



COMMERCIALISATION OF BIOSCIENCES  
RESEARCH IN OMAN: THE ENTREPRENEURIAL  
CHALLENGE

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'There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved'.

Charles Robert Darwin

Biologist, Scientist (1809–1882)

The Origin of Species By Means of Natural Selection, 1859, p 459-460

## Abstract

This research examines the process of knowledge commercialisation in a fledging national innovation ecosystem. The thesis investigates the Omani biosciences sector and its attempts to leverage its contribution to the national economy through knowledge-based activities. It focuses on the commercialisation actors and the transformation to the entrepreneurial paradigm since mid-1990s. More specifically, it seeks to understand the knowledge commercialisation in the context of the national systems of innovation and considers three main components: actors and institutions, networks, and the national support mechanisms.

Theoretically, this study draws on three strands of theory, which are: the National Innovation Systems (NIS), the Triple Helix (TH) model of innovation and Network Theory (NT). These theories are advanced by considering the institutional setting of the bio-sector and the social and cultural dimensions of the actors. Empirically the thesis is informed by mixed methods of questionnaire, semi-structured interviews that were conducted in Muscat in 2014, and the analysis of policy documents.

This thesis indicates that the Omani bio-sector represents a significant emerging setting for knowledge commercialisation process that involves the connection and co-development of actors, knowledge, and networks between the existing domains of practice (academia, government and industry). It contributes to understanding the extent of the influence of the entrepreneurial culture and the social dimension of the actors. It shows that the locus of innovation and knowledge production is the academic sphere and knowledge exchange between the actors is phase-dependent. The thesis suggests that geographic co-location is not the key prerequisite for effective interaction whereas innovation intermediaries play an important role based on their position and situation. Within the embryonic setting of knowledge entrepreneurship in the bio-sector, small-scale government initiatives have proven to be more efficient. Finally, the thesis concludes that the actors for commercialisation should develop a more sophisticated understanding of the concept and settings in which technical and tacit knowledge is formed, and of the means and mechanisms through which commercialisation practices might be enhanced.

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## List of Acronyms

CAMS	College of Agricultural and Marine Sciences
CR	Critical Realism
CS	College of Science
IPR	Intellectual Property Rights
MAFW	Ministry of Agriculture and Fisheries Wealth
MEOR	Microbial Enhanced Oil Recovery
NCSI	The National Centre for Statistics and Information
NIS	National Innovation System
NIS	National Innovation Strategy
NRS	National Research Strategy
NT	Network Theory
OAC	Oman Accreditation Council
SQU	Sultan Qaboos University
TH	The Triple Helix model
TRC	The Research Council
TTO	Technology Transfer Office
USOs	University Spin-Offs
WIPO	World International Property Organisation

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# 1. Introduction

## 1.1. Commercialisation of university research

Many governments around the world have recognised the trend towards knowledge entrepreneurship and the significant commercial and social returns that it can provide (Smith and Bagchi-Sen, 2011; Hong et al., 2016; Choi and Lee, 2017; Honjo and Nagaoka, 2018; Shan et al., 2018). Different measures have been adopted at regional and national levels of the systems of innovation to enhance the ability of universities and other knowledge-producing actors to contribute to the commercialisation of innovation, which is known as their ‘third stream’ role (Leydesdorff and Zawdie, 2010; Hekkert et al., 2011; Abreu and Grinevich, 2013; Rajaeian et al., 2018). An innovation system consists of the ‘participants or actors and their activities and interactions, as well as the socio-economic environment within which these actors or participants function that together determine the innovative performance of the system’ (Edquist, 2005, p 24). It facilitates knowledge creation, transfer, and the commercialisation of inventions and discovered technologies (Patel and Pavitt, 1994; Freeman, 1997; OECD 1999).

Accordingly, universities and other knowledge producers have become important actors of innovation systems at national (Lundvall 1992, Nelson 1993, OECD 1999), sectoral (Edquist 2005) and regional levels (Cooke et al. 2000). As innovation process is a result of systemic interactions between actors, knowledge networks are important determinants for innovation activities (Granstrand et al., 1997; Cooke et al., 2004). Whereas new roles of universities emerged, yet the key importance is in the traditional roles of providing other actors with highly qualified graduates, performing research as well providing new knowledge (OECD 1999). These knowledge actors are central elements of ‘knowledge-intensive’ development (Etzkowitz, 1995; Etzkowitz, 1996; Chatterton and Goddard, 2000; Charles, 2006; Charles et al., 2014). Furthermore, an ‘entrepreneurial university’ can become the agent of industrial innovation, technological development, as well economic and social development (Etzkowitz and Leydesdorff, 1997; Etzkowitz, 2008).

In essence, commercialisation of university research is the process by which the outcomes of the research activity are brought to the market place through the development of new products, processes, services or technologies (UNICO, 2009). However, academic entrepreneurial activities are defined as the process of transferring technology to industry and/or the commercialisation of technology, innovation or discovery by means of licensing agreements, research joint ventures and university-based start-ups (Feldman, 1999, Feldman and Martin, 2005; Bercovitz, and Feldman, 2011; Abreu and Grinevich 2013).

Consequently, high-technology/knowledge-intensive industries, like biotechnology, have become important sources of jobs and wealth creation within the context of the knowledge economy (Feldman and Desrochers, 2003; Bercovitz and Feldman, 2006, Etzkowitz, 2003, Etzkowitz, 2008). Scientific knowledge can be transferred to the industrial context via several formal and informal university-industry links, which constitute a large branch of research (Jensen, 2016). Specifically, knowledge transfer and commercialisation of university research offer great potential for promoting innovation capacities and competitiveness at regional and national levels (Cohen et al., 2002; Simmie, 2003; Bennett and Vaidya, 2005). As indicated by Heap (2008):

‘... Instead, knowledge has become commodified, and the boundaries have become increasingly blurred through the mechanisms of funding and the demands of funding bodies. Timescales from discovery to application may be greatly foreshortened, so that in biotechnology, for instance, industry-sponsored basic research into gene regulation can result in the incorporation of genetic engineering into medicine and agriculture within a single decade rather than in three decades’ (Sir Brian Heap, 2008), *Whither universities? In: The University in the Market, P 2.*

However, knowledge commercialisation involves a lot more than the ground-breaking research itself. There are many key drivers for research commercialisation, such as entrepreneurial capabilities, the presence of strong local receptor businesses, knowledge networking and intermediation, and an effective policy framework in the commercialisation management structure. This thesis focuses on the commercialisation of biosciences research in the light of the Omani government’s effort to diversify the dependence on oil, and to pursue the knowledge-driven economy. The thesis advances knowledge of the genesis and transformation of the third mission of knowledge-generating actors in a fledging innovation



system. It attempts to unpack the complexity of the processes of knowledge production, intermediation, and policy making in a dynamic and yet stable institutional setting of the bio-sector. Furthermore, it offers a unique account of different actors and even various interests underlying current government efforts and initiatives aiming at promoting knowledge commercialisation and academic entrepreneurship in Oman.

This is the first chapter in the thesis and aims at introducing the context of the study, and the rationale for conducting it. The chapter also identifies the key research questions, together with the approach taken to address these questions. The structure of this thesis is described in the last section.

## 1.2. Research rationale

Social science research on the commercialisation and knowledge entrepreneurship has flourished in recent years. In particular, the study of the biotechnology experience has become a mainstream endeavour among economists, sociologists, planners, geographers and others. While the literature gives prominence to investigating the third mission of knowledge-generating actors in well-established innovation systems, this process and its actors are less thoroughly analysed in developing systems, which creates an important research gap. This thesis addresses this gap as it explores the commercialisation within the Omani national innovation system. Therefore, it is significant to consider the creation, distribution and use of knowledge, as well as the factors that influence those processes in the light of the current capacities of a fledging innovation system and its stage of development.

By looking at the commercialisation process through its institutional and organisational actors, the thesis provides an opportunity to examine the suitability of the theoretical lenses. The study considers the application of both the National Innovation Systems and the Triple Helix Model as theoretical frameworks in the case of the Omani biotechnology sector. Knowledge commercialisation and academic entrepreneurship have been considered as fertile ground for theory-testing, especially in the context of developing world. Accordingly, the rationale for this research is based on both the relevance for

contemporary work in commercialisation and the gap in our knowledge of the experience of developing countries. The significance of this study lies in the three key themes, which are further developed below: actors and transformation, networks and geography, and the entrepreneurial capabilities.

With regard to the first theme and since the passing of Oman's Economic Vision 2020 in 1995, academia, industry and the public sector have strived to embed the role of research and innovation in Oman's economic growth and social transformation. Several policy instrumentations have been applied to enhance the national system of innovation and the transition to the knowledge-based economy. This vision was based on a previous report that was entitled: Economic balance and sustainable growth within the next stage of development (Oman's Economic Vision 2020, Ministry of National Economy, 1996). The report was prepared by the Ministry of Development (formerly), in collaboration with the World Bank. It addresses the main challenges facing Oman's economy and it outlines the policies and mechanisms needed to achieve that vision through three main dimensions: human resource development, economic diversification and private sector development (Oman Economic Vision 2020, 1996).

The diversification of the economy has remained the central long-term objective of the national economic policy. In this regard, the Oman Vision set two targets, which are reducing the share of oil in the national GDP to 9 % and raising the share of gas to 10% by the year 2020 (Oman Economic Vision 2020, 1996). This vision also aimed at pursuing a high value added strategy, which was characterised by adopting capital-intensive production methods based on advanced technology, scientific research and innovation. It also included the development of a dynamic, efficient and competitive private sector, and the support of small and medium scale enterprises. More recently, the role of research and innovation in Oman's economic growth was placed at the centre of intense national debate. In response, Royal Decree No (54/2005) was issued to establish the Research Council (TRC) with a mandate to support science and technology organisations and to manage research and innovation activities in Oman.

Among the National Innovation actors, universities play a central role in the advancement of science-based industries, such as biotechnology (Kato and Odagiri, 2012). The growing role of universities implies the need to engage in a second academic revolution by enhancing the third mission of knowledge commodification and academic entrepreneurship (Gibbons et al., 1994; Stokes, 1997; Mok, 2005). University systems throughout the world are shifting towards knowledge commodification, indicating a fundamental transformation of the conventional university mission to the notion of entrepreneurial universities (Etzkowitz and Leydesdorff, 1997).

Similarly, local knowledge-associated institutional spheres of the national innovation system in Oman shifted towards applied research in attempts to enable economic and social returns of publicly funded research (National research Strategy of Oman NRS, TRC, 2008). Since the mid-1990s, knowledge-producing actors have witnessed many changes and transformations and followed different paths to develop their organisational capabilities for knowledge commercialisation. Specifically in the biosciences sector (bio-sector), knowledge-producing actors do not take longer-term and strategic approaches to their research activities (NRS, TRC, 2008). Despite the considerable changes in the knowledge production process, only a few research projects have succeeded in becoming commercialised into products or services.

For local knowledge-producing actors, the key aspect is how to achieve the balance between curiosity-driven basic research and the directed, user-driven, applied research, while enhancing knowledge entrepreneurship. Universities and non-academic knowledge actors are embedded in a web of interactions and operate according to a set of formal policies, regulations, as well informal norms and procedures. Each actor performs at least one of the functions that are required by a well-functioning system of commercialisation, subject to the readiness of the actors to accommodate the 'third mission' beside the primary roles of education. This represents the theme of networks and is comprised of two overlapping networks: the actors that create, diffuse, and use knowledge; as well, the actors that shape policy and implement them. In order to understand the interaction between the

supply and demand of knowledge, it is essential to acknowledge the behaviour of the actors and their social and cultural dimensions.

Another important theme that this thesis addresses pertains to circumstances under which commercialisation operates; the bio-sector. The sector offers an interesting example of a promising economic sub-set whose main features are high levels of dynamism and, as having enjoyed privileges of political interest throughout the study time. According to the NIS (2008), biotechnology is considered as a key strategic focus area and one of the national research priorities (NRS, TRC, 2008). Since the mid-1990s, many biotechnology initiatives emerged in both academia and in the public sector, such as the establishment of the Centre of Excellence in Marine Biotechnology (CEMB) in Oman's main university and the hosting of the UNESCO Chair in Biotechnology. The bio-sector has managed to produce a considerable scientific output in the form of steep increase in publications and number of biosciences graduates. However, the translation of such achievement in science into the generation of economically and socially relevant products and services has been limited. Significant public investments have been directed towards the development of human resources and the construction of sophisticated laboratories, as well the availability of research funds. These investments created challenges for academic and non-academic knowledge-producing actors in their path to develop capabilities for commercialisation and academic entrepreneurship.

Like most developing countries, the 'linear' perception that investing in research and development activities will lead to innovation underpinning the public policy initiatives, has contributed to this status. These limitations can be partly due to the manner the innovation system has been developed with public research and educational organisations as the system's key knowledge-generating actors. Policy actors have been slow to adopt a systemic understanding of knowledge production, diffusion and use, and continued to treat research investments in universities and public research organisations in a linear approach (NRS, TRC, 2008). There are also challenges with coordinating the design and implementation of policy initiatives among different actors. This implies the need to connect the development

of the Omani national innovation system with the overall economic, structural and intuitional development.

The context outlined above indicates that this thesis aims at filling the research gap regarding our understanding of various aspects of knowledge commercialisation within a fledging system of innovation. The significance of this thesis lies in the understanding it offers for the overall process involved in the production, diffusion and application of knowledge as well as the factors that influence commercialisation. As commercialisation is essentially the result of an interactive process between various actors, thinking in terms of systems of innovation shifts the emphasis of studying the supply or the demand for science and technology separately towards issues that affect the interactions between them. The thesis thus looks beyond the commercialisation and its actors, and provides insights into the institutional setting for knowledge entrepreneurship, as well as the social and cultural dimensions of the topic.

To summarise, the focus of this thesis is driven by a number of important aspects of research commercialisation. Firstly, it examines the commercialisation actors and transformation of their entrepreneurial capabilities within the Omani national innovation system. Secondly, the thesis seeks to extend our understanding of the characteristics of knowledge generated by these actors, as well as intermediation processes and the policy framework. Thirdly, it considers knowledge networking and the geography dimensions of the topic, such as proximity and selection mechanism in networking in the context of multi-actors interactions based on national interests (economy diversification) on one side, and the particular actor's interest on the other side.

### 1.3. Research questions

The research rationale presented above pose a case for investigating a complex commercialisation process in the bio-sector from the NIS perspective. Research questions are framed to grasp both the micro-level of the actors and networks, as well as the broader context of the national systems of innovation, which are the support mechanisms. The first research question is: *Who are the key actors for commercialisation of the bio-sector within the*

*Omani national innovation system's institutions?* It aims to understand the structure of the bio-sector by identifying the key actors and their characteristics. It is addressed by reconstructing the full picture of the NIS in the bio-sector. Thus, while focusing on actors and institutions it invites further queries. Which key characteristics and interests of the actors that influenced knowledge production in the bio-sector? Why were these characteristics significant during knowledge sharing and use? What have been the roles of cultural and social features of the actors during the transformation to knowledge commercialisation? Perspectives from distinctive work in organisational sociology (Powell and DiMaggio, 1991; Powel et al., 2005; Huggins et al., 2012; Huggins; Johnston and Thompson, 2012) are referred to in the analysis of actors and their characteristics.

The second question is: *How are the commercialisation actors in the key institutional spheres transformed towards knowledge commercialisation and entrepreneurship?* It examines the transformation of the three institutional spheres and contributes to assessing the drivers and the path for the change. Furthermore, it addresses a frequently asked question: what is the role of the government in the transformation? It also uncovers the internal transformation within the institutional sphere, and investigates in depth the trans-institutional change and the role of intermediaries as well as the bottom-up initiatives. This question contributes to the understanding of how the involvement in knowledge-entrepreneurial activities has changed at the individual, organisational and institutional levels. Insights from the evolutionary literature (Nelson and Winter, 1982; David and Foray, 1994; Leydesdorff and Van den Besselaar, 1994; McKelvey, 1996; Nelson, 1994; Cooke, 2001; Cooke, 2005; Huggins and Thompson, 2012) are utilised for the study of the path for transformation in response to internal and external drivers. In a similar manner, the concept of the 'entrepreneurial university' (Etzkowitz et al, 2000; Etzkowitz and Leydesdorff 2000; Etzkowitz, 2003) is applied to study the transformation in academic knowledge-producing actors.

Drawing on the 'knowledge networks' (Powell and Smith 1994; Podolny and Page 1998; Powell and Snellman, 2004), the third question is: *What are the modes and dynamics of knowledge networks in the bio-sector?* It gives special attention to knowledge networking and

actors' interactions through addressing the antecedents of interaction between knowledge producing organisations and external actors in the bio-sector. By unpacking them, the thesis answers why certain modes of interactions are preferred. It advances the knowledge about bilateral and trilateral linkages, as it not only asks which are the important motivations for linkages but inquires further, why and under what circumstances their importance increases. It examines the role of local networks, inter-organisational collaboration and knowledge flows as 'the principal source of technological dynamism' (Cohen et al., 2002; Abramovsky et al., 2007; Bozeman and Gaughan, 2007). At the same time, it expands the issue of network dynamics and mechanisms for partnerships.

