiveness of institutions and policies are necessary for them to be meaningful; rules stickiness depends on their openness so that they could be adjusted and to some extent, calibrate demands and needs. Rigid irresponsive rules lead to avoidance of those rules and stimulate the emergence of parallel institutions.

(iv) The level of systemicness across these cases' institutional environment differs: up to what extent do institutions, policies and the web of organizations are approached and function as pieces of a puzzle ruled by the principle of co-dependence? A systemic approach does not mean perfect complementarity. On the opposite it only refers to a comprehensive view in which parts are seen relative to the larger context, and interaction effects are taken into account. Co-dependence and systemicness permeates New Zealand's environment. An interviewee exemplifies a co-dependent approach as follows: "in meat and wool processing there is this co-dependence: if we produce lot of sheep but the meat processing industry could not sell it then things would not work. So we talk to the main processing industry and sometimes we fund research all along the value chain. We actually support people on the ground in China teaching Chinese little processors how to better select wool and how to use NZ wool for their best advantage." (Interviewee TW).

In New Zealand agro-biotechnology capabilities are built and approached as a set of interacting and interconnected factors. Plant- and animal-based biotechnology do not constitute separate areas or subsectors. They are approached in a complementary fashion, as the whole farming is framed in a systemic view. Plant-based and animal-based biotech are functionally and research-wise intertwined. Cattle and grass are co-dependent pieces in the puzzle, as animal health and grass are too. Farming is a system and is approached as such from policies, organizational design, to knowledge production.

In Costa Rica and Uruguay plant- and animal-based biotechnology are separate enterprises, involve different actors, different research programs, firms, and approaches.

In Costa Rica, the context is different as that country does not rely so heavily on livestock, cattle and meat as New Zealand and Uruguay. In Uruguay, animal- and plant-based biotechnology conform two separate worlds. From the configuration of the academic research centers and schools (Agronomy and Veterinary are apart and disconnected), to the approaches and processes for building capabilities.

Sectoral building of agro-biotechnology capabilities varies between niche-constrained trajectories in Costa Rica and Uruguay, and more embracing trajectories in New Zealand where they involve intertwined areas like plant- and animal-based, and several layers of various actors. In Costa Rica and Uruguay sectoral capabilities have been advanced but have remained constrained to specific niches. One of the niches in which the Costa Rican sector has built a trajectory has been banana. There two local firms, hybrid organizations involving research activities, and research centers have been advancing their skills, resources and processes and today banana growing in Costa Rica is almost totally reliant on in vitro plants. The role of hybrid organizations has been key to establish this pattern and enable such a trajectory. They have been closely connected to banana growers, and have articulated different interests and agendas. Firms have played their role but have not been articulated neither among them, nor directly involved with those hybrid organizations.

Another niche around which the trajectory of capabilities has been advanced is in rice but the situation is different though. A research team has carried on a star project on a local variety of genetically modified rice for more than a decade now, and it has involved several dimensions and research problems, while bringing into researchers with different disciplinary backgrounds. However it is still in the experimental level, and there are not firms involved.

In Uruguay, sectoral building of agro-biotechnology capabilities has also been constrained to specific niches, particularly animal health and some plants. There, niches do not interact, and actors very weakly and punctually do so, for very concrete mainly short-term utilitarian needs. Few firms relate to the advancement of this trajectory. Hybrid organizations and research centers have also played a critical role, particularly the former one, but their interaction is also very limited.

An important part of the research argument is that building capabilities is part of the picture, but they need conducible environments that catalyze and leverage those capabilities into opportunities. I claim that the focus on technological capabilities is crucial, but in conjunction with the dynamics and characteristics of the institutional environments and their ability to create opportunities for those capabilities. Capabilities reveal only part of the story. They refer to what the firm/sector/country is able to do. Capabilities mainly refer to a potential: they are a necessary condition, but whether they overcome the potential to become realization or achievement strongly depends on the surrounding institutional environment.

Institutional environments could enact capabilities or they could heavily hinder them. Incoherent institutions and/or policies result in clashing signals for individuals and firms. In New Zealand the drastic reform of the 1980s that led to the creation of CRIs as important science-making actors has not been successful in establishing a clear identity to CRIs. They are supposed to contribute to the country's welfare and development, while at the same time they are fiercely pushed to be self-sustainable and fiercely compete with universities for scarce resources which have not been very specialized and diverse so that they differences and potential complementarity would be reinforced. There are few leakages in the system. However, this same institutional environment has been able to identify those knots and other problems and has attempted to establish alternative solutions for those. Responsiveness and openness are then key features to turn challenges into opportunities. Recently a CRI and a university have moved in a new collaborative direction by committing to relocate AgResearch's animal health section into Massey University (AgResearch 2005).

In Uruguay policies and institutions have blocked the development of more complex capabilities because of their rigidity, and incoherence. In spite of the technological changes in Uruguay several important agricultural laws and regulations are from the 1960s and remain ruling biotechnological related practices. There are cases of firms pushing to produce new animal vaccines with high technological standards, but that have been dismantled because of outdated laws[101]. Problems do not have to do only with scarcity and deficit of resources. There are more serious problems related to the management, and missing direction and planning for the spending of resources. The institutional environment however suffers serious difficulties to change and transform those obstacles. For the most part, the rule is to adapt practices and functionings to policies and institutions rather than the other way around. Capabilities are hindered by those rigidities, as the latter affect the overall context in which interactions, skills, processes and resources are (or are less) developed.

Agro-biotechnology embodies interaction, articulation, and interconnectedness of multiple and various types of knowledge, actors and structures. If environmental dynamics act like barriers impeding the crossing of boundaries, then capabilities will be reduced to isolated events, anecdotal, constrained to marginal applications and lack deeper integration into the productive structure. If research labs, and academic research

[101] See Bortagaray (2004).

follows a disciplinary basis, without integrating multiple disciplines, and backgrounds, and users from different sectors, whose research is framed based on a conception of sectors as static independent structures, then capabilities will be sterile and un-sustained. Trajectories then would be discontinued, missing the systemicness that biotechnology requires to be advanced.