Question four is: *What is the influence of network resources, spatial proximity, and intermediaries on knowledge networking in the bio-sector?* It examines the claims regarding the role of boundary spanners in facilitating collaboration between all sets of actors (Torre, 2008; Lorentzen, 2008), as well the geography of knowledge flow over networks (e.g. Feldman, 1999; Howells, 2000; Owen-Smith, 2004). It contributes to the debate about the role of different dimensions of proximity on the knowledge networking between the actors (Boschma, 2005). Furthermore, it uncovers the sociological perspectives on inter-organisational networks in terms of 'cultural differences and institutional support mechanisms' between the bio-actors (Fini et al., 2011; Hewitt-Dundas, 2011; Perkmann et al., 2011). By tracing linkages and actors in questions three and four, the thesis is able to contribute to wider debates: the formal versus informal linkages, proximity and networking, and mechanisms for selection of partners (e.g. Saxenian, 1991; Ernst, 2000; Salter and Martin, 2001; Zellner, 2003; Giuliani, 2005; Hu, 2007; Vincett, 2010; Roessner et al., 2013; Huggins, et al., 2014; Huggins, and Thompson 2016; Huggins, and Prokop, 2017).

Accordingly, questions three and four add to the existing knowledge of the links and interactions between the actors in three significant ways. They provide insight into the trilateral links in the bio-sector by presenting a comprehensive status of the antecedents, modes of interactions, and motivation for networking in both academic engagement and commercialisation-related activities. They also tackle the role of geography and gatekeepers in these interactions, an issue that is expected to be distinctive in the context of this study,

which is an area that is currently less researched. In addition, this study fills the gap in the knowledge about the network setting in economies that pursue the establishment of knowledge clusters by emulating successful national examples, specifically in the biotechnology sector.

The last research question that is: *What are the implications of commercialisation capabilities and government initiatives on the transition to knowledge entrepreneurship, tackles* broader area of investigation, which are the commercialisation capabilities and government initiatives. It aims to assess the extent to which actors' capabilities has influenced the process of commercialisation. This includes both the hard and soft entrepreneurial capabilities of the actors. The question also addresses the role of national commercialisation-related policies and government initiatives in accelerating the transition to knowledge entrepreneurship. It offers novel insights into the process of policy formulation and the dimensions of government support. It contributes to the understanding of actors' perspectives regarding the support mechanisms of the systems of innovations, such as emulating of foreign policies in a different institutional context, e.g. the US Bayh-Dole Act, and Patent and Trademark Law Amendments Act (1980) (Sato, 2010; Autant-Bernard et al., 2013; Jacobsson and Dahlstrand, 2013). To conclude, this thesis is guided by five research questions as below:

1. Who are the key commercialisation actors of the bio-sector within the Omani national innovation system's institutions?
2. How are the commercialisation actors in the key institutional spheres transformed towards knowledge commercialisation and entrepreneurship?
3. What are the modes and dynamics of knowledge networks in the bio-sector?
4. What is the influence of network resources, spatial proximity, and intermediaries on knowledge networking in the bio-sector?
5. What are the implications of commercialisation capabilities and government initiatives on the transition to knowledge entrepreneurship?

Pulling these threads together, the overall aim of the thesis is to assist in understanding how commercialisation and knowledge entrepreneurship came to be included within the roles of knowledge producing actors in the bio-sector. It draws on multiple theoretical lenses



of National Innovation Systems (NIS) perspective, the Triple Helix (TH) model, and Network Theory (NT) as well as several data source from interviews with academics and researchers, policy-makers, industry representatives, and the questionnaire along with documents content analysis. By employing a multi-angled theoretical prospect and empirical data, the thesis aspires to look at the topic of commercialisation from a perspective of several stances.

Firstly, this thesis responds to the research questions while giving special attention to the diversity of commercialisation actors, their interests and characteristics, as well as their interactions with each other. Moreover, the questions are framed to ensure reaching beyond the mere analysis of the process within the NIS, but allow additional important aspects to be involved. This is due to the distinct character of the fledging systems of innovation and the structure of the actors in the Omani bio-sector, which is based on universities and other knowledge-producing actor's primary role in innovation creation. This research thus considers government and academic as well as less formal sources of innovation. Furthermore, this framing takes into account the theoretical underpinnings employed and provides space for analysis of the social and cultural setting of actors and their importance for shaping the transition to the third mission. In this way, it contributes to examining the role of actors' characteristics and specifically the centralisations of roles.

In a similar manner, it explores interactions between commercialisation actors and external organisations, by offering an in-depth analysis of the motivations and dynamics of networking drawing on the literature of proximity. This thesis instead of analysing the various actors separately advances the debate by examining the trilateral linkages of the actors' networks at the same time. Furthermore, special attention is given to role of intermediary actors and network resources and by this; network theory is placed in a distinctive, institutional context (Public Research Centers, universities, government departments, sectoral organisations, private sector and non-governmental organisations). Finally, theoretical advancement is offered by the multi-angled approach to the NIS, which is supplemented by the TH model and network analysis.

Finally, the ranges of themes, which are addressed in this thesis, enable it to speak to a number of current scholarly debates in the field of economic geography. It tackles the

transformation of knowledge commercialisation in less studied system of innovation; thereby uncover the role actors and institutions. It contributes also to the understanding of the dynamics of inter-organisational and trans-institutional linkages while looking at the role of innovation intermediaries and spatial characteristics. While employing a multi-angled theoretical framework, the research serves to study the macro-level of the topic like policy instrumentation, as well as the sectoral level, such as the role of bottom-up initiatives in the bio-sector.

#### 1.4. Structure of the thesis

The previous sections have defined the main issues this thesis is aspiring to tackle and the RQs it seeks to address. Taking into account all the bases mentioned above, the thesis sets out firstly to present the main theoretical discussion and to examine the literatures concerning knowledge commercialisation. The second chapter is thus tasked with introducing the theoretical framework of the study and reviewing the concepts relevant to commercialisation. The key contribution of the chapter is based on proposing a novel approach of investigating commercialisation within NIS by involving TH model and Network theory (NT). Firstly, drawing on the scholarship of Freeman (1995), Nelson (1993), and Lundvall (1998), a brief account of development of NIS perspective is presented. The rationale of this new approach is based on interest in the wider context of the national systems of innovation to grasp a macro perspective while the TH and network analysis provide a robust framework for investigating actors' interactions and their institutional contexts. The latter part of the chapter outlines the main stream of work in commercialisation field with special attention to the biotechnology sector. As a whole, the chapter indicates the main research gaps of the current studies and provides a context for the analysed issues.

In chapter 3, Oman's country information is presented including location, demography and economics. This is followed by the description of the economics importance of the biological resources as one of the promising non-oil sectors for economy diversification. The chapter draws from the national innovation elements to present research and innovation ecosystem of the bio-sector that includes Research and Development (R&D) personnel and

human capital, R&D expenditure, the business environment, governance and policy framework. Additionally, the chapter presents the strengths and weaknesses of the NIS of the bio-sector.

Chapter 4 explains and justifies the epistemology and methodology of the thesis. It clarifies how a Critical Realism (CR) stance and the mixed method design have been employed to provide a multi-angle perspective and also to be able to answer the “how” and “what” questions. This chapter is focused on the two main tasks (questionnaire and interviews) of the fieldwork conducted in Oman, which informed the research. It explains the approach of performing data collection through on-line questionnaire as well as the interviewing process. The chapter also presents the methods of data analysis and describes how other sources of data (field notes, policy documents, and government report) added to the quality of the fieldwork outcomes. Equally importantly, the chapter briefly discusses ethical issues relating to the study.

Chapter 5 is the first empirical chapter that addresses research questions one and two. It provides an account of the national innovation system actors in the bio-sector and explains the path and drivers for transformation towards knowledge entrepreneurship in the key institutional spheres. Not only does it draw from secondary data and policy documents, but also employs first-hand accounts perceptions from interviewees who, either worked at knowledge-producing organisations or have been close to the decision-making processes in the government. Moreover, the chapter addresses an important gap identified by the interviewees: the role of bottom-up proposals in developing institutional setting.

Chapter 6 focuses on the second element of the systems of innovation, which is the linkages between the commercialisation actors in the bio-sector, and hence draws on both questionnaire and interview data. It continues answering research question two and starts answering research questions three and four. It also responds to parts of question five. The chapter provides a unique blend of accounts provided by biosciences academics, policy makers, representatives of intermediary actors and the business as well as retired public sector staff. It is argued that the interaction between knowledge-producing actors and external organisations is phase-dependent with specific features for both bilateral and

trilateral linkages. By considering the key phases of the networking process, this chapter discusses the dynamics and motivation to interact along with the role of network resources, geography and intermediaries. Additionally, it offers an analysis of the mechanisms of selecting partners between network actors.

Chapter 7 positions the debate on the commercialisation in the context of the national governance system for science and innovation while focusing on the role of government initiatives. It thus concludes the response to questions two, three and four to address question five. Drawing on interview data, the chapter unpacks the impact of entrepreneurial capabilities and support mechanism of the commercialisation actors. It discusses the perception of the actors about the implementation of imported policies, and assesses the type of policy instrumentation that is followed by the government to enhance the development of knowledge entrepreneurship. Whereas the attention of this chapter is directed towards governments' actions, it includes the influence of sectoral organisations and individual initiatives by offering an in-depth analysis of the 'commercialisation spaces'.

Finally, Chapter eight reflects on the results of the study by building on the empirical material presented in the whole thesis. It summarises the most important findings and connects them to the current scholarly debates. The thesis suggests a larger focus on incentives for linkages and interactions between the key actors that the government should consider. Secondly, it proposes a more intense involvement of the industry in building of the entrepreneurial capabilities and culture. The chapter concludes with suggestions of future research that can be built on the foundations set by this thesis.

## 2. Literature review and contextualisation

### 2.1. Introduction

This chapter engages with two main topics; the theoretical perspectives of the thesis and the overview of the existing knowledge and research gaps relevant to the subject matter. It is divided into five sections. Firstly, the theoretical underpinnings are discussed to explain the multiple-theoretical approach that is employed in this thesis. Then the chapter reviews the existing commercialisation scholarship in the field of innovation studies, knowledge entrepreneurship and more broadly, economic geography.

The second section analyses knowledge commercialisation in the biotechnology from the viewpoint of its economic impact. In this part, attention is given to the three dimensions of economic benefit, which are university licensing and spin-offs, tacit knowledge transfer through researcher mobility, and impact of science parks and technology incubators. Further in the third section, the transformation towards the third mission is discussed with regards to its drivers, path and the institutional support mechanisms.

The fourth section examines University-Industry linkages from several perspectives: the motivation and benefits of interactions, the geographical dimension, and the role of intermediaries. The existing research on biotechnology networks is presented to elucidate the rationale for engaging multiple components of the innovation system to the problem. The fifth section offers a closer examination of the commercialisation policy following the release of the United States' Bayh-Dole Act. This allows identification of the policy instrumentations and directs the argument towards the issue of direct versus indirect policy framework under which the sector is operating. Finally the chapter concludes by drawing together the material presented in the chapter and the multi-angled theoretical approach that is employed in this thesis.

### 2.2. The theoretical framework

As becomes clear, knowledge commercialisation and academic entrepreneurship are interactive practices that engage several actors and linkages. The topic is enmeshed in larger

debates, particularly: the national systems of innovation and entrepreneurial ecosystem, knowledge networks and University-Industry (UI) linkages, as well as commercialisation policy. This thesis is involved with the transformation of knowledge actors in the bio-sector, the dynamics of interactions, the role of entrepreneurial capabilities and policy framework, and the social and cultural dimension of actors that extend beyond commercialisation itself. Hence, its theoretical background draws more heavily on economic geography than any other discipline. Accordingly, this thesis adopts a multiple theoretical approach that includes the National Innovation Systems (NIS) approach, The Triple Helix (TH) Model, and Network Theory (NT).

Adopting and integrating a framework based on multiple theoretical perspectives is motivated by the intersections of various spheres of practices (academia, government, and industry) that are present in this research. Taking into account the themes of this thesis, the model enabled grasping both the dynamics of transformation and interactions of commercialisation actors while keeping the analysis of a broader commercialisation picture at the national system of innovation still present. Furthermore, it has allowed linking the methods that stem from the three approaches applied.

In a broader sense, this section offers explanation of how the three theories characterise the world this thesis investigates based on the explanatory mechanisms they provide. As these theoretical approaches have been successfully applied for research on knowledge commercialisation, they are described with special attention to their significance to this thesis. This section starts by presenting their basic assumptions, criticisms that they face and their theoretical relevance for the analysed issue. Further, it explains how and why the NIS is utilised as the main theoretical framework for the thesis in complementary to two more approaches; (TH) and (NT).

### 2.2.1. The first theoretical lens: the National Innovation Systems (NIS)

Considering the context of the analysed issue, the NIS promises to be the main theoretical framework among the three theories applied. Central to this thesis is a need to understand the role of national innovation components in which the bio-sector is functioning, for which

NIS has advanced a series of important propositions. Firstly, NIS gives prominence to the focusing on the question of which institutional elements shape the commercialisation process. Secondly, it allows one to study the connectivity and the interactions between economic actors. Thirdly, this approach provides for classification of the innovation-relevant actors, thus it allows more understanding of processes of knowledge creation and reproduction. More precisely, the NIS theoreticians would claim that the approach is a mean to understand the impact of organisations and institutions on national innovative activity that is seen as the result of interactive processes determined by various actors and framework settings (Lundvall, 1992; Nelson, 1993; Patel and Pavitt, 1994; Freeman, 1995; Edquist, 1997).

The concept of National Innovation System derives from the scholarly work by Freeman (1995), Nelson (1993), and Lundvall (1998), among others. It inspired interest into this line of inquiry of both academic scholars and policy-makers, since late 1980s. Lundvall (1992) defines NIS as ‘the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge and are either located within or rooted inside the borders of a nation state’. While, Nelson (1993) describes it as ‘a set of *institutions* whose interactions determine the innovative performance of national firms’.

The more inclusive definition appears to be that of Metcalfe (1995), which elaborates it as ‘a set of distinct institutions that jointly and individually contribute to the development and diffusion of new technologies and provides the framework within which governments form and implement policies to influence the innovation process’ (Metcalfe, 1995, p 460). Historically, Lundvall has first introduced the term NIS, however, the first systematic and theoretical attempt to pursue national systems of innovation goes back to Friedrich List’s notion of ‘the National System of Political Economy’ and von Hippel’s work on informal technical collaboration among firms (Freeman, 2000). According to Freeman (1997), the NIS is ‘the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies.’

Over time, the approach has become further refined and it gained additional concepts, such as the financial systems and the role of the state, as reported by Vertova (2014), in

particular production systems and became National Systems of Innovation and of Production (NSIP) (Vertova, 2014). Therefore, additional level of analysis of the interactions and co-evolutionary dynamics developed. For Freeman (2002), the analysis tackles five sub-domains and their related institutions, which govern knowledge generation, the technology domain, the 'economic machine', the political and legal structure; and finally, the cultural domain that shapes values and norms (Freeman, 2002).

The approach of national systems of innovation draws on three theoretical premises: first, technological development is assumed the key driving engine behind economic growth (Romer, 1990; Edquist, 1997). According to OECD (1999) report, the NIS is based on the main assumption of New Growth Theory that is the significance of increasing returns to knowledge accumulation from investment in new technologies and human capital (OECD, 1999). Second, the NIS approach is based on the assumption that economic agents, e.g. firms, do innovate mainly to survive and succeed in an enormously competitive setting caused by accelerating pace of globalisation (Wu and Pangarkar, 2006). Third and foremost, the approach has stemmed from the central realisation that national institutional configurations, are significant for the analysis of how technological capabilities are built, sourced, diffused, and harnessed (Nelson 1993; Freeman, 1995; Edquist, 1997; Lundvall, 1998). However, with increased internationalisation '... national borders are losing their meaning as economic frontiers' (Howells, 1997), and technology is becoming a product of 'interlinked economy' (Batholomew, 1997).

Furthermore, involvement of institution is central in the creation, diffusion and utilisation of knowledge, which implies the interconnection of different actors (Freeman, 1987, Lundvall, 1992). As stated by Hauknes (1999), the NIS literature 'reflects Marx's broad conceptions of the economy as a social process' (Hauknes, 1999, p.1). The most important institutions, therefore, are the following: innovative firms; public and private institutions conducting and supporting research and promoting the diffusion of knowledge and innovation; the systems of education and training of the personnel; and financial systems (Freeman, 1995). As indicated in prior literature, institutions provide incentives through norms and regulations, as well as its position within the institutional setting, as Solow (1985)



stated “Economic activity is always embedded in a web of social institutions, customs, beliefs and attitude” (Solow 1985, p. 325).