Processes for accessing codified types of knowledge are relatively common across case studies, however large differences appear when the focus is one level deeper on how easy/accessible are they. Access to journal articles for instance is difficult in Uruguay where the University nor INIA have extended access to databases. Furthermore differences are notorious regarding strategies and processes to access tacit types of knowledge, including bringing in skilled people like New Zealand is doing with an aggressive skilled migration policy; or bringing into the organization, advice and consulting for in-site (in-house) training; or mobility of personnel which is very rare in Costa Rica and Uruguay. In Costa Rica mobility has taken place on a *sui generis* basis, and that is by having a small group of elite scientists moving around different settings (policymaking, academia, hybrid organizations) who have contributed to form new types of organizations, and have imprinted them with broad common goals and functionings.

8.3. Theory implications

So, how does the institutional environment shape innovation, and agro-biotechnology capabilities in particular? The role of the institutional environment in innovation is of particular importance because of the nature of innovation itself. The innovation literature has emphasized the importance of institutional dynamics on innovation. However, to an important extent the emphasis bas been on technological capabilities as independent variable and their role on economic performance. This dissertation has attempted to focus on the processes more than on the outputs or outcomes, with capabilities being the shaped phenomena.

Building technological capabilities applied to agriculture refer to very complex processes, in which multiple types of knowledge and actors are required. The nomenclature of low-tech and high-tech is useless and misses the point about the importance of understanding the dynamics behind the processes of producing and using knowledge. 'Learning' and 'searching' processes are rooted in instances of *interactions* and *interconnectedness*.

Firms' searching and learning processes are bounded by their institutional environment. Their decisions and strategies respond, to a large extent, to their perceptions and sensing of that environment. This ability to make sense does not only have to do with information on markets, business and technological trends, but also relates to the ability of identifying and figuring out how to find their niche in that context and how to function.

A firm's external sensing ability has to do with its alertness and responses to the opportunities and signals perceived. It is not only about perceiving opportunities and calibrating how they can be appropriated given the particular features of the firm, but also about implementing changes oriented to take advantage of those opportunities. This ability totally depends on the environment, on how connected the firm is to the environment, and on the 'quality' of those connections given that what matters here is not only perceiving signals but more importantly about perceiving the 'right' signals. Communication and information are fundamental inputs for firms' quality-based sensing.

To sense the right signals, firms need information and communication about them. Apart from the flow of information and communication, firms also need some level of *clarity*, *certainty* and *stability* in the rules of the game to decide in what direction to move. If rules are volatile depending on issues like who are subject to rules application, or who is enforcing them (or if they are not enforced at all), or if they change all the time because loose interpretation, then firms' strategies for building capabilities are importantly harmed and could be very disrupted. Innovation inheres uncertainty, but requires stable commitment and effort from firms. In those environmental conditions the time frame for building capabilities is largely constrained, and incentives are negative for longer-term efforts. The firm's ability to draw on previous experience and knowledge is harmed. And previous experience is a key resource for innovation and capabilities given the path dependent character of what firms can and cannot do. Thus the *sustained* character of capabilities is important for firms to cumulate and learn. This also applies at the sectoral level regarding the trajectories of capabilities.

In many cases small countries' institutional environments lack resources, from critical mass to financial assets in most cases. *Variety* and *complementarity* of the institutional environment becomes crucial to substitute for those missing resources. Complementary combined with variation in types of organizations are fundamental inputs and resources for individual firms to rely on, and complement for the lack of resources. That is, for a firm in a small country, it is fundamental to count on a thick institutional environment that could provide for the varying resources it needs and internally lacks to build novel capabilities. A single agro-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.

For firms to engage in acquiring and building new agro-biotechnology capabilities in small countries, they need to interact with complementary as well as varying organizations so as to search in different directions and preview novel building paths. Complementarity and cross-fertilization of capabilities at the sectoral level expands the boundaries of resources available as well as the opportunities to engage in new types of capabilities. This is particularly the case when subsectors interact between them and boundaries are intertwined, for instance between plant-based and animal-based agro-biotechnology. The combination and interaction of their knowledge bases, and resources push the boundaries towards alternative paths, and contributes to the emergence of common strategic purposes that encompass more than the single sector. For example, agro-biotechnology involves different types of knowledge, from core scientific knowledge (molecular biology, cell and tissue biology, etc.), to knowledge on the specific techniques (micropropagation, genetic engineering, etc.), and knowledge of the area of application (animal health, plants, agrofood, etc.). Thus, the building of capabilities in this sector requires the articulation of these different types of knowledge, the set of related processes and heuristics to build them, and the articulation of different types of actors. Actors that could bring into, and couple these different types of knowledge as well as inter-connect various actors are the cornerstones of this sector. It is not only thickness, cohesiveness, and consistency what matters, but also within that thickness to have actors facilitating the *articulation* of those varying organizations, and contributing to frame and guide the sector towards a next biotechnology direction.

This research claims for the need to bring into the picture socio-institutional processes that shape the types and trajectories of technological capabilities through a narrative about how incoherence, connectedness, cohesiveness, rigidity and responsiveness of institutional environments contribute to shape more or less complex capabilities, more niche constrained or more encompassing, expanding or more stagnated, more cumulative or more disperse agro-biotechnology capabilities.

Institutional environment that drive and leverage opportunities draw on a series of mechanisms: (i) thickness (ii) learning-based policies and (iii) institutions that balance competition and cooperation, and contribute to sustainable and inclusive production paths. These stick together through cohesiveness at the meso-level of the institutional environment: a strategic purpose holds them together.

8.4. Policy implications

What are the policy implications of this work, or alternatively, so what with these findings? What could policymakers do different if capabilities want to be enhanced? The next paragraphs attempt to tackle these issues but with the understanding that countries and local contexts are unique, and models serve for analytical purposes but in reality there is not an a priori one best way of doing things as local arrays and configurations are not transferable. Still several lessons could be learned, and efforts for strengthening those local arrangements are fundamental mechanisms to change paths and start creating new conditions for biotechnological development. I point out some of these issues in the following paragraphs.

First agro-biotechnology constitutes a powerful sector for these countries given the importance of agriculture and of having value added or intelligent agricultural products. Agro-biotechnology is a powerful platform because it permeates many industries and sectors, and draws on different knowledge types and necessarily requires interactions, and ties between multiple and various types of actors. Strengthening ties and linkages is crucial not only for agro-biotechnology but for learning in general. Agro-biotechnology is then an opportunity-driver sector, as it is about intersections and interactions. It relies on the integration of different knowledge types, interactions and users. It draws on and embodies different but interacting types of knowledge: (a) core knowledge including the fundamentals of genetics, molecular biology, virology, cell biology, and others; (b) knowledge about the instruments and techniques to either produce biotechnologies such as vaccines, GMOs, fermentations, for instance, or to use biotechnologies for further applications: to use a genetically modified organism to study its reaction against a pathogen, for instance; and (c) knowledge about the problem area towards which biotechnologies are applied.

This interdependency between types of knowledge and actors that characterizes agro-biotechnology requires porous and open structures to enable those flows and interactions. Agro-biotechnology stands on intertwined forms of knowledge and permeates different subsectors. The articulation of these different subsectors is necessary, and in the case of small countries it adds an extra benefit given the shortage of critical mass.

Policy frameworks need to carefully consider intangibles and flows, and foster collaboration on a sustained base, for learning to be cumulative, and actors to be more prepared to adapt to changing knowledge bases. Processes about how and why are interactions blocked or feared, or why are they flowing between actors; what mechanisms are preventing researchers from articulating knowledge areas and cognitive approaches;

how does the organizational mapping counts are all questions that should be stressed as part of a policy framework on this subject.

This thesis suggests that beyond the need of strengthening the influx of resources such as funding, what substantially matter for technological capabilities are the quality, purpose, and sustainability of interactions and frames. It is not interactions alone what matters the most, rather it is interactions involving hybrid organizations as they act as multipliers of approaches, interests and resources, while bridging broader (farmers associations for instance) and narrower structures (academic laboratory), enhancing their complementarity and to an important extent, holding them together. Holding them together refers to the presence and involvement of actors of different type, and this is an important part of the function that support organizations play. They play a bridging role, on the one hand; and facilitate the emergence of a shared sense of strategic direction, on the other. Thus, it is not only *more* interactions what makes the difference, but their further embeddedness within the sector with actors of varying kind, and oriented to different purposes, and outside the sector with other sectors, and countries but engaged in linkages that surpass the strictly asymmetric necessity of accessing funds.

This dissertation also suggests that flexibility, a fundamental feature for small countries and their institutional environments, has to be built into the system dynamics, that is through strengthening organizations that are able to lead and pool resources into the sector as well as leverage sectoral resources, which might also contribute to generate a common sense of strategic purpose. It does not necessarily has to be government, but in small countries it is critical to have organizations which are not firms nor research centers per se but organizations that bridge their different interest and seek for those interstices of collective action. For example, organizations that involve users (i.e., farmers, firms) and different producers of knowledge (i.e., academic researchers, 'hybrid' researchers, firms, etc.) with their *various* approaches and interests help to complement for the shortages and constrained resources of these contexts. The structural breadth helps to build more encompassing capabilities which to some extent will embody the variety of approaches and interests of those actors. These organizations are critical to reinforce complementary strategies and more sustained capabilities building.

Across case studies these hybrid organizations appear to be fundamental for the processes and types of capabilities being built. Hybrid organizations entail wider social bases as they involve more than one type of actors in their structure: farmers, firms and/or academic researchers. The involvement of more than one type of actors implies the co-existence of different rationales, interests, and approaches. The built-in variety and complementarity are fundamental platforms for agro-biotechnology given the multiple types of knowledge behind it. This becomes even more important in the context of small countries: scarcity and shortage of critical mass and resources. Thus built-in variety and complementarity of actors strengthen the processes of building technological capabilities.

Hybrid organizations encompass enough variety to facilitate the process of knowledge creation and utilization. The wider social bases that these types of organizations involve are a good match for the variety and complexity of modern technological platforms such as agro-biotechnology. The complexity and variety of the knowledge involved and the multiplicity of dimensions on which it draws on, including social processes, require organizational settings and institutional arrays that favor interaction, multidisciplinarity, connectedness, systemicness and co-dependence. The advancement and building of capabilities and knowledge stands on the shoulders of multifaceted organizations, which involve and are in close interaction with more pure types of actors such as academic research and firms. But the building of capabilities in an area like biotechnology requires of variety and complementarity built in an organization.

Finally, this dissertation also suggests that among the peculiarities of these cases is the constraint imposed by size. Size becomes a trigger to actively strengthen variety and complementarity within organizations. Organizations involving different types of actors, with different backgrounds, cognitive frameworks and tools, approaches, and social bases helps to complement for the limited critical mass. Flexibility is certainly an empirical matter: policies, institutions and organizations could seek to build flexibility in their own dynamics.

APPENDIX I. CASE STUDY PROTOCOL

I.1. Overview

This appendix presents the case study protocol[102] guiding the model and research approach to the dissertation. It attempts to connect the research sequence from the theoretical ground, to the research question, hypotheses, data collection, and analytical framework.

This dissertation aims at analyzing the role of the institutional environment on the building of technological capabilities in a specific sector: agro-biotechnology, in the context of small countries. It draws on multiple case studies, involving three small countries: Costa Rica, New Zealand, and Uruguay. It is framed by the sectoral system of innovation approach, and the analysis focuses on two levels: firms, and sector. I explore this relationship in a comparative way by looking at how variations between the institutional environments in Costa Rica, New Zealand and Uruguay lead to cross-country differences in the types of technological capabilities built over time. However, at the national level I expect to find common patterns in the types of technological capabilities built by firms, based on the characteristics of the sectoral institutional environment. This study is not only about how the sectoral system of agricultural biotechnology works, but also about how it changes and adapts, and whether the way in which institutional environment change enhances or hinders the building of technological capabilities.

In the following sections I briefly sketch the theoretical background, research question, and hypotheses; procedures for data collection; analytical framework, and data analysis.

I.2. Theoretical approach

<u>(i) Propositions</u>

- Firms' strategies and mechanisms for the building of agro-biotechnology capabilities are shaped by the characteristics and dynamics of the institutional environments, which in these case studies are expected to be:
    - connectedness of the firm to the sector and outside, and connectedness of the sector
    - the configuration of the sector involving multiple and diverse types of organizations
    - the level of coherence between organizations, policies and institutions
    - the cohesiveness of the institutional environment, that is the extent to which actors share a sense of strategic purpose.

[102] See Yin, R. K. (2003). <u>Case studies research: designs and methods</u>. Thousand Oaks, Sage Publications.