In essence, institutions are defined by institutional theorists as ‘systematic patterns of shared expectations, taken-for-granted assumptions, accepted norms and routines of interaction that have profound effects on shaping the motivations and behaviour of interconnected social actors’ (Chang, 1994, p.84). This is consistent with the NIS approach that has pursued to tie national institutions to the innovative performance of firms and economic actors (Freeman, 1995; Lundvall, 1998; Nelson, 1993). Based on her study of biotechnology innovation systems of different countries, Batholomew (1997) argues that ‘national patterns in biotechnology R&D are primarily shaped by the configuration of country-specific institutional features and the particular national path of technological development in turn reinforces country-specific patterns of organisation’ (Batholomew 1997, p. 243). Therefore, innovative activities of the US biotechnology industry are thought to be motivated by the individualistic, commercially oriented and self-sufficient characteristics, unlike their Europe counterparts, which are more diverse but much less commercially oriented.

The NIS approach accounts for two positive impacts, on the one hand it has supported a general shift in the attention of economists and policy makers toward national policy strategies (Yoon and Hyun, 2009). On the other hand, the ‘system’ dimension of the term has transferred the interest in policy circles in terms of research and development from linear to interactive thinking of innovation. This can be considered as a shift from ‘Science Policy’ and ‘Technology Policy’ to ‘Innovation Policy’ (Lundvall and Borrás, 2004), as it extended the typical set of policy instruments with more focus at fostering linkages and strengthening the absorptive capacity of knowledge actors.

Principally, ‘private firms with an explicitly defined R&D function are the primary actors in the generation of technology, and for applying them in the search for competitive advantage, as well in the development of tacit knowledge (Metcalfe, 1995). For example, Nelson defines innovation as the process by which firms master new technologies, with firms as the primary locus of industrial innovation (Nelson, 1993, p. 4). Other kinds of actors and

institutions are significant, but they are still considered as peripheral components of the innovation system. Thereby, the academia sphere is less concerned with the development of technological artefacts, and only contributes in terms of knowledge and skill to support firm activities. Thus, the 'component institutions' make complementary contribution to the innovation process, but they differ significantly with respect to motivation and with respect to dissemination of the knowledge they generate' (Metcalf, 1995, p 465).

The NIS approach has been a focal point for researchers across different fields of economic and innovation studies. The concept takes into account and integrates the importance of the economic environment for firms' opportunity to innovate, giving rise to two important and interrelated topics. On the one side, it presents international differences or similarities in countries' ability to innovate. On the other side, it acts as a normative tool provides policy recommendations in order to support firms' innovative capabilities (Yoon and Hyun, 2009). Some see the analysis of the national systems of innovation as an important framework as 'having its explanatory power' (Yoon and Hyun, 2009), hence answering the questions that economic geographers tend to ask: 'How?' 'what?' and 'why?'- these clearly correspond with the research questions this thesis is asking.

First, one vital enquiry for this thesis is the evolution of knowledge entrepreneurship in knowledge producing actors, in the light of the hypothesis that there is a 'trade-off between traditional and third mission activities' (Larsen, 2011). Second, the analysis takes into account characteristics of biosciences' knowledge that is produced by these actors and in particular, the university as an economic actor that is a 'provider of both public and private goods' (Deiaco et al., 2012). A third, complementary line of investigation is the role of knowledge networks where the concern here is the institutional linkages between the bio-based industry, on the one hand, and the publicly funded 'science base' in universities and similar institutions, on the other hand. Therefore, the themes that are analysed in this thesis pertain to address the question from three dimensions that are the actors, the knowledge, and networks.

Only when the Omani Government started to consider the biological sector as another economic sector that potentially can be utilised for economy diversification, did the sector

and its actors gained momentum in public policy agendas. Accordingly, the transformation of the university into an economic actor attracted the interest of researchers and policy makers, especially in light of government' efforts to strengthen its NIS. However, the type of actors and the distribution of commercialisation-related activities in Oman differ fundamentally compared to the developed economies. Indeed, in the context of Oman's bio-sector, universities and public research centres are assumed the locus of both education and research. Recognising the significant role played by firms as the prime locus of innovation within NIS, the concern in this thesis is at integrating both micro- and macro-levels analysis of commercialisation process in order to fully grasp this complex phenomenon.

Considering the theoretical advances in the NIS approach, Gibbons and his colleagues (1994) moved further the debate by introducing Mode 2 Innovation model that is characterised by continuous flow between basic and applied knowledge and organizational divergence in knowledge production. Therefore, knowledge is produced in different loci through 'a process of continuous negotiation of needs, interests and specifications of all the involved actors' (Jacob et al., 2000, P 27). With the diversification of knowledge production, firms remain the leading actor, suggesting decline in the role of universities. However, innovation cannot be reduced to the level of firms, and this is the first perspective that the NIS fall short within.

At the central thinking behind the analytical framework of NIS, are two major branches of economic theories, which are the evolutionary theory and the institutional theory (Hauknes, 1999). Therefore, the NIS approach can be viewed in evolutionary terms with reference to how different national systems create diversity, reproduce routines and select firms, products or routines. This thesis aims to study the evolution of knowledge entrepreneurship and to identify the drivers for such transformation. Accordingly, the NIS approach is useful when a focus on coevolution of production structure, technology and institutions are applied to understand the historical transformation of the systems' components, as stated by Lundvall, 2005:

I would argue though that the most important reason for seeing NIS as an evolutionary concept is the strategic role it gives to knowledge and learning. The analysis of innovation

systems may be seen as an analysis of how knowledge evolves through processes of learning and innovation (Lundvall, 2005, p 79).

Therefore, the evolutionary dimension forms the core of the NIS concepts. As presented in the introduction to Lundvall (1992), 'the most important resource in the economy is knowledge and the most important process is learning' (Lundvall, 1992, p 11). However, elements of knowledge important for economic performance are localised and embodied in the minds and bodies of agents, in routines of firms and in relationships between people and organisations. Hence, the most basic characteristic of the innovation system approach is that it is 'interactionist' (Lundvall, 1992). The process of interactive learning is socially embedded and therefore a purely economic analysis is insufficient.

This relates to the objectives of this thesis that attempts to put attention to issues of organisational capacity and learning of the actors within the NIS that are involved in commercialisation and knowledge entrepreneurship processes. It is well accepted that the learning economy is 'more than a mere accumulation of scientific knowledge, but an economy based on the adaptability of individuals, firms and other organizations' (Lundvall and Johnson, 1994). Thus, 'governments are increasingly looking at innovation policy as a way to promote sustained economic growth' (Lundvall and Borrás, 1998). Such perspective looks into different types of activities performed by the system, so government role supports not only the activities related to the provision of knowledge (R&D investment, and human resources development), but also at the demand-side activities, by supporting business services to firms (Edquist, 2008).

Drawing on all these theoretical grounds, the analytical framework of this thesis links the characteristics and activities of the actors within the NIS to the evolution of entrepreneurial capabilities and networks. It is a useful guiding line to examine commercialisation and knowledge entrepreneurship processes, in addition to the role of geography and the interfaces between academia and industry. Among other entrepreneurial capabilities, it is functional to examine the role of policy framework for commercialisation where efforts towards change have taken place in related economic sectors in Oman.

In more practical terms, national systems for innovation are systemic in a way that different components are interdependent and that linkages count for innovation performance. The connectivity between these components is achieved via formal links such as researchers' mobility and collaboration grants, as well as informal links. Technology embodies a certain degree of tacit knowledge that is local and cumulative (Kogut and Zander, 1993; Nonaka 1994). Different forms of linkages are significant for technology transfer and to acquire tacit knowledge. Thereby, innovations usually stem from search and learning processes of both individuals and organisations, and in turn, building of knowledge is embedded in organisational or behavioural routines.

In addition to the linkages between the actors, the NIS approach takes into account the role of interface between science and technology spheres concerning the effective transition of scientific knowledge into products. However, the management of these interfaces poses number of difficulties such as 'the distribution of creative talent between two worlds, The balance between research and skill formation in higher education, links with and sponsorship from industry undermine the openness and development of basic science' (Metcalfe, 1995, p 465).

At this point, it is significant to shed some light on the key methodological and analytical issues enclosing empirical studies informed by the NIS approach. First, while NIS researchers has gradually abandoned the conventional approach to measuring and quantifying innovative performance (e.g. input and output method) , alternative methods have not yet put in place (Yoon and Hyun, 2009). Critics would argue that such limitation weakens the analytical power of the NIS framework despite the recent on-going research efforts, which attempt to alleviate the issue by bringing together several set of indicators equivalent to each innovative activity. Batholomew (1997)'s comparative study of the US, UK, German and Japanese systems of biotechnology innovation systems, that mentioned earlier, can be considered as an attempt to overcome such difficulty, as her analysis of knowledge flows between intertwined actors is largely based on qualitative data.

Second, the level of analysis is at the core of the NIS approach and recent empirical research has extended the analysis to different levels including supra national and sub-

national along with sectoral and technological (Yoon and Hyun, 2009). Indeed, significant industrial and regional variations remain even within the NIS, suggesting supremacy of one level of analysis against another on methodological basis. However, the analysis at different levels can be complementary, and serving various purposes.

A third issue is of the call for more systemic approaches to the study of NIS (Nelson, 1993; Lundvall, 1998; Archibugi *et al.*, 1999). For instance, Liu and White (2001) argue in their discussion of the Chinese innovation system that although it aims to analyse systems, ‘...most scholars have actually focused on the roles of specific actors and the impact of specific policies and institutions to explain system-level outcomes - no way to describe alternative system level structures of which actors and institutions are only elements, and hence no way to make comparisons among alternative systems’ (Liu and White, 2001).

Although the NIS brought new and complementary direction into innovation studies and knowledge-based perspective on technical change, it has however encountered several difficulties that need consideration. According to Vertova (2014), the definitions are so broad that they can encompass almost everything; (2) while all definitions share the essential role played by institutions, the state and its policy are not explicitly stated; and (3) it is not obvious if the NSI concept is a descriptive or a normative tool (Vertova, 2014). Therefore, the adoption of the concept for simply describing the role and performance of particular actors, institutions and policies, is considered too straightforward. Even though these categories are applicable for this thesis, they may be insufficient given the complexity of the issues tackled and variety of actors involved.

This thesis aims at understanding the characteristics of commercialisation actors and the evolution of the third mission in knowledge producing actors. Therefore, consideration of interactive learning between actors calls for more detail referring to specific regions and sectors rather than remain at an aggregate national system’s level. The locus of innovation in the biosciences sector is not the firms; therefore, the role of other actors needs to be included. In addition, the negotiated character of knowledge production and its context-dependence character suggest that diffusion of knowledge is acquired via researchers

mobility from one context to another making the transmission of tacit knowledge unachievable, suggesting the role of knowledge networks and geography.

Therefore, the NIS approach requires enhancement with a model that does not decline the role of actors, enhanced and evolutionary role of actor, as well as inclusion of new-non ordinary potential actors. Some of the crucial ideas inherent in the innovation system concept on (vertical interaction and innovation as an interactive process) appear in Porter's industrial clusters as well as in Etzkowitz and Leydesdorff's Triple Helix-concept (Etzkowitz and Leydesdorff, 2000).

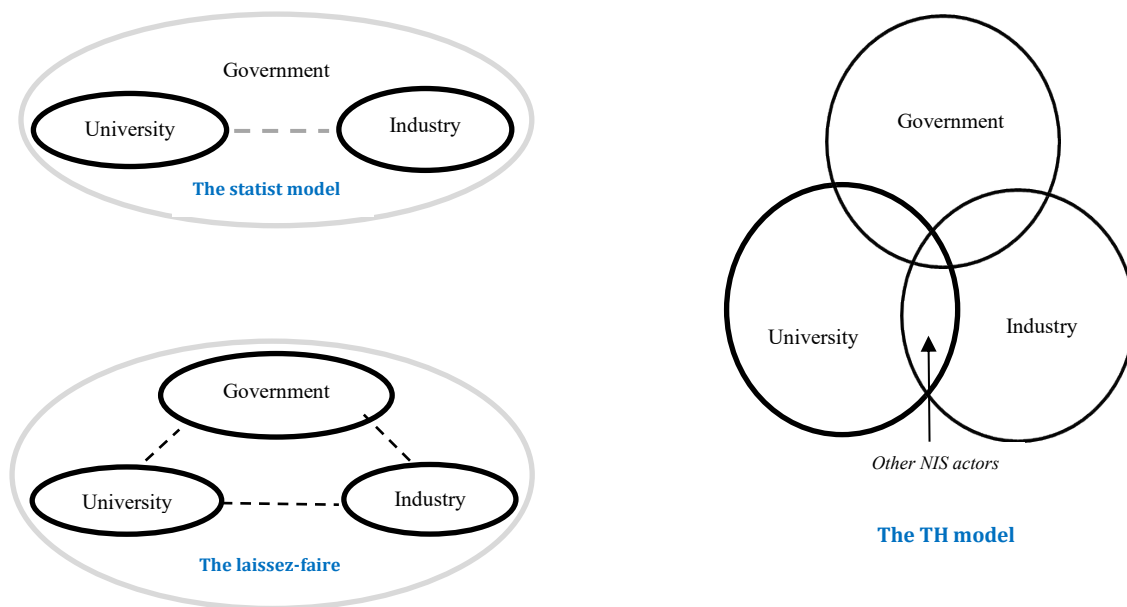
### 2.2.2. The refinement provided by the Triple Helix (TH) Model

Following the explanation of NIS's appropriateness, this section shows how the Triple Helix (TH) model advances the understanding of the interactions of commercialisation actors drawn by NIS. The TH looks at the exchanges between the stakeholders in a more refined manner by focusing much more on 'why' and 'how' questions rather than simply 'what'. The TH model of university-government-industry interactions has a prominent position in innovation studies and was first introduced by Etzkowitz and Leydesdorff, in 1997, for the analysis of innovation in a knowledge-based economy, which implies a new role for universities that extends beyond teaching and research including the mission of enterprising.

The model is a non-linear paradigm, which explains interactions between the key knowledge actors that are referred to as 'spheres of influence' (Etzkowitz and Leydesdorff, in 1997): universities as knowledge producers; industry/business representing the users of knowledge; and the government, which controls knowledge acquisition through its policies and regulatory framework. According to Leydesdorff and Etzkowitz (2001), the TH approach 'opens a window on a universe of discourse that generate a set of coordinates transcending the points of reference of discourses that previously took place within separate institutional spheres' (Leydesdorff and Etzkowitz, 2001, p. 4).

The TH model emerged from two opposing standpoints; the statist model with the government dominates other institutional spheres (Figure 2.1), and the laissez-faire model

where industry, government and university operated separately and interact across strong institutional boundaries (Etzkowitz, 2008). The pathway towards the TH model is derived by a movement towards greater independence of both university and industry from the government, but greater interdependence of these institutional spheres. In the statist model, the government plays a dominant role and is expected to take the lead of developing projects and resources for initiatives. The model depends on distinct and specialised institutions with the presence of central planning agency (Etzkowitz and Leydesdorff, 2000).



**Figure 2.1:** The evolution of the Triple Helix model of innovation (Source: Etzkowitz, 2008).

In the statist and laissez-faire models, the university is the key provider of both basic research and trained human resources yet; there is no direct communication with the industry (Etzkowitz, 2008). Generally, there are limited interactions between government, industry and university. When such interactions take place, they occur across highly protected boundaries and rather through an intermediary (Etzkowitz, 2008). Boundary maintenance for spheres interactions has attracted attention to the model. Especially, when various actors are involved in R&D process, such as patents, Intellectual Property (IP) rights, and firm equity in spin offs.



In contrast, the triple helix seeks to promote increased interaction across three broad institutional spheres of academia, industry and government, and to produce new forms of collaboration and partnerships among them (Etzkowitz, 2008; Etzkowitz, 2003; Etzkowitz and Leydesdorff, 2000). Based on this regime, interactions between overlapping spheres of government-industry-academia take place across hybrid organisations, which function within the intersections of the three core spheres. These intermediaries allow each sphere to undertake activities from which they were previously overlooked. The government holds the role of manifesting these interactions by providing sound industrial policy, and an infrastructure that permit inter-organisational alliances and networks. In addition, universities are expected to extend their role to become key facilitators of academic entrepreneurship and technology transfer, beside teaching and training of human resources (Etzkowitz and Leydesdorff, 2000; Etzkowitz, 2003).