    - the responsiveness of institutions and policies to incorporate sectoral demands and change needs
    - the flexibility of the environment to adapt and change to sectoral requirements

<u>(ii) Unit of analysis</u>

This research has embedded units of analysis: the sector, and the individual organizations, read: firms, policy agencies, research centers. The boundary of these units is defined by the formal boundaries of the organization. If it is a firm, is the firm; in the case of a research center is the center/unit.

I.3. Research question

The research question is *how and through what mechanisms do institutional environments affect agro-biotechnology capabilities in small countries?* The focus is on processes rather than on outcomes: the *building* of agro-biotechnology capabilities. This research question is placed in the broader context related to flexibility in small countries.

I.4. Research hypotheses

Characteristics of the institutional environment

H1. The higher the contradiction/**incoherence** of the institutional environment, the more constrained and harmed the accumulation of technological capabilities are going to be.

<u>Definitions</u>

Incoherence is defined by the contradiction between organizations, policies and institutions' goals and means to achieve those goals (Amable, Barré et al. 1997). Incoherence between and/or within the components of the institutional environment act like energy losses in which certain goals collide between them, or means are dysfunctional to specific goals.

Incoherence at the sectoral level is studied through the following indicators:

- goals and means of:
    - institutions including:
        - patents' regulations, Biosecurity, and GMOs;
        - broad S&T related frameworks
    - learning related policies
    - organizations such as policymakers, regulatory, etc.

Goals refer to objectives or visions of organizations, institutions and policies. Means have to do with the way those goals are seek: strategies to reach goals, or set of concrete policies that are aimed to be conducive towards broad innovation framework.

For example if one of the sectoral problems in New Zealand is the excessive competition between universities and CRIs, one issue I look at is what are the means and strategies put in place and how incoherent they are with the broader aim. The goal of stimulating collaboration is incoherent with the lack of financial mechanisms to strengthen their collaboration. The focus is not on the absence of solutions to the problem, but on the presence of incoherent mechanisms in relation to building agro-biotechnology capabilities.

H2.The higher the **connectedness** of the sectoral system, the better it is for building technological capabilities.

Connectedness refers to the "…existence of transactions tying organizations to one another. These transactions might include formal contractual relationships, the participation of personnel in common enterprises such as professional associations, labor unions, or boards of directors, or informal organizational-level ties like personnel flows" (DiMaggio and Powell, 1983, p 148

H2a. The more **inter-connected** the organization is to other organizations within and outside the sector, the better for the building of its capabilities.

H2b. The **broader** the type of interconnections, the better for the building of technological capabilities.
Breadth of interconnections refers to the previous hypothesis and complements it. Broader type of interconnections is about whether interconnections are bilateral or multilateral matters for the building of technological capabilities, because of the nature of agro-biotechnology, which requires different parties involved with different areas of expertise and knowledge.

H2c. The more **diverse** interconnections are, the better for the building of technological capabilities.
Diversity refers to the kind of organizations involved, such as firms' associations or other types of organizations that pool interests together.
This hypothesis builds on the previous one, as it is not only number what matters, but also the type of organizations involved.

H2d. The more **sustained** interactions among them are over time, the better for accumulating more complex capabilities.
The sustained character of interactions is defined by the continuity (time wise) of those linkages.

H2e. The more **asymmetric** interactions are, both in terms of financial power and technical competence, the more the building of capabilities are going to be inhibited (Lundvall 1992b).
Asymmetry is indirectly observed through the purpose of the interaction and the types of exchanges the parties have: whether it is through a research project in which they co-participate, a firms' consortium, etc.

H2f. The more directly **articulated** knowledge users and producer are, the better it is for the better for the building of technological capabilities.
Articulation refers to the co-participation of different types of actors in a common organizational instance.

Generally, connectedness then involves several dimensions:

- Interactions with whom? name categories of involved parties
- Interactions with how many/in bilateral or multilateral fashion?
- Interactions for how long?
- Interactions with whom at the same time?
- Interactions of what type? (symmetric/asymmetric)
- What types of organizations take part of the interaction?
- Direct articulation of users and producers

H3. The more cohesive the institutional environment is, the better for the building of technological capabilities.
Cohesiveness refers to the presence of a common sense of strategic purpose at the sectoral level.

Dynamics of the institutional environment

H4. The more rigid the institutional environment, the less innovative technological capabilities are going to be.
Rigidity refers to the extent of change of organizational settings, policies and regulations over the last decades, and to the direction of change.

H5. The higher the responsiveness of institutions and policies to changing requirements, the more strengthened capabilities are.
Responsiveness refers to mechanisms of processes within organizations, institutions and/or policies that contemplate changing demands at the sectoral level and show some response after that.

I.5. Research model

Characteristics and dynamics of institutional environments → building of technological capabilities

Independent variable — Dependent variable

Independent variable	Dependent variable
Institutional environment is defined as composed of the web of organizations, institutions and policies	Technological capabilities is defined as composed of skills, processes and resources
Characteristics	*Types of building processes of technological capabilities*
Incoherence	More complex: from involving new layers of skills and resources to less complex ones
Connectedness	From niche constrained to encompassing: that is, from constrained to a single area, to encompassing multi-focuses
Breadth of interactions	Expanding: from expanding areas of research/production to stagnated
Diverse interactions	Cumulative: from cumulative to disperse
Sustained interactions	
Asymmetric interactions	
Articulated interactions	
Cohesiveness	
Dynamics	
Rigidity of institutional environment	
Responsiveness to changing demands	

Table I.1. Summary of variables, dimensions, indicators and data				
Concept and definition	**Dimensions**	**Indicators**	**Data**	
			Primary sources	**Secondary sources**
Incoherence refers to the contradiction between the set of goals and means of policies, institutions and organizations	Goals and means of policies, programs, institutions and organizations	Objectives of relevant policies/programs/institutions/organizations means and mechanisms defined to achieve those goals organizational design *vis a vis* objectives and goals	Open-ended question: *Are there any regulations, policies, and/or laws that in one way or another affect your everyday work? If so, what are these?*	Reports and documents containing regulatory frameworks Strategic plans of government agencies Laws Legislative minutes Organizations' websites (missions, visions, core values, strategies) Sectoral reports Evaluation documents Financial agencies reports Organizations' documents with values, visions, evaluations of programs/initiatives Industrial/firms periodicals

Table I.1. Continued

Connectedness	Linkages between sectoral actors	Type of interactions	Open-ended question: *Have you participated in a joint effort (project, proposal) with other universities/firm, or any other organization, within and/or outside the country? If so, could you tell with which other organizations have you collaborated with, and for what purposes?*	Previous empirical studies Sectoral reports Organizations' reports Data-bases with information on funded research projects, Organizations' websites including firms, funding organizations, academic research centers.
	Interactions: With whom does the organization interact? (external interaction)		Open-ended question: *Have you participated in a joint effort (project, proposal) with other universities/firm, or any other organization, within and/or outside the country? If so, could you tell with which other organizations have you collaborated with, and for what purposes?* [next paragraph is not mentioned as such, just for self-reminding and used to cover the spectrum of possible relationships] Relationship with companies: (with whom, what for, how frequently, bilateral or multilateral)? Relationship with other academic agents? Relationship with governmental agents? With legislative agents? With lawyers, or patent offices? with NGOs?, with international agencies? Had any strategic alliance with other universities or firms?	Organizations' reports of activities, information on research projects and application from organizations websites, Financial organizations' reports and websites.
	Breadth: Number of parties involved in the interaction		Open-ended question: *Have you participated in a joint effort (project, proposal) with other universities/firm, or any other organization, within and/or outside the country? If so, could you tell with which other organizations have you collaborated with, and for what purposes?*	
	Diverse: Type of actors involved in the interaction Varying nature of the actors involved in interactions			
	Sustained: length of interactions			
	Asymmetric: inferred from information on purpose of interaction, motive of interaction			

Table I.1. Continued

	Articulation: the extent of direct articulation of users and producers				
Technological capabilities as composed of: skills, processes and resources	**Skills**	(Sa) education and experience background and trajectories	Background Types and levels of skills	Open-ended question: Could you please tell me about your background?	sectoral reports; evaluation reports, previous empirical studies of some org. firms (see Appendix III)
			Background	Which have been the key research projects/developments in your organizations?	
			Education/qualification levels	Open-ended question: What is the qualification level of the people working here	
			Techniques employed	Closed question (list of biotechnologies provided): *Could you please indicate what of these biotechnologies has been used in the firm?, And for what purpose?*	
			Paths of skills	What are the current projects? Could you recall some earlier ones?	
		(Sb) areas of application, actors involved and knowledge structure.	Scope	Closed question (list of biotechnologies provided): *Could you please indicate what of these biotechnologies has been used in the firm?*[103]*,* *And for what purpose?*	
			Actors involved and role played	*Open-ended question:* *Could you please identify what are the firm's inputs? And its providers? Are there different levels of inputs? If so, what are they?* *Users and customers?* *What are the competitors and with what products/processes?*	
				Open-ended question *Do you participate in any network?*	

[103] The source of this list is *Biotechnology Canada 1997*, http://www.oecd.org/document/55/0,2340,en_2649_34537_1950135_1_1_1_37417,00.html, accessed on March 2004

Table I.1. Continued

	Processes	(Pa) the mechanisms and strategies implemented to access and absorb knowledge: Mechanisms and processes implemented to access and update knowledge and information	Open-ended question: What type of mechanisms and/or strategies do you have to access to new knowledge? What would you identify as the main sources of knowledge for your work? *How do you decide what topic/problem to research on?* *Who does get involved in the process and through what mechanisms?*	
		Internal interacting mechanisms: context of interactions; frequency of interactions	Open ended question *How do the different units in this organization interact with each other? Do you hold formal meetings? If so, how frequently do they take place?* How do you all interact? (mechanisms, frequency)	
	Resources	(Ra) infrastructure: organization's infrastructure	(Limited) observation during interview (lab facilities)	Organization's information (website, brochures, periodicals) and sectoral and national reports (see Appendix III)
		(Rb) R&D investment and funding: level of effort	Open ended question: Could you provide an approximate idea about your annual investment on R&D?	Organizations' publications and websites
		(Rc) research and productive agendas and future regards: new areas of interest	*Open-ended question:* *Are there any research areas that you might consider to start in the immediate future? If so, what are those?*	Organizations' publications and websites

Table I.1. Continued

Institutional environment as composed of the web of organizations, institutions and policies	**Organizations**	(i) public academic research orgs.			Previous empirical studies related to the sector
		(ii) private, and semi-public orgs.that offer biotechno. products/services			
		(iii) intermediate and bridging organizations			
		(iv) companies-users and/or producers of biotechnological developments			
		(v) suppliers			
		(vi) funding organizations			
		(vii) policy-advisers			
		(viii) regulatory organizations			
	Institutions	(i) IPRs – patents	Type of patent regime	Open-ended questions: *Have you patented any product or have you attempted to do so? Have you used any other type of property rights protection? What do you think about IPRs and patents? How do you see them in the context of your org./country? Have you been involved with any of these issues?*	Reports and documents containing regulatory framework; legislation
			Utilization of patents		
		(ii) bio-related regulations	Regulations (types)	Open-ended question: *Are there any regulations, policies, and/or laws that in one way or another affect your everyday work? If so, what are these?*	Regulations and legislation Reports Discussion documents
		(iii) broad sectoral frame regulations	Broad framing policy such as S&T policy, innovation policy, and/or sectoral development policy		National/Sectoral program, planning, policy framework

Table I.1. Continued

	Policies	(I) means to learn: policies that have to do with enhancing/weakening the means to learn. Those that constitute the basis for learning	Investment on R&D, education and training; Orientation of the education system (goals); Types of education structures; Multidisciplinary character of programs; Approaches of education programs		International organizations' reports (OEI for instance) government' reports, plans, and frameworks Laws Regulatory frameworks Financial agencies reports Organizations' documents with values, visions, evaluations of programs/initiatives
		(ii) incentives to learn	Scholarships Incentives to engage in collaborative efforts		
		(iii) capability to learn	Continuous education programs Circulation of personnel/individuals		
		(iv) access to relevant knowledge	Access requirements for university and higher level education		
		(v) remembering and forgetting	Promotion of continuous reskilling		
		(vi) opportunity to learn	Mobility of individuals Bridging mechanisms		
		(vii) policy learning	Policy evaluation mechanisms		
		(viii) social learning	Public involvement in policymaking		