The NIS and network analysis cannot inform the enquiry about the dynamics, but only about evolving institutional relations of the actors. On the other hand, the TH model gives special attention to the dynamics of innovation systems, but in a different, complementary to NIS approach. Thus, dynamics of an innovation system are non-linear as they are based on interactions between (economic) demand, (political) objectives, and (technological) opportunities, and due to path-dependencies in all systems of reference (Lengyel and Leydesdorff, 2010). The 'Systemness' of the innovation accepts that synergy is produced in the interactions between subsystems. Schumpeter (1939, 1942) indicated the combination of knowledge production and market dynamics as 'creative destruction,' which provides the basis for changes in technological paths.

As this thesis addresses the topic of knowledge commercialisation, different levels of interactions are essential to provide insights about the topic. The TH model has been incorporated by academics and policy-makers because of its neo-corporatist implications and its emphasis on collaboration at local, regional, and national levels. Unlike the *a priori* approach of the national level, the TH model can be applied at various levels of geographical integrations (Leydesdorff and Fritsch, 2006). Knowledge dynamics tends to uncouple from institutional conditions as shown from empirical studies. For instance, Lengyel and

Leydesdorff (2010) found that the assumption of national integration fall short in addressing the dynamics of transformation and differences among regions of the Hungarian system of innovations.

In a similar vein, the study of the emergence of biotechnology during the 1980s revealed that technologies form their own innovation systems as selection environments needed for the advance of technological invention (Carlsson and Stankiewicz, 1991). Therefore, the TH can be also appreciated in the study of the evolution of the interactions and linkages. As Lengyel and Leydesdorff, 2010 have argued that ‘the TH perspective can be elaborated into a neo-evolutionary model which enables us to recombine sociological notions of meaning processing in different discourses, economic theorizing about exchange relations, and insights from science and technology studies regarding the organisation and control of knowledge production’ (Lengyel and Leydesdorff, 2010). Etzkowitz et al, (2000) points out that the concept of entrepreneurial university is becoming a global phenomenon with an isomorphic development path, reaffirming the inclusion of the entrepreneur paradigm in the academic context as the heart of the new mission of the university (Etzkowitz et al, 2000; Link and Scott 2005; Philpott et al., 2011).

The TH model is, in that way, employed as the second theoretical tool in this thesis as it provides tools for a better understanding of the interaction of the three institutional spheres, together with the study of bi-lateral academic-industry relations or government-university policies. Considering the new knowledge production mode, the neo-institutional model of arrangements among different stakeholders can enrich empirical research by observing reflexively the interactions among the three sub-dynamics (Lengyel and Leydesdorff, 2010). Based on empirical studies that address issues similar to this thesis, TH model was used in two less developed innovation systems and resulted in interesting insights. In their case study of University of Goias in Brazil, Silva et al (2012) studied the structure and model of entrepreneurship of the university as well as its interaction with local businesses. Similarly, Moeliodihardjo et al. (2012) applied the TH model to university-industry-government partnerships in Indonesia, in the context of projected university contribution to economic development.

Secondly, this thesis aims at studying the transformation of the three institutional spheres towards the third mission and the TH model is a suitable tool as it adds to the meta-biological models of evolutionary economics (Leydesdorff, 2010). Finally, regarding the dimension of studying commercialisation policies, the TH allows the examination of divergences between the institutional dimensions in the arrangements and the assumed social functions supported by these arrangements. At the same time, while being broadly concerned with the context, TH model closely investigates the frictions between the two spheres; knowledge-based expectations and institutional interests, and among the three domains (economy, science, and policy) offer a tool for puzzle solving (Lengyel and Leydesdorff, 2010).

Although the TH approach has important features contributing to the understanding of the issue, there are several criticisms it faces. The first argument of the critics points to the doubts about role of the institutions within the TH model as a knowledge source for the growth of national and regional innovation systems (Saad, 2004; and Saad and Zawdie, 2005). The three strands of the Triple Helix are assumed as (formally equivalent) with the ability to assume the role of one other with the university as entrepreneur (Etzkowitz, 2003). Therefore, it places a major emphasis on the role of universities to achieve a hybrid status, especially in developing regional innovation. Moreover, Etzkowitz (2008) has not presented examples or suggestions for other types of hybrid TH institutions.

Moreover, scholars believe that the TH Model is entirely based on ideal or phenomenal situations such as Massachusetts Institute of Technology (MIT), so it works poorly for the average universities and regions (Cooke, 2004). As well, some scholars consider that the TH model is inadequately 'contextuated', a criticism made for a failure to recognise the role of social movements in shifting innovation targets (Gibbons et al. 1994). The challenge with the hybrid TH model is that 'its emergence as an institutional system could be elusive, as it involves a complex process based on high levels of commitment, understanding and trust between all three spheres' (Saad, 2004).

Accordingly, there is a risk of losing the leading academic role of the university, as in the context of the model; the university will pursue the role of entrepreneur, becoming

exposed to the logic of the market (Nelson, 2004). It can also lead the university to lose sight of its critical thinking and become too business-oriented (Saad, 2004). Based on this, the application of the TH model is subjected to doubts as to its suitability in a region where universities lack good infrastructure and enough knowledge capabilities. Such universities face challenges in the engagement with other institutions within the TH model, raising the question of how will these issues affect the interactive process between the actors. Another weakness to be considered is about the relevance of universities, which are not interested in engaging in a more entrepreneurial role to the TH model.

### 2.2.3. Network theory for the study of commercialisation

The two previous sections discussed two related theories. This section introduces Network Theory (NT) as an extension of the two and answers some of the deficiencies they struggle with. It provides thus a perspective on the inter-organisational settings and geography dimension on which the actors interact. As this thesis studies commercialisation and investigates knowledge networks, in which knowledge creation, knowledge diffusion and innovation take place, network analysis provides useful insights about the study topic. Network analysis makes it possible to get a picture about commercialisation atmosphere and knowledge spillovers. In this respect, knowledge networks are of particular important and are defined as the network that links firms through the transfer of innovation-related knowledge (Giuliani 2010).

In essence, network analysis aims at explaining change in existence and intensity of relations, providing regional scientists with new perspective and several levels of analysis by accounting for variance in spatial embeddedness (Castells, 1996). It allows researchers to investigate spatial systems of interactions between actors and their types of dependencies, considering formal and informal relations (Balland, 2012). Networking and proximity need to be considered as key themes of the debate. The interactions among commercialisation actors and the role of intermediaries tackled here calls for a geographical take, as spatial relations contributes to understanding the changes of actors role and the transformation to the third mission.

Therefore, network approach can be instrumental to appreciate the complexity and variability of reality, which may be neglected by research approaches assuming a more linear and causal approach. It helps economic geographers to conceptualise how different realities are experienced and enacted by different actors, which reflects the dynamic interactions among actors without neglecting their inter-relatedness. This is important when considering the evolving area of biosciences itself, and particularly so in relation to government-led change initiatives.

Some network literature claims that the innovation process is impaired when complementary organisations such as research institutes, educational organisations and capital suppliers are not either developed or not well-connected in a region as well at the national level (Glückler, 2012). By adopting the network approach, the concept of national and regional innovation system can be studied more systematically by mapping the network relations of key actors. The network approach informs economic geographers on how well actors are connected, and at what spatial levels; which relations are not well developed causing a bottleneck for the innovation process, and to what extent are these networks non-local and, hence, depend on non-local actors? An additional challenge for a network approach is to define how place-specific institutions affect the structure of the network.

A central debate in economic geography relates to 'whether places are more relevant for the competitiveness of firms, or whether networks matter more' (Castells, 1996). Whereas the concept of 'space of places' states that the location matters for learning and innovation (being in the right place is essential), the notion of 'space of flows' emphasises the importance of networks as vehicles for knowledge transfer and diffusion (being part of a network is crucial) (Castells 1996; Ter Wal and Boschma, 2009). Drawing on cluster literature, the space of place and the space of flows exhibited a great deal of overlap (Boschma and ter Wal, 2007). According to Tobler's first law of geography: 'Everything is related to everything else, but near things are more related than distant things'. Accordingly, firms in clusters benefit almost automatically from knowledge externalities that are 'in the air' (Marshall, 1920).

According to Giuliani and Bell (2005), networks display two characteristics: inequalities so networks are unevenly distributed among actors, and they have geography (Giuliani and Bell 2005). Accordingly, economic geographers tend to use the methods of network analysis in order to address primal questions of the field, such as what is behind the spatial concentration of economic activities, firms or innovation. However, most of studies have adopted a static analytical perspective of network analysis, meaning that to capture the whole network at a certain point in time, e.g. clusters (Powell et al. 1996; Owen-Smith and Powell, 2004). Such studies, basically, provide a snapshot of the network. Nevertheless, this thesis is interested in the study of the dynamics of the knowledge networks among the actors of the bio-sector. It aims at examining how these networks evolve and how they change over time.

Moreover, knowledge networks are not territorial but social constructs that may cross the boundaries of regions, with knowledge diffuses, mostly, through social networks (Glückler, 2012). Therefore, network approach is applied in this thesis to study commercialisation from both macro and micro levels. From the former, the types of knowledge-based interactions, the drivers of network formation, and intermediaries are critical. For the latter, the approach is utilised to study the dynamics of networking and the mechanisms for selection of partners (e.g. Giuliani, 2007). For instance, when investigating why some links exist whereas others are absent, the so-called determinants of matching in a network, as well when explaining why some actors are more central than others are, such information is central to this thesis.

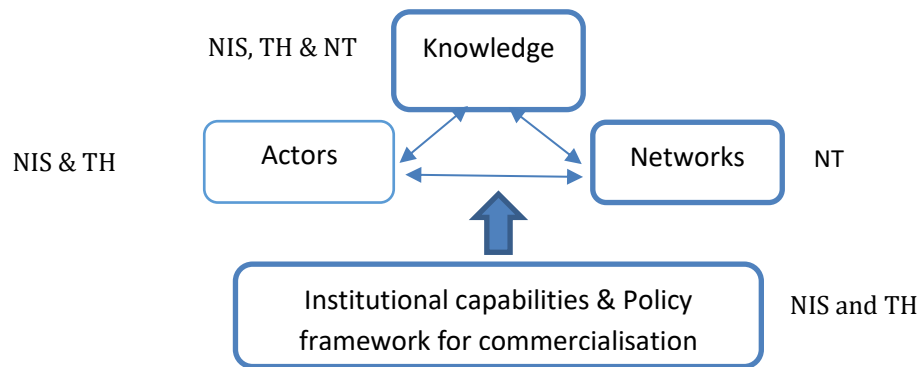
Drawing on existing empirical work, network dependencies appear weaker than spatial dependencies in context of knowledge networks and regional innovation (Powell et al. 1995, Maggioni et al. 2014, Broekel et al. 2015). Therefore, geography is relevant to the purpose of this thesis, as inclusion of different forms of proximity widen the understanding of the current interactions of the actors. As Boschma (2005) argues, 'the importance of geographical proximity cannot be assessed in isolation, but should always be examined in relation to other dimensions of proximity (social, technological, institutional, organisational

and cognitive) that may provide alternative solutions to the problem of coordination' (Boschma, 2005).

With exception of social resource theory, diffusion, social influence, and knowledge flows, the NT is considered a static approach, since network researchers tend to avoid longitudinal research designs (Watts, 2003). The main trend in network researchers is to focus on the consequences of networks rather than antecedents. Other critics have argued that network theory may imply that all network actors are of equal importance, as it conceptually does not consider pre-existing structures, such as power (Provan et al., 2007). The approach perceives these structures as evolving from the actions of actors and their capability to support their interests. In particular, various contemporary research challenges in economic geography using the network approach focus on questions regarding structural dynamics and their implications in entire networks for the collective outcomes (Glückler and Doreian, 2016). This implies the need for new perspectives of theorising the evolution of network dynamics and other power structures of actors to enhance relational thinking in this field.

### 2.2.3. Combining the three approaches to the study of commercialisation

This thesis adopting the multiple-theoretical approach that comprises of the NIS, TH model and NT. The topic is divided into four concepts: actors, network, knowledge, and institutional capabilities. NIS and TH model can be considered complementary to each other and they address several issues that are examined in this thesis: actor's characteristics, transformation of actors towards the third mission, role of institutions, and the policy context for commercialisation. NIS and TH talk to each other by involving directly with commercialisation actors and both pay attention to evolutionary nature of the process. What is more, TH model provides a structure that holds together the interactions and institutional changes observed by NIS. These two approaches call however, for a framework that could bind them and offer a better understanding of a larger network context in addition to the role of geography. Here, NT is charged with this task as it succeeds better in grasping large scale (inter-organisational and cross-institutional links), multilevel perspectives (Figure 2.2).



**Figure 2.2:** The theoretical framework for this thesis indicating the conceptual components together with the three theoretical lenses.

NT complements the mapping of actors and allows a more sophisticated structure where the interactions tracked by NIS and TH analysis are projected against the geographical dimension. The approach addresses also the dynamics of knowledge networks during the study period by indicating relations across the institutions. As mentioned before, NIS and TH contribute to understanding better the actors and network characteristics that this research examines. Therefore, NT is able to look at the changes of these characteristics in addition to other issues such as the role of geography and intermediaries. It also contextualises these interactions and gives a more humane angle to the whole issue going beyond transformation of actors, the creation and reproduction of knowledge and dynamics of networking. This allows a better understanding of the role of social and cultural dimensions of the actors, which is one of the key contributions of this thesis.

One more angle needs to be highlighted while looking at the advantages of blending the three theories. The institutional setting of the bio-sector is unique and still evolving, so the use of single theory cannot fully address the commercialisation topic in fledging innovation system like Oman. Therefore, NIS appears to be the most inclusive and suitable theory to adopt in the context of this research. The concept of a system of innovation brings together in a single framework the elements of the different processes of knowledge generation, sharing and use. It effectively investigates the processes and is able to engage with various actors. However, other core themes like the dynamics of interactions between the actors and



the contextual roles of other actors are addressed by employing two additional approaches while using NIS theory as the main framework.

Finally, the mixed methods approach of this thesis (chapter 4) allows going beyond what each of the approaches suggests. Therefore, the utilisation of three approaches helps to capture the various dimensions of the issues examined here and provides multi-level insight into the topic. The three approaches applied situate the actors institutionally (NIS and TH model) as well as geographically (NT). Thereby, the data are captured and analysed simultaneously through three theoretical lenses chosen.

### 2.3. Commercialisation of biotechnology innovation: the economic impact

In biotechnology and across other technology-based fields, research commercialisation contributes to economic development in many ways such as application of new and technical knowledge in industry (Uctu and Jafta, 2013), creating of new firms, licensing of new inventions to industry, and provision of highly skilled graduates (Roessner et al., 2013). Moreover, there is a long-term economic impact, which includes three target sectors. The business, which benefit from new and improved technologies and skills, followed by the government that utilises new knowledge to enhance policy making, and the general population, which gain from a better quality of life. For example, the income from MIT's intellectual property amounted to approx. 5% of its research budget (MIT-sponsored research budget for the fiscal year 2007, \$1306 million; number of inventions disclosed 487; royalties, \$61 million; expenditure on patents, \$13 million) (MIT Faculty Newsletter, 2007).

The dynamic of biotechnology industry is unique in the context of its key players and the role of university researchers who remained in academic sector while interacting with industry. Accordingly, the impact of research in life sciences and biotechnology are rather characteristics (Daple, 2003). Historically, the modern biotechnology industry first came into existence in 1953, following the discovery of the double helix structure of DNA by Dr James Watson and Mr Francis Crick of Cambridge University in the United Kingdom. After two decades, biotechnology took an important step towards commercialisation of their technological breakthrough by a series of patenting and licensing initiatives.

The bio-based industry is characterised by its increased demand for innovation and value, diversity of actors across the value chain, and an ever-changing regulatory and risk environment (Daple, 2003). For nearly four decades, universities, venture capitalists, pharmaceutical and other R&D firms, and governments have supported the evolving of the biotechnology industry by providing financial resources and support and an institutional framework within which to enhance commercialisation of life sciences research outcomes (Kenney, 1986; Orsenigo, 1989). As Kenney argues:

Biotechnology, a science that is capable of being commercialised, has been totally-dependent on university research. In no other fledging industry, have scientists played such an all-encompassing role (Kenney, 1986, pp. 4-5).

According to the global life sciences outlook (2016), equity market and venture capital funding in the United Kingdom (UK) for biotech firms in 2014 were at their highest levels in a decade (Deloitte, 2016). In Switzerland, biotechnology firms remain attractive acquisition targets with high opportunities for Mergers and Acquisitions (M&A) transactions within the sector and non-traditional market entrants. For the purposes of this study, three dimensions of the economic benefits are reviewed, which are university licensing and spin-offs; tacit knowledge transfer through researcher mobility; and impact of science parks and technology incubators.