Table I.1. Continued

Multiple focus/agrobiotech areas	Related areas of production	Production and/or research areas	What is the sector of application of your main products? a. Agriculture b. Animal c. Food industry d. Other industries e. Human health f. Environmental g. Other	
Cohesiveness Common sense of strategic purpose	Common sense of strategic purpose	Shared mentioning in the interviews of a new path/area of sectoral orientation, and in reports and plans	Open-ended question: *Are there any research areas that you might consider to start in the immediate future?*	Secondary data: reports, websites, policy documents; laws and regulations, etc.
Rigidity: extent of change in goals, design, and instrumentation of relevant institutions and policies: change in patents' frames; regulatory frameworks; change in innovation policy in conditions of changing requirements	Path of change between organizations-sector-institutional environment		Open-ended question: *What would you consider the most important events/milestones in this organization?, and in the sector?*	Reports (government agencies, legislative, sectoral, policy) Articles and analytical pieces Websites Laws
	Triggers/loci of change: organization, actor or unit carrying on change			

Table I.1. Continued

responsiveness refers to the extent to which policies and institutions respond to changing demands	Historical analysis of critical demands and policy and institutions responses; Establish a chronology based on secondary data, and identify critical points of change/absence of change	Identify milestones/critical events Trace responses of organizations/policies/institutions after requirements for change	Open-ended questions: *What is the research area of this organization?* *What are the main lines of research?* *What is the area of application of the research conducted here?*	Evaluation reports of organizations/policies/institutions Reports
	Policies/institutions/organizations change *vis a vis* demands for change		Open-ended question: *What would you consider the most important events/milestones in this organization, and in the sector?* Open-ended question: *Are there any regulations, policies, and/or laws that in one way or another affect your everyday work? If so, what are these?*	
Tracing back internal and sectoral trajectory	Internal	Previous initiatives/projects	Open-ended question: *Which have been the key research projects/developments in your organization?*	Organization's information (periodicals, website, case study, sectoral reports)
		Future initiative/projects	Open-ended question: *Are there any research areas that you might consider to start in the immediate future? If so, what are those?* *What are the current projects? Could you recall some earlier ones?*	
	Internal/external	Past-present	Open-ended question: *What would you consider the most important events/milestones in this organization?, and in the sector?*	Organization's information (periodicals, website, case study, sectoral reports) Sectoral information (reports, evaluation documents, etc.)

I.6. Data collection

Two main sources of data inform this research: in-depth interviews as sources of primary data, and archival data contained in documents such as reports, programmatic documents, program and policy evaluations, websites, periodicals, laws, and journal articles as sources of secondary data.

The strategy for data collection consists of the following phases:

(a) background analysis preceding the interview:

1. identify and define the structure and configuration of the sector, and organizations involved. For that the first step is to search the Internet, government and agencies' reports, and databases looking for secondary data containing information about the history, configuration and related legislation, regulations and policies in the area of agro-biotechnology in Costa Rica, New Zealand and Uruguay. These documents are included in Appendix III;
2. from these different and complementary sources, identify a list of individuals who are related to the sector, and/or have analyzed the sector;
3. contact these individuals asking for information, references and contacts;
4. exchange information about the possible list of candidates to be interviewed in each country;
5. define the list of individuals to interview in each country;
6. prepare a questionnaire protocol for in-depth interviews;
7. test it with a qualified informant;
8. The identification and definition of the list of individuals to interview in each country the steps are the following:
    - in Costa Rica I count on two main sources of expert opinion: CONICIT, and the Institutional Commission of Biotechnology at the University of Costa Rica
    - in New Zealand, the Ministry of Research, Science and Technology, and complement it with interviewees opinion when contacting them by email
    - in Uruguay, the coordinator of the Uruguayan Association of Biotechnology Firms, which is not active currently, but still the association exists and has a group of firms as part of it, and a qualified expert who has worked in the sector in different positions. There is also a report that provides a list of the organizations involved in this sector (INIA-MEC-DINACYT 2001).
9. contact the list of candidates by email inviting to participate in this research project and asking for personal interviews;
10. schedule the interviews;
11. plan the on site process for a two week stay in Costa Rica, and then same procedure for New Zealand (I will be living in Uruguay when conducting the interviews in that country)

(b) during site-visit

12. travel and conduct the interviews, which are electronically recorded if agreed by the interviewee;
13. ask the interview for possible documents, reports, brochures, etc. with information on the organizations, and the sector;

(c) post-visit

14. store the recorded interviews in a CD, together with the secondary sources of data, and notes of the interviews;
15. follow up with interviewees for clarification, if necessary.

I.7. Data analysis and reporting

1. The raw data for this research consists of:
    a. interviews notes and quotations (no literally transcription)
    b. lists of biotechnologies utilized responded by each (applicable) interviewee with two questions: (i) mark the biotechnology used, and (ii) for what purpose
    c. documents, brochures, annual reports, government reports, evaluation reports, and other types of publications both provided by interviewees, and gathered through databases, internet, and websites (some in electronic format)
    d. list of publications records of organizations from the sector indexed in SCI.

2. The analysis involves two levels:
    (i) the within-case based on the sector at the national level (Case Costa Rica, Case New Zealand, Case Uruguay), and
    (ii) the cross-case level based on the comparison of the three case studies.
3. Each case study is analyzed individually, based on the following broad dimensions:
    a. Definition of the main structure of the sector: involved organizations, and their types, institutions and policies;
    b. Patterns of interactions and linkages between the sectoral actors, and with outsider organizations (cross-sectoral, and/or cross-national);
    c. Retrospective tracing of organizations evolution over time: I trace the critical points in time, their evolution, and their response to critical events, considering a time lag. These critical events are defined based on secondary sources of data, and interviews.
    d. Analysis of the set of skills, processes established to access and absorb new knowledge, and resources dedicated to build capabilities both at the sectoral and organizational level, based on interviews' and secondary data;
    e. Articulation of the narrative and argumentative interpretation of the connections between types of capabilities and characteristics and dynamics of the institutional environment, at the individual case study level;
    f. Triangulation of interviews' data with secondary data

Generally the same analytical procedure is applied to the cross-case study comparison. They are analyzed in a comparative way, by looking for similarities and differences in the broad evolution of their institutional environment, in the characteristics of the environments, and the types and mechanisms involved in building capabilities. This analysis takes place at the two levels: firms and sectoral. The former relies mainly on interviews' analysis, while the latter focuses more on trajectories and general aspects such as areas of application, scope of the sector, etc.