### 2.3.1. University licensing and academic spin-offs

It is well accepted that the creation of new firms is considered as an economic benefit resulting from the commercialisation of publicly funded research. The most observed benefit is the agglomeration of new firms in technology clusters in which the research-intensive university is taking the central role, such as MIT and Stanford. There is little convincing evidence regarding the positive correlation between significant investment in basic research and the generation of spin-off companies (Salter and Martin 2001). However, this correlation was found to be sector-specific; for example a positive relationship between university research and the creation of spin-offs is statistically significant in the electronic equipment sector (Bania et al., 1993).

Most of the work on the economic impact of publicly funded research represents the broader impact on regional economy, whereas the benefits to the national economy have seldom been studied. It appears there are still difficulties in quantifying the incremental impacts and attribution of university research to public investment. Vincett (2010) studied the cumulative direct economic impact of academic spin-off companies that results from the commercialisation of non-medical natural sciences and engineering research funded by the Natural Sciences and Engineering Research Council of Canada from 1960 to 1986. The findings suggest incremental contribution to the Canadian GDP, which was much higher than government funding.

However, there is a consensus regarding the significance of university research licensing of intellectual to economic growth, although there is very little published data regarding the measures of economic performance such as value added, contribution to the Gross Domestic Product (GDP) and employment. Roessner and colleagues (2013) used licensing data for US universities over a period of 15 years, to estimate the national economic impacts of university licensing of intellectual property as annual increase in the GDP, total industry output and employment. They found significant contribution of university licensing to gross industry output, and the total number of additional jobs created. In earlier study, Pressman et al. (1995) investigated the MIT Technology Licensing Office (TLO) to study the pre-production investment and jobs created, as a complement to prior estimates of post-production economic impacts. The data indicated an induced investment and employment.

Research identified various resources that are needed prior to maximising wealth creation from research commercialisation. In their study of entrepreneurial opportunity and capacity, Hindle and Yencken (2004) argued that New Technology-Based Firms (NTBFs) which result from technological innovation depend on two main resources, the accumulation of tacit knowledge, such as technological, managerial, risk management, and financial experience, and the culture of the entrepreneur. Both resources influence the institutional interactions, organisational culture and external business atmosphere, suggesting the importance of tacit knowledge in combining needed resources for successful economic benefit from commercialisation.

### 2.3.2. Researcher mobility

Further significant socio-economic benefits from university research can be achieved through researcher mobility between the main institutional spheres of academia, public sector and industry. Zellner (2003) studied the value of knowledge driven by researcher migration and indicated that knowledge transfer by scientist migration includes critical elements of knowledge that underlie complex problem-solving strategies in basic research. Regarding the human resources flow from university to industry, most studies consider the producing of skilled graduates as the key economic benefits from mobility of skilled R&D workers. Particularly in applied areas like science and engineering, young scientists transfer the tacit knowledge that was acquired during their study to the industry sector (Salter and Martin, 2001); yet industry still continues to invest in the training of new graduates to develop the required industry-specific skills (Wilson, 2012).

Research, however, has shown that there are difficulties coupled with researchers and graduate mobility to local industry. In their study of the contribution of mid-range universities to economic change through transfer of tacit and codified knowledge, Wright et al. (2008) found that the movement of researchers and graduates into local SMEs is considered a key economic benefit as it facilitates access to highly skilled human capital. However, limitation of resources in local SMEs and lack of awareness of the existing opportunities make this movement more challenging (Wright et al., 2008).

### 2.3.3. Science Parks and technology incubators

A large body of literature has investigated the role of Science Parks (SP) and technology incubators in regional economic growth. Scholars have argued that the concentration of highly skilled individuals in innovative firms within a region helps to create an entrepreneurial culture by sharing information and knowledge spill-overs between the key knowledge produces (e.g. Saxenian, 1996). These linkages and spill-overs are integral to the success of technology parks. Therefore, the establishment of science parks throughout the world is driven by the argument that a concentration of high-tech firms contributes to the diffusion of new technology; hence promoting regional economic development (Hu, 2007).

According to Link and Scott (2003), the definition of SP implies the existence of three main elements; a real estate development; an organisational programme of knowledge transfer activities and a partnership between the key spheres. Under the term 'Science Park', different parks are included, such as research parks, technology parks and commercial or industrial parks. Research parks are those with a majority of tenants that are heavily engaged in basic and applied research. Technology or innovation parks represent parks where a majority of tenants is heavily engaged in applied research and development, and therefore, the park holds new start-up companies and incubator resources. However, industrial parks are concerned with adding value to R&D-based products rather than undertaking R&D activities (Link and Scott, 2003).

SP are linked with increasing job opportunities and wealth creation. According to the statistics of the UK Science Parks Association (UKSPA) for the year 2009-2010, the total number of operational parks that are full members of UKSPA has increased together with the number of property per square metres and number of tenant companies (UKSPA Annual Statistics, 2010). The largest producing sector is computer and telecoms, followed by the bio-related activities. Regarding employment, the number of jobs in tenant companies increased from 3,317 in 1985 to 70,133 in 2010 (UKSPA Annual Statistics, 2010).

The contribution of sciences parks to the economy, however, seems to be dependent on the economical setting and infrastructure for innovation. For example, Ratinho and Henriques (2010) investigated the efficacy of Science Parks (SPs) and Business Incubators (BIs) in promoting economic growth, using the case study of Portugal as a representative sample of converging countries. The results indicate a modest role of SPs and BIs in job creation and economic growth, which is a significant outcome for policy makers and urban planners to understanding the extent of contribution of these institutions. They also found that university links with business and management practices are critical elements for the success of SPs and BIs.

## 2.4. The evolution of the third mission

Several studies have focused on the implications of how knowledge institutions (academic, industry and public sector) respond to the debate on the production of knowledge and its commercialisation to the potential productive sector or industry. Although the majority of this strand of research tends to emphasise the transformations of the higher education institutions towards the third mission of knowledge entrepreneurship, transformation was reported from all the three institutional spheres. Historically, entrepreneurial academic activities started in the US universities during the late nineteenth century due to the lack of a formal research funding system, suggesting a 'bottom up' approach, while in Europe the Entrepreneurial University emerged as a 'top down' experience (Soete, 1999).

At the university level, evidence indicates that the role of the university has evolved from performing conventional research and education functions to serving as an innovation-promoting knowledge hub (Youtie and Shapira, 2008). Etzkowitz et al. (2000) presented comparative evidence of the emergence of two patterns of transformation toward an entrepreneurial university from different bases, in the US, Latin America, Europe and Asia. The first pattern is the shift to more dependence on knowledge production (Stehr, 1994), while the second trend represents the endeavours associated with future trend identification and guidance for sustainable knowledge production and their societal implications.

The transformation is seen as a response to the co-evolution of organisations with changes in the institutional framework. For example, in Japan, Lynskey (2006) reported significant institutional transformations that took place to enhance technology transfer and commercialisation in biotechnology, including changes to universities' legal structure as well as the emergence of bio-venture firms. However, such a transformation is not easy to implement particularly in the context of developing countries. For instance, Jurado et al. (2008) studied UI links in Bolivian public universities and showed that academics were in favour of strengthening ties with industry despite the barriers. For example, lack of institutional support, unfavourable university atmosphere and unsupportive industry

structure, suggesting the need to consider the transformation of the national research system, which reflects the role of institutional changes.

Jonkers (2011) analysed the transformation of the Chinese research system in the period 1980-2005, and its movement from the 'centrally planned ideal type' to the 'perfect market ideal type'. The central elements of transformation, which was gradual and has adopted the trial and error approach, are the plurality of funding agencies at the intermediary level and internationalisation of research outputs and visibility. Therefore, successful transformation to an 'Entrepreneurial University' might be essentially to get access to new funding schemes such as public seed capital or specialised programmes, rather than being forced to redistribute basic research and teaching funds (Rasmussen et al. 2006).

Furthermore, Etzkowitz (2008) stated that 'We have passed from an era based on an assumptions that research automatically translates into use, to an era where policies are continuously reinvented to achieve that objective' (Etzkowitz, 2008: p 137). He argues that decentralised innovation policies that integrate the three institutional spheres can be more effective compared to the traditional linear model, as the former consider regional differences and involve bottom-up initiatives. Such transformation towards meta-innovation system of multiple sources of initiatives fulfilled the 'endless transition'.

#### 2.4.1. Institutional support mechanisms

As universities experienced transformation process towards the third mission, the entrepreneurial capabilities plays a central role. Fini et al. (2011) studied the role of University-Level Support Mechanisms (ULSM) and Local-Context Support Mechanisms (LCSM) in supporting the creation of academic spin-offs. They found that the marginal effect of the ULMSs on universities' spin-off productivity may be positive or negative depending on the contribution offered by different LCSMs; therefore it is crucial to consider the joint impact of different forms of support. These results call for more attention to the interaction between various determinants that operate at different levels.

At the national level, different antecedents are found to enhance the evolution of university entrepreneurialism. In their comparative study of the German and US experience,

Lehrer et al. (2009) identified three macro-level antecedents which are de-centralised competition; latitude in mission and revenue mix; and a nationwide, diversified bidding system for the funding of large-scale university-based research. Great emphasis is placed on the role of organisational support mechanisms. Hewitt-Dundas (2011) studied the difference in knowledge transfer activity among high research-intensive (HRI) and low research-intensive (LRI) universities in the UK. The findings suggest a vital role of institutional and organisational resources rather than the capability to undertake knowledge transfer directly through a Technology Transfer Office (TTO). Therefore, it is necessary to build up a university as a dual-structure organisation that allows for the pursuit of both research excellence and research commercialisation at the same time (Changa et al., 2009).

At the university level, several factors have been identified as stimulators to academic entrepreneurship, such as scientific productivity was found to be positively associated with entrepreneurial activity (Looy et al., 2011). The academics' level of entrepreneurial capacity in terms of opportunity recognition capacity and their prior entrepreneurial experience are important predictors of academic entrepreneurship (Clarysse et al., 2011). Previous research has predominantly found a positive relationship between the quality of academics' research output and their commercialisation activities.

However, Perkmann et al. (2011) found that this relationship differs across disciplines, depending on the complementarities between industrial and academic work. In technology-oriented disciplines, like medical and biosciences, departmental faculty quality is positively related to industry involvement, while in social sciences there was some support for a negative relationship particularly in more applied forms of industry involvement (Perkmann et al. 2011). Furthermore, Abreu and Grinevich (2013) argued that there is a need to widen the current focus of the academic entrepreneurship literature, which is mostly on patent-based activities such as spinouts and licensing, to include other informal commercial and non-commercial activities.

According to Hoyer and Pries (2009), repeat commercialisation activities among university faculties are increasing and this emerging phenomenon is calling for programmes and policies of technology transfer that address the needs of this sub-population of the of the



research community. However, scientists who participate in academic entrepreneurship take active steps to preserve their academic role identity by adopting a hybrid role that compromises a focal academic self and a secondary commercial persona (Jain et al., 2009). Wennberge et al. (2011) suggested that commercial knowledge of academics that is gained through prior industry experience is more valuable for entrepreneurial performance. Scientists perceive the value of patenting differently and the level of reputational importance placed on scientific compared to commercial achievements matters in shaping commercial involvement (Haeussler and Colyvas, 2011). Bramwell and Wolfe (2008) argued that the success of University of Waterloo in Canada as an 'entrepreneurial research university' is due to the extreme benefits of combining a world-class academic reputation for teaching and research with the enabling atmosphere of "entrepreneurial attitude of mind" among faculties and students.

Scholars have emphasised the engagement of universities with industry not only by commercialisation of academic inventions but also in a broader collaboration forms e.g. joint research, contract research and consulting. Colyvas (2007) has traced the early formation and development of Stanford's technology transfer programme in the life sciences from 1968 to 1982. The findings suggested that the programme emerged from the confluence of multiple approaches based on scientists' early experiences with technology transfer, and that their interaction with industry took different forms, reflecting faculty efforts to utilise new opportunities in the context of preserving scientific reputation and advancing their research programmes.

In less developed regions, entrepreneurial capacity can be further influenced by cultural traits. At the local level, evidence showed that there is a significant link between enterprise activity and the overall community culture (Huggins and Thompson, 2012). Community cultural characteristics such as social cohesion were found to be positively associated with a strong business culture by rising entrepreneurial confidence in individuals. These findings suggest that it is significant to include community cultures when studying the drivers for entrepreneurial activities.

### 2.4.2. Genesis of knowledge clusters

At this point, it is significant to consider insights from clusters' literature. The existence of the concept of cluster is dated back to the days of Marshall, yet it has become predominant in academic and policy discourse as a result of the significant work of Michael Porter in the area of competition and competitive advantage (Porter, 1990; Porter, 1998; Porter, 2000). In his extended edition of 'on competition' (2008), Porter identifies clusters as 'a geographically proximate groups of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities' (Porter, 2008, P. 215). According to Porter, clusters provide real economic advantages to the companies that co-locate by enabling them to leverage the opportunities of a given business environment (Huggins and Izushi, 2011).

The mechanisms by which economic growth can be attained through cluster development are: by increasing the productivity of companies due to better access to human capital, specialised information and suppliers as well by interacting with supporting institutions; by enhancing innovation and increasing capacity for technology development; and by stimulating the formation of new business (Huggins and Izushi, 2011). The network system underlying knowledge cluster is complex, yet there are four strategic resources are fundamental to their formation: highly skilled human capital; technological infrastructure in term of sophisticated research institutes and laboratories; knowledge resources such as patents and intellectual property; and financial capital to support technological development and commercialisations (Fujita, 2003).

In this perspective, high technology and knowledge-intensive clusters are considered important economic generators due to their role in job and wealth creation. According to Marshall (1920), geographical concentration of innovative firms and individuals in a region generate externalities through localisation and agglomeration. He defined three forces that drive the formation and regional clustering of industries: exchange of information or knowledge spill-overs; the advantage of existing labour; and the networks that can be enhanced by a large local market. Although world-leading cluster, such as Silicon Valley, Route 128, and the Research Triangle in the US, did not exist by design, countries throughout

the world of have tried to emulate the American success experience in clustering by supporting high-tech firm concentration in designated locations (Hu, 2007). As in the case of San Diego biotechnology cluster where social networks linked to inter-firms staff mobility emerged and became sustainable (Casper, 2007).

In her work on the success of Silicon Valley, (Saxenian 1994) argues that a culture of decentralised social ties, which link up scientists and engineers across local firms, facilitates diffusion of innovation. Similarly, Cooke and Huggins (2004) performed a case analysis of biotechnology and ICT clusters in Cambridge and suggested that the two clusters are embedded in network relationships, which are partially exclusive. They argue that geographical concentration is not enough if there are no adequate interactions between the key actors of the cluster, which differentiate a cluster from a mere agglomeration of firms with similar activities (Cooke and Huggins, 2004).

Government policies are highly instrumental in bringing about the genesis of most high-tech clusters, although locational determinant was given more weight in most studies (Sternberg, 1996). According to Porter's (1990) system of determinants of national competitiveness, the competitiveness of high-tech clusters are determined by factor conditions, demand condition of the market, related and supporting industries, and firm strategy, structure and rivalry (Porter, 1990). The government technology policy should be defined as an additional fifth determinant, as its function in the competitive advantage of nations rests in its influence over the four determinant factors (Sternberg, 1996).

In another case study of high-tech clusters, Huggins (2008) presented four case study clusters as a means to understand clusters' development. The selected case studies are Silicon Valley (United States), Cambridge (Great Britain), Ottawa (Canada), and Helsinki (Finland). The findings indicated that knowledge is increasingly flowing across clusters, suggesting a shifting in cluster's development from internal reliance model to wide connectivity pattern of evolving. The author developed a framework outlining the key stages of cluster's evolution, which are genesis, development, growth and renewal stages. At the first stage, the creation of knowledge cluster is associated with institutional trigger in form of pre-existing of social network, trust, strong ties and localised linkages. During the

development phase, the driving force is centrifugal in the sense that new entrepreneurs and spin-offs are attracted and pushed to create new collaborations and linkages through informal networks, dense ties, and frequent contact. As knowledge clusters grow and a critical mass is developed, new capital inputs will take place in the form of venture capital or business service firms. In addition, the existing networks evolve into more formalised forms and strategic alliances through global ties. The last stage of knowledge cluster life cycle depends on the ability of the cluster to withstand disruptive knowledge shifts, which implies the role of skilled human resources and integrated network types (Huggins, 2008).

The literature of geography of knowledge production has reported the emergence of a new form of geographic cluster in developing countries that is called knowledge services clusters (KSCs). According to Manning (2013), KSCs can be defined as geographic concentrations of lower-cost technical and analytical skills serving global demand for increasingly commoditized knowledge services, including software development, engineering support, product design, and analytics. These clusters are characterised by exhibiting combined features of high-tech clusters (e.g. availability of high-skilled talent, existence of technical universities, specialization in knowledge work), and low-cost manufacturing clusters (e.g. low cost of labour, orientation to global demand, emergence in developing countries).