The reporting of data follows the analytical plan. Each case study is first reported individually, and then followed by the comparative analysis. Same categories and analytical framework is utilized, but the comparative level involves more tabulations and matrices with comparative data.

APPENDIX II. INVITATION LETTER AND INTERVIEWS' PROTOCOLS

This appendix includes (1) the letter sent to interviewees with the invitation to participate in this research; and (2) the protocols that guided the interviews to research organizations, firms and policy agents.

II.1. Letter of invitation to participate in research related to a doctoral dissertation on agro-biotechnology capabilities in small countries: The cases of Costa Rica, New Zealand and Uruguay

Dear Mr./Ms./Dr,

How are you? My name is Isabel Bortagaray, I am a PhD Candidate at the School of Public Policy at Georgia Institute of Technology (Atlanta, United States), now working on my doctoral dissertation on the **building of technological capabilities in agricultural biotechnology in small countries**. For that I compare three countries, Costa Rica, New Zealand and Uruguay.

In each country, I interview firms, policy-making actors, research organizations, funding agencies, and other actors related to the building of biotechnological capabilities. I have already completed the fieldwork in X, and now I am planning my trip to X (or my fieldwork in Uruguay, for that matter).

In the context of this project I will be in X for two weeks, between (date of arrival) and (date of departure). I am contacting you as I would like to invite you to participate in this research, and if you agree I would be interviewing you about your background, the work you do, and your organization's trajectory regarding the building of technological capabilities, and interactions and relationships. Your comments and opinions will be only used for research purposes, will not be identified, and only I will be dealing with that information.

Would you be willing to participate? If so, could I meet you at some time during those days? The interview takes an hour average. I understand your agenda is very busy, and I hope that I could interview you, as your participation would certainly be a key contribution to this research.

I deeply appreciate your time and attention.

Sincerely yours,

Isabel Bortagaray

II.2. Interview Protocols

(A) Research centers/departments

Organization's Name	
Interviewee's Name	
Role	
Time of entry	
Address	
Telephone	
Interview's date and time	

I. Background

Date when it was created	
Number of researchers at beginning	
Current number of researchers	

1. Could you please tell me about your background?

Significant events in the history of this department/unit
(Within the university and outside (sectoral, national))
2. What would you consider the most important events/milestones in this organization?, and in the sector?

II. Characterization
3. What is the research area of this organization?
4. What are the main lines of research?
5. What are the funding sources of this department?
6. Are there any research areas that you might consider to start in the immediate future? If so, what are those?
7. What are the current projects? Could you recall some earlier ones?
8. What is the area of application of the research conducted here? (if there is an area of application?)

a. Agriculture
b. Livestock
c. Food industry
d. Others
e. Human health
f. Environmental
g.Others ____

III. Internal organization
9. How is this department organized?

10. How many researchers do they work here?
11.How do you all interact? (mechanisms, frequency)
12. How do you decide what topic/problem to research on?
13. Who does get involved in the process and through what mechanisms?
14. How do the different units in this organization interact with each other? Do you hold formal meetings? If so, how frequently do they take place?
15. Has the unit experienced changes in its organization since it was created/you have been here?
16. In what sense has it changed?

IV. Knowledge base
17. Do you participate in any network?
18. What type of mechanisms and/or strategies do you have to access to new knowledge?
19. What would you identify as the main sources of knowledge for your work?

V. Collaboration, cooperation and connectivity
20. Have you participated in a joint effort (project, proposal) with other universities, or any other organization, within and/or outside the country? If so, could you tell with which other organizations have you collaborated with, and for what purposes?

Relationship with companies: (with whom, what for, how frequently, bilateral or multilateral)?
Relationship with other academic agents?
Relationship with governmental agents?
With legislative agents?
With lawyers, or patent offices?
with NGOs?
with international agencies?
Have you had any strategic alliance with other universities or firms?

VI. Regulations, policies and institutions
21. Are there any regulations, policies, and/or laws that in one way or another affect your everyday work? If so, what are these?

VII. Intellectual property, normalization and quality
22. Have you participated in a patent or a process alike?
23. Have you used any other type of property rights protection?
24. What mechanisms do you employ for quality control purposes?

VIII. Employment and training
25. What is the qualification level of the people working here?

IX. R&D Projects
26. Could you provide an approximate idea about your annual investment on R&D?
27. Which have been the key research projects/developments in your organizations?

X. Biotechnologies

28. Could you please indicate what of these biotechnologies has been used in the firm?[104], And for what purpose?

	Mark with X	For what purpose?
DNA – the coding		
Genomics		
Pharmo-genetics		
Gene probes		
DNA sequencing synthesis and amplification		
Genetic Engineering		
Proteins & Molecules –the functional blocks		
Protein/peptide sequencing/synthesis		
Lipid/protein engineering		
Proteomics		
Hormones, growth factors		
Cell receptors signaling		
Pheromones		
Cell and Tissue Culture, and engineering		
Cell/ tissue culture		
Tissue engineering		
Hybridization		
Cellular fusion		
Vaccine/immune stimulants		
Embryo manipulation		
Process Biotechnologies		
Bioreactors		
Fermentation		
Bioprocessing		
Bioleaching		
Bio-pulping		
Biobleaching		
Biodesulphurization		
Bioremediation		
Biofiltration		
Sub-Cellular Organisms		
Gene Therapy		
Viral Vectors		
Other		
Bioinformatics		
Nanobiotechnology		
Other		

(B) Firm's protocol

Technological capabilities in agricultural biotechnology firms

Organization's Name	
Interviewee name	

[104] The source of this list is *Biotechnology Canada 1997,* http://www.oecd.org/document/55/0,2340,en_2649_34537_1950135_1_1_1_37417,00.html, accessed on March 2004

Role in the firm	
Since when in the firm	
Address	
Phone number	
Day and time of interview	
Place	

I. Firms background

When did the firm start?	
Who did start it?	
How many employees did the firm had at the beginning?	
How many does it have now?	
What is the capital composition (national, foreign and country)	
Has it always been like this?	
Does it have other branches? Where?	