## 2.5. University-Industry (UI) linkages

University-industry (UI) linkages emerged as a separate field of study three decades ago as part of an increased policy emphasis on research commercialisation and the need to form closer linkages between basic research and societal needs (Rappert et al., 1999; Gulbrandsen et al., 2011). They can be defined as interactions between all parts of the higher educational system and the industrialising economy (Anon, 1974). Research has highlighted the complexity and heterogeneity of the UI interface and it is significant that policy makers be aware of the importance of allowing this heterogeneity to flourish (Mueller, 2006; Jensen, 2016).

It is very common that the terms 'academic engagement' and 'commercialisation' are used interchangeably in the literature on UI relationships, yet recent reviews point out that they do differ. Perkmann et al. (2013) performed a systematic review of research on academic scientists' involvement in UI knowledge to identify the individual, organisational and institutional antecedents and consequences of academic engagement, and then compare these findings with those on commercialisation. They define academic engagement as 'knowledge-related collaboration by academic researchers with non-academic organisations, while commercialisation involves 'the patenting and licensing of inventions as well as academic entrepreneurship' (Perkmann et al. 2013).

Thus, academic engagement is closely aligned with traditional academic research activities, and is pursued by academics to access resources supporting their research agendas. It is a significant mode of interaction between the academic sector and the industry and consists of both formal and informal interactions. The former includes training, collaborative research, consulting, and contract research, whereas the latter represents networking and transfer of knowledge through informal consulting (Abreu et al., 2009).

A large and growing body of literature has investigated modes of UI interactions. Scientific knowledge can be transferred to the market in several formal ways: education and training, contract research, consultancy, licensing, collaborative research, and spin-off companies, in addition to numerous informal contacts between universities and industry (Lambert, 2003). These linkages exhibit different phases and actors (Freitas et al., 2013; Plewa et al. 2013), whereas the engagement between universities and the business sector must be based on an understanding of the role of both regional knowledge networks and market-based knowledge interactions (Huggins et al., 2008).

Given the broad range of UI interactions, different factors influence the mode of these linkages such as researchers' skills. Este and Patel (2007) indicated that university researchers interact with industry using a wide variety of channels, particularly consultancy activity, contract and joint research, or graduate training as compared to patenting or spin-out activities. Likewise, individual characteristics of researchers have a stronger impact than the characteristics of their departments or universities. Hence, the range of UI interactions

is better explained by the disciplinary origin, the characteristics of the underlying knowledge, individual characteristics and institutional characteristics (Bekkers and Freitas 2008).

Among different forms of UI interactions, academic consulting is the most widely practiced activity. For academic staff, scientific publications, patenting, academic spin-offs and consultancy are relatively more significant in the science-based regime (Gilsing et al. 2011). However, in the development-based regime, joint R&D programmes, participation in conferences, regional and/or professional networks and inflow of PhD graduates are relatively more important. Perkmann and Walsh (2007) indicated that ‘search and match’ processes precede UI collaboration. In another study, Perkmann and Walsh (2008) showed that commercialisation and research-driven consulting are likely to enhance research productivity. According to Tether and Tajar (2008), the use of specialist knowledge providers tends to complement firms’ own internal innovation activities as well as other external sources of knowledge.

### 2.5.1. Social capital and network capital

Knowledge network may have great importance for knowledge transfer and commercialisation of university-generated research (Brass et al., 2004; Balland et al, 2013<sup>a</sup>). Among other metrics of knowledge transfer, social network is defined as ‘a social structure made of nodes (which are generally individuals or organisations such as universities and businesses) that are tied by one or more specific types of interdependency, such as values, visions, ideas, knowledge, technology or financial exchange, or friendship’ (Library House, 2008, p. 8). In addition, the concepts of both social capital and network capital have recently emerged in social networks literature as powerful tools to analyse the mechanisms by which knowledge, especially tacit knowledge, flows within and across organisations (Huggins and Izushi, 2007).

According to Coleman (1988), social capital consists of obligations and expectations that are dependent on trust, the capability of social structure to facilitate knowledge flow, and norms. On the contrary, network capital is defined as perceived value inherent in

networks and relationships developed and maintained by network actors as a result of business or professional expectation (Huggins and Izushi, 2007). These concepts can be distinguished by understanding their characteristics, functions and motivation for network participation. As Huggins and Izushi (2007) argues: ‘Typically, a network will possess and allow actors to build network capital when the rationale for interaction and participation is based on expected economic return, while networks will possess and allow actors to build social capital if the rationale of actors is more social in its expectations’ (Huggins and Izushi, 2007, P. 59).

The process of knowledge production is deeply embedded in a network of social structures and practices (Zucker et al., 2007). For the success of knowledge commercialisation, network capital is required to facilitate the combination between innovation and business. In high-technology clusters like biotechnology, the location of the first organisation is a historical accident; subsequent ones will find advantages by joining the group. However, scholars think that cluster’s location is determined by the presence of other key players like universities or research centres, which allow the development of knowledge alliances and contact networks with the knowledge supply side (Cooke and Huggins, 2004).

As argued by Powell (1990), networks are more effective than market or hierarchical structures, as they influence both regional innovation capability and regional competitiveness. Networking between the key players of knowledge acquisition is an essential component for effective innovation ecosystem, where university represent the key player within knowledge network (Huggins et al., 2008).

### 2.5.2. Motivations and benefits of UI Linkages

There are different reasons that enhance firms and organisations to enter networks. Within the context of effective linkages, firms of the same sector located in proximity will have access to specialised labour force, associated infrastructure, and benefit from relations with public research organisation, suppliers, customers and competitors (Huggins and Izushi, 2007). Networks also reduce the transaction cost of knowledge and information exchange between the key actors of the network. Networks are vital means to transfer knowledge from

one actor to another within the knowledge acquisition and creating organisations. They involve interactions, relationships and ties between actors, which can be either internal or external (Huggins and Izushi, 2007).

Scholars have introduced the concept of network resources (Gulati and Gargiulo, 1999; Gulati et al., 2000) which explain the benefits from knowledge and valuable information or resources derived from inter-organisational network partners. Drawing on the notion of network resources, Huggins and Johnson (2012) examined the relationship between network resources and the innovation performance, as well the influence of geographical location of network partners. Their findings suggest a correlation between innovation performance and a combination of both network resources and core characteristics of firms. In knowledge alliances, network resources seems to play a critical role in enhancing innovation, as network-oriented firms tends to exhibit superior innovation performance (Huggins et al., 2012). Besides, regional growth is partially-derived by the network capital, which is defined by the nature of both, the inter-organisational networks within and across regions and the knowledge accessed through these networks (Huggins and Thompson 2013).

However, the engagement with industry is heterogeneous, so the motives and attitudes reflect not only disciplinary and institutional affiliation, but also personal preferences, individual assessment of the value of scientific reputation and other values (Haeussler and Colyvas, 2011). Firms gain multiple types of benefits from collaboration with universities that range from basic research to assistance with market introduction (Bishop et al. 2011; Crespi et al. 2011). While formal networks possess the potential to out-perform informal structures, yet informal networks are the most valued type especially pertaining to improving overall competitive performance (Huggins, 2001).

Bercovitz and Feldman (2011) studied the composition of teams of academic scientists engaged in inventive activity. They found that there are coordination costs associated with transcending academic departments and organisational boundaries to build teams, and the expected benefit is due to knowledge diversity, mostly in the case of truly novel combinations. Ankarah et al. (2013) studied individual actors' motives to engage in UI



knowledge transfer for both academics and industry. The findings showed that the motives of and outcomes for university and industry partners match in spite of their divergent work environments; and the key determinant of engagement is stability-seeking.

UI linkages are viewed as a two-way interaction in which universities gain funding from industry while the industry can enjoy various benefits from the commercialisation of academic research outcomes (Salter and Martin, 2001). Regarding the relationship between academic activities and commercialisation activities, Larsen (2011) suggested a curvilinear relationship in various cases, unlike earlier empirical analysis that found a positive relationship, which means that positive relationship between academic and industry-linked activity may weaken beyond a high level of commercial involvement. This study confirms the earlier findings that academic achievement may precede commercialisation rather than the vice-a-verse.

At the individual level, there are different drivers that motivate researchers to engage in commercialisation and interaction with industry. Lam (2011) indicated a mixed motives; scientists with conventional beliefs about the parting of science from commerce are more likely to be extrinsically motivated, using commercialisation as a means to obtain resources to support their quest for the 'ribbon'. However, those who identify closely with entrepreneurial norms are motivated by the autonomy and 'puzzle-solving' involved in applied commercial research while also motivated by the 'gold' (Lam 2011).

At the university level, there is a need for a defined portfolio of UI linkages that set out the scope of activities as well the type of firms involved in the interactions (Wright et al., 2008). Unlike most prior research that envisions cultural difference as an obstacle impeding knowledge exchange, Bjerregaard (2010) indicated that institutional logics enhance UI collaboration and knowledge transfer due to converging logics emerging from academic open science norms supported by private researchers and commercialisation norms held by university researchers. These findings have significant implications for managing long-term R&D collaborations that are exposed to tensions arising from institutional multiplicity.

From the firms' perspective, various benefits can be gained from interaction with universities whereas these benefits are instrumental in nurturing the multiple facets of a firm's absorptive capacity as well as its explorative and exploitative capabilities (Bishop et al., 2011). Furthermore, these benefits are dependent on firms' R&D commitments, geographical proximity and research quality of university partners. However, long-term perceived benefits depends on the type of interaction so that those related to joint and contract R&D, property rights, and human resources have a higher impact on long-term benefits for firms (Fuentes and Dutrenit, 2012).

Firms with internal R&D strategies that favour exploratory activities allocate a greater share of their R&D resources to exploratory university research, develop deeper multifaceted relationships with their university research partners and spend a greater share of their R&D budget on these areas of research (Bercovitz and Feldman, 2007). Besides, universities, in contrast to other external partners, are preferred when the firm perceives potential conflicts over intellectual property. Furthermore, firm's cooperation activities are linked to the characteristics of the industry and the characteristics of the firm including R&D intensity (Blasco and Carod 2008).

At the level of small- and medium-sized enterprises (SMEs), various factors shape university–industry R&D alliance. Fontana et al. (2006) examined the determinants of research cooperation between firms and Public Research Organisations (PROs). They found that acquiring knowledge through the screening of publications and involvement in public policies positively affects the probability of signing an agreement with a PRO, but not the number of R&D projects developed. Firms that outsource R&D, and that patent to protect innovation and to signal competencies, show higher levels of collaboration. While firm size is less of an influence, factors with the greatest influence on IU interaction are those related to structural characteristics, in particular managers' qualifications and the sector of activity (Aracil and Lucio, 2008). Hence, the quality of both firms and universities is the key driver for valuable UI links (Giuliani, 2008).

In addition to individual and institutional characteristics of universities and industry, specific technological and relational features play a significant role in the establishment of

effective UI links. Thursby and Thursby (2011) found that recent disclosure activity is associated with higher levels of both industrial and government research funding. Petruzzelli (2011) indicated that two factors shape UI links that are complementary technological competencies and the existence of prior links that allow development of trust between partners and reduce institutional difficulties. Therefore, relationship qualities such as trust and commitment are critical for improving UI collaborations to facilitate research commercialisation (Boehm and Hogan, 2013). At the country-level, the key structural factors at determining UI interactions are the university's country of location and the magnitude of its research activities in industrially relevant fields of science (Tijssen, 2006).

On the other hand, the UI interactions can also have negative impacts. In his analysis of survey data of Australian academics, Harman (2001) highlighted some risks of such interactions such as threats to research autonomy and reduced time of talented researchers available for teaching and academic activities. Therefore, higher levels of UI interactions over an academic career are associated with declining levels of academic achievement.

### 2.5.3. Knowledge networks in biotechnology

Worldwide, there are successful models of commercialisation and UI collaborations in life sciences and biotechnology, like Stanford and Silicon Valley, whereas Stanford's technology transfer programme is currently extensively emulated (Ebers and Powell, 2007). Interestingly, researchers across disciplines have different perceptions about UI interactions. According to Welsh et al. (2008), bio-scientists view UI links and university intellectual property (IP) policies in complex and often conflicting ways. The UI links are considered valuable for increasing contact with scientists, and yet challenging because working with industry can restrict communication among scientists. Bio-scientists believe that IP policies should be used both as revenue-raising vehicles, and to address public good issues such as technology transfer (Welsh et al. 2008).

Different factors from both the university and industry influence the UI linkages in the life sciences. At the university level, the researchers are still important players (Daple, 2003);

also, the development of university degree programmes can have a positive impact on stimulating UI linkages (Adeoti and Adeoti 2005).

In Japan, for example, the expansion of university programmes of sciences and biotechnology since the 1950s has contributed to the promotion of UI joint research. Also, UI joint research projects increased following the enactment of the 1998 legislation to promote technology transfer from universities (the so-called TLO Act) and the 1999 legislation to allow universities to retain rights on their inventions created with government research funds (the so-called Japanese Bayh–Dole Act) (Kato and Odagiri, 2012). Similarly, in the case of a developing country, the reforms in funding programmes in five Thai universities have promoted university-industry links and the cooperation activities have become more frequent (Schiller and Liefner, 2007).

As one of the most extensively-studied examples, Daple (2003) identified five institutional arrangements that characterised the development of US biotechnology industry. First, the American academic system allowed researchers to remain in university while being involved with industry by holding interests in equity positions in small biotechnology firms or as members of the executive or scientific advisory board. Second, American universities were quicker to develop institutions dealing with UI links like (IP) and patents (Daple, 2003).

Third, the Bayh-Dole Act 1980 modified the interaction between the academic sector and industry, particularly in relation to the IP issues, and the Act made the interaction more efficient. Fourth, venture capital is readily available in the US economy. Finally, the American patenting system based on the *Dimond vs. Chakarabarty* decision makes patenting new biotechnology knowledge and invention much easier. *Dimond vs. Chakarabarty* was a United States Supreme Court case dealing with whether or not an invention embraces living matter is irrelevant to the issue of patentability. The decision held that 35 U.S.C. 101 does not exclude microorganisms produced by genetic engineering from patent protection (*Diamond v. Chakrabarty*, 447 U.S. 303 (1980), The United States patents and Trademark Office (USPTO)).

Furthermore, many variables related to industrial structure influence UI interactions such as firm's absorptive capacity (Fabrizio 2009). According to Nieto and Quevedo (2005), absorptive capacity determines innovative effort, which is greater than technological opportunity and knowledge spillovers. Murovec and Prodan (2009) found that there exist two kinds of organisational absorptive capacity; demand-pull and science push. Both kinds are positively-related to innovation output, and are determined by internal R&D, training personnel, innovation cooperation and attitude to change.

Colyvas (2007) traced the origins of the commercialisation of life sciences since the foundation of Stanford University's technology transfer programme in 1968, using data from key basic life science department documents at Stanford. The analysis indicated that the programme's origins were uncertain and highly idiosyncratic, where the norms and practices of academic science shaped the evolving definitions of the main elements of commercialisation like inventor, invention, rewards, and incentives. This analysis of the early phase of research commercialisation is significant as it reflects on the period when university-industry ties were forged, showing how widely diverse and idiosyncratic practices became settled into organisational routines, as technology transfer became institutionalised (Ebers and Powell, 2007).

In similar line, Ding and Chois (2011) studied the entrepreneurial activity of life scientists and found that commercial activity of academics tends to peak earlier in their careers, as most scientists prefer certain types of engagement such as membership on scientific advisory boards. Gilding (2008) performed a network analysis of biotechnology firms located in Melbourne, Australia. He indicated the influence of 'the tyranny of distance' that exacerbated by cultural dynamics, favouring ties with the US and UK rather than with Japan and Korea.

#### 2.5.4. Geographic dimension of UI linkages

The link between inter-organisational flow of knowledge and geography is well accepted in the literature indicating that proximity remains the key driver of tie formation. Boschma's (2005) identified five-fold classification of geographical, cognitive, social, institutional and

organisational proximity. Organisational proximity denotes membership to the same organisational body, for instance when two departments follow the same organisation (Balland, 2012). Institutional proximity refers to the actors who work under regular rules and incentives, e.g. when co-located in the same country (Gertler, 1995; Hoekman et al., 2009), or functioning in the same social subsystem of the three institutional spheres (Etzkowitz and Leydesdorff, 2000; Ponds et al., 2007). Social proximity is referring to the informal linkages between actors (Uzzi, 1996), e.g. following a previous successful collaboration (Breschi and Lissoni, 2009). Cognitive proximity refers to the extent to which two actors share the same knowledge base (Nooteboom, 1999).

Institutional-level ties are valuable in knowledge transmission only when such ties are geographically proximate. Irrespective of geographic location, organisation-level ties fail to act as transmitters of knowledge, whereas geographically distant individual-level friendship ties are superior conduits for knowledge flow, suggesting what so-called 'geographic holes' (Bell and Zaheer, 2007). However, research showed that geographical proximity is less important in some types of spill-overs. Ponds et al. (2010) analysed the possibility of knowledge spill-overs stemming from UI research collaboration over greater distances, and found that academic knowledge spill overs take place through both geographically localised mechanisms, as well as collaborative research over greater distance.

The effect of geographical proximity is further enhanced by the presence of other innovation institutions, such as Science Parks. Abramovsky and Simpson (2011) provide evidence on the role of geographic proximity in UI linkages in their study of spatially mediated knowledge transfer in the UK. They found that in the pharmaceutical sector, the co-location (within 10km) of R&D facilities with high research-ranked departments of chemistry provides localised knowledge spill-overs and benefits of accessing academic knowledge, whereas the presence of Science Parks enhance linkages with universities and provide further infrastructure advantages for R&D firms (Abramovsky and Simpson, 2011).

Taking into account the regional dimension, research showed that there is an unambiguous relationship between functional UI linkages and enriched regional innovation systems. The work of Agrawal and Cockburn (2003) was carried out to develop and test the

'Anchor Tenant' hypothesis, which proposes that the presence of a large, local, R&D-intensive firm enhances the regional innovation system such that local university research is more likely to be absorbed by, and to stimulate local industrial R&D. Their findings showed that the degree of geographical association between downstream industrial R&D and upstream university research indicates a substantial localised component of vertical knowledge spill-overs, which is further mediated by the presence of anchor tenant firms in the local economy (Agrawal and Cockburn, 2003).

In their study of the economics of knowledge interaction, Antonelli et al., (2008) indicated that knowledge transactions and knowledge interactions are often complementary. They found that inter-organisational and qualified interactions are an intermediate knowledge governance mode between the extremes of pure market transactions and vertical integration. In addition, Van Wijk et al., (2008) performed a meta-analytic review to examine how knowledge, organisation and network-level antecedents differentially affect organisational knowledge transfer. They found that the antecedents of organisational knowledge transfer could be classified into three categories: knowledge characteristics, organisational characteristics and network characteristics.

Furthermore, Huggins et al., (2012) used survey of UK universities to investigate the inter-organisational knowledge networks that universities in the UK engage in through their knowledge transfer activities as well the extent to which organisational and locational factors are associated with the nature of these networks. They found that the nature and formation of inter-organisational knowledge networks is shaped by the organisational characteristics of network actors and their spatial location, where proximity remains significant for establishing effective knowledge networks. As well, knowledge network patterns are influenced by firm's size, as larger firms tend to engage in alliance network with external actors (Huggins and Johnston, 2010).

It is, therefore, important to maintain both potent local links and global ties, as networks are more effective when each node is strong by its own and possess defined function in the process of knowledge production and diffusion (Autant-Bernard et al., 2013). Research further revealed the effect of social network on regional innovation by stimulating

knowledge spill-overs. Ponds et al., (2010) indicated that over longer geographical distances, academic knowledge spill-overs occur via collaborative research networks that drive scientific and technical progress in certain fields, i.e. biomedical sciences. Hence, key scientists engage in both scientific and technical activities such as patenting, industrial consulting and membership in advisory boards in industry (Murray 2002).

#### 2.5.5. The role of intermediaries

There is a growing consensus in the literature that boundary-spanning communication is a fundamental factor for successful UI linkages (Izushi, 2007). Boundary spanners or intermediaries exhibit a heterogeneous role in the process of knowledge acquisition; knowledge flow and its transfer between the knowledge components can be increased or restricted depending on the network context in which the intermediaries exist (Tortoriello et al., 2012). In most cases, intermediaries bridge the knowledge gap between knowledge producers and recipients, thereby promoting successful and effective knowledge acquisition by facilitating the flow of knowledge. This applies to the institutional spheres, as well as between the organisational units within a single organisation (Tortoriello et al., 2012).

Intermediaries that can exist as external or internal (Wright et al., 2008), facilitate knowledge transfer by narrowing down the information gap and reducing transaction costs for both parties (Yusuf, 2008). External intermediaries are those that have existed for a long time and were established initially to promote R&D efforts in local industries as well as their collaboration with research centres in universities. The second type comprises the internal intermediaries such as Technology Transfer Offices (TTOs). Thus, different types of knowledge require different intermediaries, so boundary-spanning activities play an important role in developing effective UI collaborations (Wright et al., 2008).

Different factors influence cross-organisational knowledge flow. Within IU interactions, the willingness to engage Technology Transfer (TT) needs to be viewed from three points; the technology transferor (university), the technology transferee (industry), and the TT intermediary institute (Lai, 2011). From the universities' perspective, the 'transferor's incentive' and 'capability of transferor' positively influence willingness to



participate in TT. For industry, on the other hand, 'capability of transferee' and 'incentive for establishing technological resources' play a major role. TT intermediary is also important, as the 'intermediary's fundamental resources' and 'intermediary's transferring process" have a positive impact on willingness to participate in TT (Lai, 2011).

Colyvas and Powell (2006) traced the evolution of the process of institutionalisation of technology transfer in Stanford University by drawing on the neo-institutionalisation theory. They demonstrated the three stages of technology transfer throughout the path to institutionalisation, which are as follows. The idiosyncratic phase represents the introduction of commercialisation practice, the standardised phase, which signifies the implementation of new rules and activities for handling research outcomes; and the institutionalised phase, which is the stage of expansion in commercialisation in a *modus operandi* manner. They argued that transformation towards technology transfer was process-oriented, which was shaped by both endogenous dynamics as well as the demand to enhance the role of universities as loci of innovation (Fisher and Grosjean, 2002; Colyvas and Powell, 2006).

At the regional level, two crucial elements are necessary to develop an efficient regional technology transfer system between universities and firms: the development of an effective intermediary organisation and enhancing absorptive capacity of regional firms (Kodama, 2008). This is particularly important when transferring tacit knowledge. Many studies have focused on the role of boundary spanners in overcoming the obstacles to cross-organisational knowledge transfer. Theodorakopoulos et al., (2012) studied how the function of intermediaries for knowledge transfer can be optimised in Colombia, using the situated learning theory. He found that intermediaries had a catalytic effect in promoting successful technology diffusion and adoption.

## 2.6. Policy framework for research commercialisation

An effective policy framework plays an important role in promoting successful knowledge commercialisation and increasing Science, Technology and Innovation (STI) capacities (Sato, 2010; Kato and Odagiri, 2012). Autant-Bernard et al. (2013) studied the role of the regional

innovation policies in supporting the institutions, which generate knowledge, and innovation learning within the European regions. It seems that 'the search for a universal policy tool is unrealistic'. As regional features varies, it is important to set original strategies that are based on accurate knowledge of the local/global knowledge flow and are resilient enough to cope with the challenges faced by regional innovation policies (Autant-Bernard et al., 2013).

Most of the literature on commercialisation policies discusses the famous policies and their success experience, suggesting their perceived benefits in the introduced regions. Conversely, emulsion of well-established policies has its drawbacks. For example, in Japan, Sato (2010) argued that policy shifts towards more integrated STI policies are not easy to implement, and 'imported' STI policies have damaged the existing academic system. These findings support the argument that imported policies will conflict with existing national policies.

Therefore, more studies are needed to evaluate the impact of implementation of 'imported' policies in countries undergoing transition towards increasing their STI capacity. Similarly, Chung (2013) studied the role of government in the Research Technology Development and Innovation (RTDI) policy-making process in the Taiwanese pharmaceutical biotechnology sector and concluded that the Taiwanese government has to understand the individuality and dynamics of particular national, sectorial, and technological innovation systems prior to introducing policies. RTDI policies reproduced from foreign countries or another national sector or technology are problematic or ineffective, or cannot generate the desired outcomes (Chung, 2013).

According to the United Nations Education, Science and Culture Organisation (UNESCO, 2010) Science Report, the world is witnessing an increase in the stock of 'world knowledge' that is optimised by new digital technologies and inventions in biotechnology and nanotechnology. Thereby, this provides promising opportunities for emerging nations to attain higher economic and social development. For economies that possess sufficient absorptive capacity and efficiency, these opportunities can be utilised by exploiting technology gaps, taking into account the considerable investment in infrastructure taking

place in these economies. At the national level, STI policies are facing challenges to mediate knowledge production, flow and sharing among knowledge components of the national innovation system as stated by Hollanders and Soete (2010):

National STI policies clearly face new global landscape today, one in which the territorial policy focus is coming under severe pressure... the steep drop in the marginal cost of reproduction and diffusion of information has led to a world in which geographical borders are less and less relevant for research and innovation. Knowledge accumulation and knowledge diffusion are able to take place at a faster pace, involving a growing number of new entrants and providing a threat to established institutions and positions. (Hollanders and Soete, 2010, page 26).

Government policies to enhance the commercialisation and knowledge transfer take different forms according to the stage of institutional transformation. For example, Rasmussen et al. (2006) used a case study approach to investigate the transformation towards commercialisation in four European universities of science and technology in Finland, Ireland, Norway and Sweden. They identified two waves of commercialisation that represent distinctive policy initiatives. The first wave occurred from the beginning of the 1980s and is known by the establishment of 'traditional' science parks, mostly to attract advanced companies and increase UI collaborations through industrial funding programmes. The second-wave initiatives accelerated around the last half of the 1990s and are differentiated from the first wave by a stronger focus on spin-offs and patenting/licensing rather than industry collaboration more generally, representing an increased involvement by students in commercialisation (Rasmussen et al., 2006).

When it comes to policies for handling research outputs, little is known about governments' policies relating to the commercialisation of research in the Arab world, as some countries possess a sizable STI capacity and many endeavours were witnessed for commercialising research outputs (Badran and Zou'bi, 2010). Therefore, further investigation is needed to examine the policy framework that is adopted for commercialisation such as the intellectual property regime, patent culture, and policy for streamlining R&D into basic research, applied research and technological development. For

the purpose of this study, the existing work in policies of knowledge entrepreneurship is divided into direct and indirect policy instruments.

### 2.6.1. Direct policy instruments

Direct interventions represent policies that are directly related to the main components of the knowledge production and utilisation, such as IP regime, funding opportunities and inter-organisational relations (Huggins and Williams, 2011). One of the direct measures to justify and reduce government investment in R&D is by enhancing the plurality of commercial-oriented funding stakeholders. MacAdam et al. (2012) used the stakeholders' theory relationship together with stage development models to review the impact of the establishment of Local Enterprise Partnership (LEPs). The LEPs were introduced by a UK Government white paper in replacement of the Regional Development Agencies (RDAs) to carry on a central role in technology transfer activities. The study evaluated the stakeholders' relationship between the Technology Transfer Office (TTO) and RDAs so that LEPs can benefit from a faster learning curve, as LEPs are expected to be self-sufficient.

The findings showed that the linkages between the TTO and RDAs progressed along different stakeholders' paths as joint means and alignment of performance measures were developed in accordance with the policy and funding approach. They also found that over-reliance on a unitary form of TTO-RDAs relationship may trigger dependency on another stakeholder for funding. These findings reflect the importance of stakeholders' relationships within commercialisation-governing institutions, specifically from the funding opportunities' perspective (MacAdam et al., 2012).

The US experience in adopting institutional reforms has inspired different countries to initiate similar reforms within their national research institutions. Lehrer and Asakawa (2004) studied the role of R&D reforms in Japan and Germany in facilitating research commercialisation in biotechnology. When comparing Japan and Germany, Japan exhibited more seriousness towards enabling a public sector science system, as R&D institutions were converted into independent administration institutions. In Germany, however, only marginal reforms were made, such as public sector incentives to encourage academic

entrepreneurship. The paper concludes with the argument that ‘the success of the commercialisation of biotechnology depends solely on the overall economic framework rather than on the reform of R&D policy alone’ (Lehrer and Asakawa, 2004).

At the university level, the policy approach regarding supporting structures plays an important role. Different initiatives have been studied such as the ‘research pooling’ initiatives in Scotland and the development of university cooperation at the regional level, both of which are considered as vehicles for obtaining ‘strategic resources’ for promoting research commercialisation (Kitagawa, 2009). Moreover, the overall research agenda can impact the performance of academics across the research disciplines and their selection of research that may have commercialisable potential (Antonelli et al., 2011).

In his review of the Canadian support structure for the commercialisation of university research at the federal level, Rasmussen (2008) discussed two programmes: a structural reforms induction programme and a programme providing support to specific commercialisation projects. The Canadian case revealed that the government initiatives encourage a bottom-up approach. This is accomplished by providing resources for direct use in commercialisation projects or to develop skilled ‘know-how’ in technology transfer as well as by facilitating cooperation between key organisations in research commercialisation.

### 2.6.2. Indirect policy instruments

The indirect policy instruments are related to policy interventions that stimulate entrepreneurship in the longer run with a wider contribution to both regional and national development. As mentioned by Huggins and Williams (2011), these include commercialisation policies that aim to achieve much longer-term targets like supporting of business creation, access to finance, support of technology clusters, and enhancing entrepreneurial culture. These policies can be associated with ‘both top-bottom’ and ‘bottom-top activities’ and are thought to have weight in the long-term commitment to accomplish overall regional, economic and social development (Huggins and Williams 2011).

The focus of research on knowledge transfer and UI links seems to be limited to specific areas, and in order for policy makers to use evidence-based findings, research focus has to

be extended. For example, Lockett et al. (2008) studied the challenges of knowledge transfer from HEIs to industry in the UK and four themes are identified as central factors promoting or hindering knowledge transfer; motivation and reward mechanisms for researchers, process management and evaluation within HEIs, clustering and brokerage, and trust- and bridge-building. These findings suggest the need to focus future research on the exploitation of the process of knowledge transfer, rather than on defining and justifying it, if proper policy interventions are to be achieved. Furthermore, there is a need to shift science policy from the supply side to the demand side, and to pay more attention to the global perspective when formulating regional policies for innovation and knowledge transfer (Huggins and Kitagawa, 2013).

Many scholars have studied policy interventions to foster entrepreneurship at the regional level. Huggins and Williams (2011) examined the policies that were implemented by the UK Labour government during the period 1997-2010 to study the extent to which regional policies in less competitive regions contributed to entrepreneurship performance and overall regional competitiveness, as well their relation to the economic and social dimensions of policy agendas. The findings suggest a multi-dimensional nature of these policies with either economic or social origin. They found that there was substantial policy activity in the areas across less competitive regions, yet the enterprise policymaking remains undifferentiated and is both formalised and generically delivered. They reported an evolution in policy approach favouring development of a regional ecosystem, and argued that policy makers are 'under pressure to measure short-term output at the expense of development in the long term' (Huggins and Williams, 2011).

At the regional level, research has indicated different factors that affect entrepreneurial capabilities and has suggested relevant policy-making approaches. For example, community cultural characteristics such as social cohesion have been identified as a potential strength that is positively associated with business enterprises by increasing the confidence in individuals (Huggins and Thompson, 2012). The study concluded by arguing that policy making needs to include community cultures as a useful tool to enhance entrepreneurship,

and to ensure that entrepreneurship policies have to be compatible with the underlying culture.

In a similar vein, Mok (2005) applied the Triple Helix model of government-university-business/industry network system to study the change in research and innovation governance in Hong Kong, in comparison with the developments in Taiwan and Singapore. The analysis indicated the significant role of government as facilitator and coordinator in engaging effective UI interactions to foster knowledge entrepreneurship, which was exemplified by the establishment of the Hong Kong Science and Technology Park. The analysis showed a change in the governance as the state acts as a 'market facilitating state'. This is similar to the challenges of the progression of different regions towards a knowledge economy. As Huggins and Strakova (2011) stated, the main challenge for these regions is realising the 'new value' of knowledge, as regional policy-making is a relatively new area of intervention.

### 2.6.3. The Bayh-Dole Act for Patents and related policies

In developing countries, the growing recognition of the role of science and technology on the economic growth and social development poses more pressure countries to consider policies that promote innovation. In this line, there is a growing interest to integrate effective commercialisation policy initiatives, e.g. IP issues and patenting. Consequently, the development Agenda of the World Intellectual Property Organisation (WIPO) (2007) emphasises the need to promote creativity and innovation in developing countries (Recommendation 19), and to consider intellectual property (IP) policies to serve this end (Recommendation 25).

Two of the most studied innovation policies are the 1980 Bayh-Dole Act for Patents and the Trademark Law Amendment Act of the United States, which deal with intellectual property arising from publicly-funded research. The Bayh-Dole Act enables universities to claim title to inventions and to licence those inventions to the private sector (Mowery and Sampat, 2001). Therefore, it reduced the influence of federal agencies over university licensing policies. Since 1960s, significant changes in university patent policies induced the

passage of the Bayh–Dole Act in 1980. They include the emergence of commercialisable research resulting from the growth of 'use-oriented' basic research in new fields such as molecular biology and biotechnology. There was a decline in federal and other public funding for university research together with university failure to return licensing revenues. Accordingly, shifts in federal policy emerged to enhance patenting of research biomedicine outcomes (Mowery and Sampat, 2001; Mowery et al., 2001). Since 1980, the Bayh-Dole has remained as a vital element of the IPR policy regime in the US and this policy experience has attracted scholars and policy makers from both the industrial and developing worlds.