1. Could you please tell me about your background?

Significant events in the history of the firm

(Within the firm and outside (sectoral, national))

2. What would you consider the most important events/milestones in this organization?, and in the sector?

II. Characterization of the firm

3. What is the area of production of the firm?
4. What are the main four products/processes?, And, what is their share in the total sales?
5. Are there any areas of your interest that have not been developed yet? Which ones?
6. Could you please identify what are the firm's: inputs? And its providers? (do not read: Are there different levels of inputs? If so, what are they?) Users and customers?
7. What is the type of market in which this firm operates (national, regional)? What are the competitors and with what products/processes?
8. What is the sector of application of your main products?
    a. Agriculture
    b. Animal
    c. Food industry
    d. Other industries
    e. Human health
    f. Environmental
    g. Other ____

III. Organization of the firm

9. What units or departments does the firm has?, Is there a hierarchical relationship among them? If so, what is it?
10. And how many employees work in each department?

11. How do these departments interact? Through what mechanisms?, How frequently do they do it?
12. Has this firm experienced changes in its organization since it was created? If so, What have been the reasons for those changes?
13. In what sense has it changed?

IV. Knowledge base

14. Do you participate in any network?
15. What type of mechanisms and/or strategies do you utilize to access to new knowledge?
16. What would you identify as the main sources of knowledge for your work?

V. Collaboration, cooperation and connectivity

17. Have you participated in a joint effort (project, proposal) with other universities, or any other organization, within and/or outside the country? If so, could you tell with which other organizations have you collaborated with, and for what purposes?

Relationship with companies: (with whom, what for, how frequently, bilateral or multilateral)?
Relationship with other academic agents?
Relationship with governmental agents?
With legislative agents?
With lawyers, or patent offices?
with NGOs?
with international agencies?
Have you had any strategic alliance with other universities or firms?

VI. Regulations, policies and institutions

18. Are there any regulations, policies, and/or laws that in one way or another affect your everyday work? If so, what are these?

VII. Intellectual property, normalization and quality

19. Have you patented any product or have you attempted to do so?
20. Have you used any other type of property rights protection?
21. What mechanisms do you employ for quality control purposes?

VIII. Employment and training

22. What is the qualification level of the people working here?

IX. R&D Projects

23. Could you provide an approximate idea about your annual investment on R&D?
24. Which have been the key research projects/developments in your organizations?

X. Biotechnologies

25. Could you please indicate what of these biotechnologies has been used in the firm?[105], And for what purpose?

	Mark with X	For what purpose?
DNA - the coding		
Genomics		
Pharmo-genetics		
Gene probes		
DNA sequencing synthesis and amplification		
Genetic Engineering		
Proteins & Molecules –the functional blocks		
Protein/peptide sequencing/synthesis		
Lipid/protein engineering		
Proteomics		
Hormones, growth factors		
Cell receptors signaling		
Pheromones		
Cell and Tissue Culture, and engineering		
Cell/ tissue culture		
Tissue engineering		
Hybridization		
Cellular fusion		
Vaccine/immune stimulants		
Embryo manipulation		
Process Biotechnologies		
Bioreactors		
Fermentation		
Bioprocessing		
Bioleaching		
Bio-pulping		
Biobleaching		
Biodesulphurization		
Bioremediation		
Biofiltration		
Sub-Cellular Organisms		
Gene Therapy		
Viral Vectors		
Other		
Bioinformatics		
Nanobiotechnology		
Other		

(C) Policymaking/Intermediary organizations protocol

Organization's Name	

[105] The source of this list is *Biotechnology Canada 1997*, http://www.oecd.org/document/55/0,2340,en_2649_34537_1950135_1_1_1_37417,00.html, accessed on March 2004

Interviewee name	
Role	
Since when	
Address	
Phone number	
Day and time of interview	
Place	

I. Organization background

When did that person started	
When did org. started?	
How many people working?	
Broader organizational situation?	
Does it have other branches? Where?	

1. Could you please tell me about your background?

Significant events in the history of the organization
(Within and outside (sectoral, national))
2. What would you consider the most important events/milestones in this organization?, and in the sector?

II. Characterization
3. What is the area of involvement of this unit?
4. What does this organization do? How? With whom?
5. Could you please identify what are the organization's inputs? Users/members/stakeholders?
6. What is the area of influence of this org.?
7. What would you say is the sector it relates to?

III. Organization
8. What units or departments does it involve?, What hierarchical structure?
9. And how many people is working here/area?
10. How do these departments interact? Through what mechanisms?
11. Has this org. changed? If so, How? Why?

IV. Knowledge base
12. Do you participate in any network?

V. Collaboration, cooperation and connectivity
13. Does the org. take part in any network?
14. Through what mechanisms?
15. Could you tell me if the org. has taken part in joint effort (project, proposal, policymaking process, etc.) with other organization, within and/or outside the country? If so, could you tell with which other organizations have you collaborated with, and for what purposes?

Relationship with companies: (with whom, what for, how frequently, bilateral or multilateral)?
Relationship with academic agents?
Relationship with governmental agents?
With legislative agents?
With lawyers, or patent offices?
with NGOs?
with international agencies?
Have you had any strategic alliance with universities or firms?

VI. Regulations, policies and institutions
16. What would you say are the regulations, policies, and/or laws that in one way or another affect/you deal with in your everyday work?
17. How do they affect you?
18. How do you participate in the process of affecting these regulations, processes, mechanisms?

VII. Intellectual property, normalization and quality
19. What do you think about IPRs and patents?
20. How do you see them in the context of your org./country?
21. Have you been involved with any of these issues?

VIII. Employment and training
22. What is the qualification level of the people working here?

Thank you very much,

APPENDIX III. LIST OF PUBLICATIONS UTILIZED AS SOURCES OF SECONDARY DATA

III.1. Costa Rica

Chacón Vega, I. M. (2003). La biotecnología y su perspectiva para los países en desarrollo [Biotechnology and its perspectives for developing countries]. San José de Costa Rica, Universidad de Costa Rica.

Espinoza, A. M., A. Sittenfield, et al. (2001). "Developing Transgenic Rice at the University of Costa Rica: Perspectives and Considerations for Managing Intellectual Property Rights." Interciencia **28**(2): 111-07.

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Snoeck, M., J. Sutz, et al. (1994). Políticas y Estrategias Gerenciales de Empresas Agrobiotecnológicas en Uruguay. 21 estudios de caso de empresas biotecnológicas. W. R. Jaffe. San José de Costa Rica, Instituto Interamericano de Cooperación para la Agricultura.

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