Most studies examining the impact of the Bayh-Dole Act have been based on data generated by offices of technology transfer. However, Aldridge and Audretsch (2011) conducted a study to identify which factors are conducive and which are inhibitors to scientific entrepreneurship by developing a new database measuring the propensity of scientists funded by the National Cancer Institute to commercialise their research as well as the mode of commercialisation. Their results suggest that scientific entrepreneurship may be considerably more robust than has generally been indicated in studies based on TTO data.

Regarding spin-offs formation, Kenney and Patton (2011) studied the effect of inventor ownership on academic entrepreneurship using data of technology-based university spin-offs from six universities. Their results demonstrated that inventor ownership could be extremely productive from spin-offs. These findings suggest that inventor-ownership can be an alternative to the current university IP regime, so governments seeking to encourage invention commercialisation and academic entrepreneurship need to experiment with this system.

On the other hand, Japan and many European universities currently emphasise a patent-centered model of technology transfer. Despite the trend towards institutional ownership, universities' IPR regulation in Europe continues to be differentiated and there is no one-to-one mapping to the US system (Geuna and Rossi, 2011). According to Grimaldi et al. (2011), most European countries have been interested in legislative changes that, even when not in line with the Bayh-Dole Act, e.g., not granting universities the legal ownership



of inventions, share with it the objective to spur the commercialisation of public research results.

The issue of patenting and university IP regulation remains a significant component in commercialisation-supporting policies. In their comprehensive case study, Locatt et al. (2008) used 50 semi-structured questionnaires to study the challenges to technology transfer between higher education institutions and the industry in the Information and Communication Technology (ICT) sector in north-west England, the UK. Four challenges were identified: motivation and reward mechanisms; process management and evaluation; clustering and brokerage; and trust and bridge-building.

More factors may contribute to the performance of patenting activities within internal university regulations. Baldini et al (2006) studied patenting activities in Italian universities between 1965 and 2002 to assess the institutional changes towards commodification of knowledge. Their findings indicate that patenting activities increase in the universities with an internal IPR regulation compared to universities without such regulation. However, Jacobsson and Dahlstrand (2013) argued that the policy of transferring the ownership of intellectual property rights by universities is a risk in terms of weakening established UI linkages, creating bias to technical change and decreasing academic entrepreneurial activities.

## 2.7. Conclusion

This chapter has outlined the main streams of research in which the topic of the thesis is situated and set out the theoretical framework for this study. As it emerges from the material presented, commercialisation process involves dynamic, actor-rich and technology-shifting context. The review has identified research gaps in the literature concerning the commercialisation and knowledge entrepreneurship.

The current scholarship in commercialisation concentrates on the study of well-established settings for commercialisation in developed economies, such the USA, and the advanced OECD countries. While there are authors interested in the introduction and evolution of the third mission, the focus is mainly on the economic dimension. The social and

cultural perspectives are usually limited to the analysis of the overall social environment and its impact on entrepreneurship. Hence, there are still important areas that are scarcely addressed. Those relate to the evolution of the concept of knowledge entrepreneurship within the developing countries, specifically the oil-based economies that pursue the diversification towards knowledge-based development. Also, is not fully considered in innovation studies.

Drawing on the research context, the research questions and contemporary approaches for the study of research commercialisation, this chapter has described the theoretical underpinnings for the thesis. It explained how and why NIS became the main theoretical framework for the thesis and why two more approaches supplement it: TH and NT. The three theories (NIS, TH, and NT), which are employed stand out among the others applied in the field. Recognising the weaknesses and building on each other's strengths, the theoretical framework offers a more robust approach to address the research questions. It also guided methodological choices by combining methods that stem from the approaches employed in this thesis.

More precisely, the framework enables grasping both the dynamics of the organisations and networks investigated while keeping the analysis of a broader picture of commercialisation still present. While NIS offers a national and inclusive perspective to commercialisation actors at the macro-level, the TH model accommodates the meso-level, and NT offers closer investigation on individual and institutional levels. The theoretical framework employed indicated the critical confluences where the theoretical lens intersect and complement each other. In this way, it allows a focus on the commercialisation process (including actors, networks, supporting elements) and the issues related to social and cultural dimensions of the topic.

Until now, the thesis has presented the research context, the questions enquired as well as the status of the literature and the theoretical framework. The next chapter is tasked with providing insights into research and innovation of Oman's bio-sector that this thesis aimed to study. It engages hence with the key components of the systems of innovation, research and development profile, and the business environment for commercialisation activities.

### **3. Oman: Economy, innovation and the bio-sector**

#### **3.1. Introduction**

This chapter presents the overall research and innovation ecosystem in which the Omani bio-sector works. It begins with the country information that includes location, demography and the national economy. Following that, the chapter introduced the economics significance of the bio-sector in terms of its contribution to the national GDP and employment. Then the chapter presents the key components of the National innovation System in the bio-sector. In this section, the key actors and institutions are described with attention to the knowledge production capacity. Further in the chapter, the weaknesses and strengths of the NIS is discussed. The chapter concludes with an overview of the main characteristics of the NIS in the bio-sector.

#### **3.2. Oman: Location, demography and economics**

The Sultanate of Oman occupies a significantly strategic geographical location, which is the south-eastern corner of the Arabian Peninsula (Figure 3.1). Throughout centuries, the location shaped the county's foreign policy and trade relations with other nations. It overlooks both the Gulf of Oman and the Arabian Sea with a coastal line of 1,700 kilometres that extends from the Strait of Hormuz in the North to the borders of the Republic of Yemen in the south (Ministry of Information, 2014). The total area of Oman is 309,500 square kilometres, and hence it is the third largest country in the Arabian Peninsula. In addition to the main land, Oman has several scattered islands in the Arabian Sea; the most important are Masirah and Al-Halaniyat Islands (Ministry of Information). The topography of Oman is composed of various landscapes ranging from plains, wadis (dry riverbeds) and mountains (National Centre for Statistics and Information (NCSI), The Statistical Year Book, 2013).

The Omani culture has been shaped by the geography of the country. The core of the Omani culture is mainly derived from the Islamic religion and the official language is Arabic. The influence can be seen in type of clothing, architecture, and regular life activities. Omani culture is thought to have special characteristics. This is due to the fact that the geography (large mountains and deserts) of the country has played a role in isolating Oman from its

neighbouring countries. In addition, Oman's long maritime history has enriched the culture through the exposure to other culture (Ministry of Information, 2013).



**Figure 3.1:** Oman political map (Source: Ministry of Information Publications, Sultanate of Oman).

In terms of demography, the total population is 4,018,000, where Omanis account for 55.9%, according to the NCSI quarterly publication in April 2014. The population pyramid showed that the highest percentage is found in two age structures: the 15-24 years group, which accounts for 19.9% and the 25-54 years group, which accounts for 42.6%. The estimated growth rate is 7.89% and the life expectancy at birth for the total population is

74.97 years (Male: 73.07 years; Female: 76.97 years). The total government expenditures in education is 4.3% of the total GDP and the literacy for total population is 86.9% (Male: 90.2%; Female: 81.8%) (NCSI, Facts and figures, 2012).

Oman is a middle-income economy with notable oil and gas resources and considerable trade and budget surpluses. Fossil fuel resources account for 64% of total export earnings, 45% of government revenues and 50% of the country's GDP NCSI, (The Statistical Year Book, 2013). Energy sector represents one of the most important economic segments with 5.50 billion barrels of proven crude oil reserves that account for 1.2% of the total GCC reserves, nearly 0.4% of the world total reserves. With current oil production (0.806 million barrels/day), oil reserves are expected to last for almost 20 years. The economy witnessed an optimal performance during 2003 to late 2008 due to sustained high oil prices, which resulted in Oman's twin surpluses (budget and trade surpluses), as well foreign reserves.

The Omani private sector is modest and yet diversified, which covers mining industry, agriculture, textile, retail and tourism. Its major industries are copper, mining and smelting, oil refining and cement plants (Ministry of Information, 2013). However, it further seeks private foreign investment, especially in technology-based fields such as IT and biotechnology. The current industrial development plans aim at supporting gas resources, metal manufacturing, petrochemicals, and international transshipment ports. Oman was challenged with high liquidity and inflation until late 2008 (Ministry of Information, 2016).

### 3.3. Economic significance of the bio-sector

This thesis studies the commercialisation in biosciences, which belongs to Oman's biological resources sector. Based on its contribution to the national GDP and employment, the sector is the fourth significant economic segment after oil and gas, mining, and manufacturing (National Research Strategy (NRS), TRC, 2008). It is divided into sub-sectors that are agriculture, fisheries, and environment. While oil and gas sector constitutes 25% of Oman's overall GDP. The biological resources sector (specifically agriculture and fisheries) contributes to 3% of total country's GDP, which accounts for 16% of the total contribution of all non-oil sectors (Figure 3.2). It employs 50% of the total workforce (Figure 3.3) (NRS, TRC,

2008). While most of the wealth of Oman comes from the oil and gas sector, it is not the key employment source and exposes the national economy to several risks, i.e. price volatility and declining reserves.

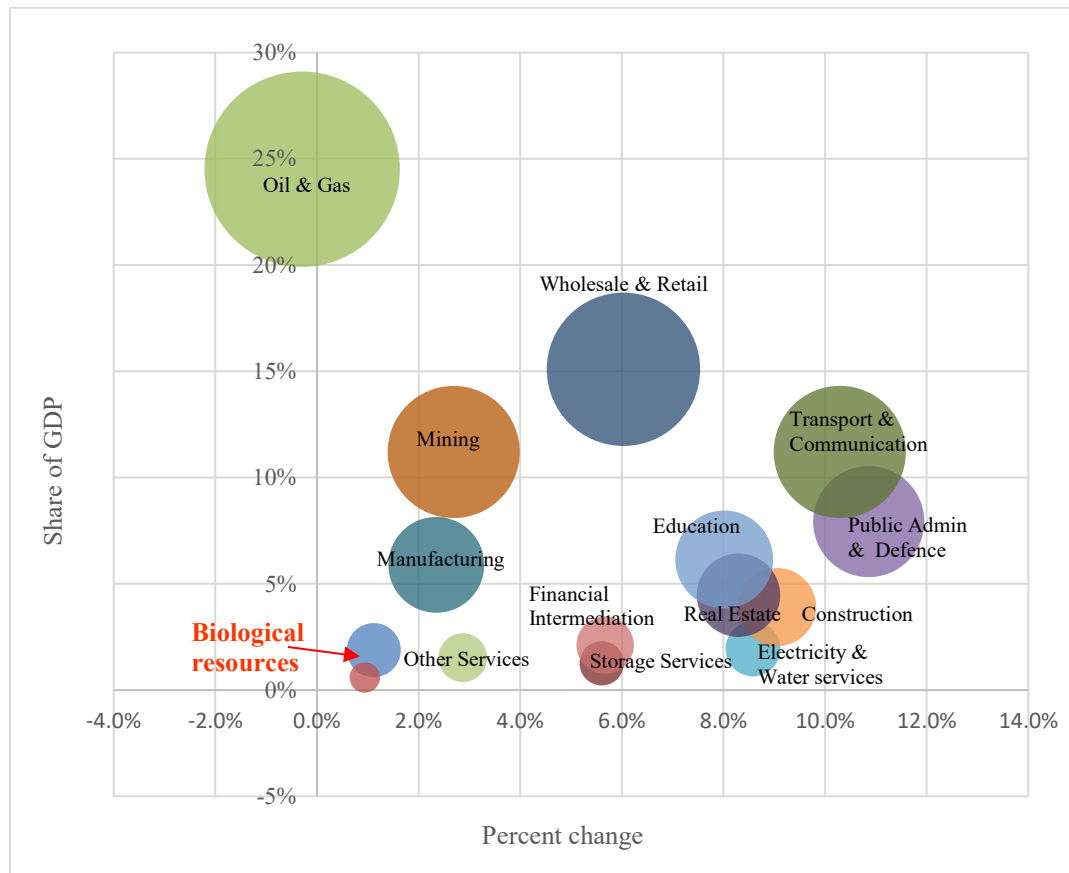


Figure 3.2: The percentage of contribution of key economic sectors to the national GDP (the biological resources in red) (Source: National research Strategy, TRC, [www.trc.gov.om](http://www.trc.gov.om). Accessed 07/08/2017)

Compared to oil and gas sector, which accounts for 84% of total exports, the biological resources' share is only 2% (NRS, TRC, 2008). Most sub-sectors are growing, with the majority of the sector's GDP value and exports attributable to dates production and the fisheries industry. The environment sector also contributes from ecotourism and ecological services. Sector's low productivity is mainly due to the lack of focus on value added downstream agro-industries, as well high-tech applications.

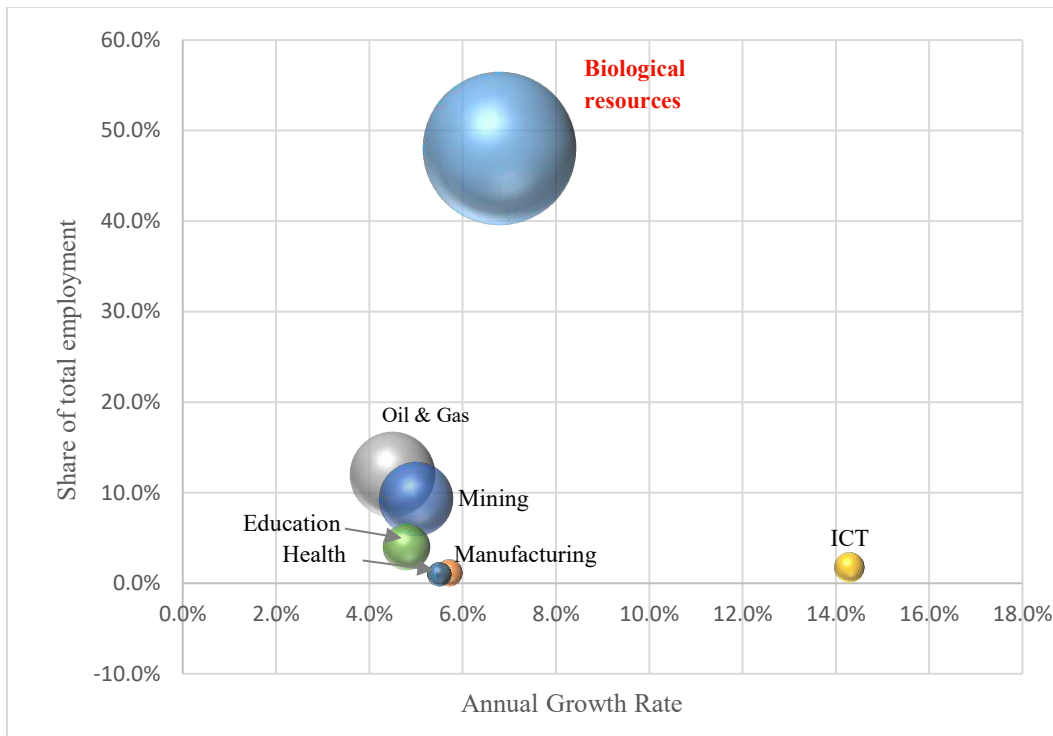


Figure 3.2: The contribution of the biological sector to the employment (*Source: National Research Strategy, TRC, www.trc.gov.om. Accessed 07/08/2017*).

Therefore, the main economic value of the sector is in its contribution to the total employment, whereas agriculture and other sub-sectors accounts for 43% and fisheries accounts for 7% (NRS, TRC, 2008). On the other hand, the sectors of oil, gas, and mining together employ 15% of the total workforce. The biological resources sector faces challenges that can be addressed through research and innovation. For example, for agriculture and fisheries sub-sectors the key difficulties are enhancing the production, resources management and the development of downstream industries (NRS, TRC, 2008). The environment sub-sector faces challenges of biodiversity sustainability, environment monitoring, and water resources management. The strategy suggests the need to align research with the needs of the sector and to support innovation with regard to areas of national priority, such as water technology and biotechnology.

In essence, the Omani Government first identified biotechnology as a field of strategic importance in the late 1980s and different public measures were formed to advance the sector during early 1990s. In the academia, the first programme of BSc degree in

biotechnology was established in 1997, in the College of Science of SQU. Around the same time, the Ministry of Agriculture and Fisheries Wealth (MAF) set up the tissue culture research laboratory. Later on, the industry sector witnessed increased tendency towards biotechnology activities. Among other research areas, the National Research Strategy identifies biotechnology among National Research Priority fields.

### 3.4. The NIS components of the Omani bio-sector

All innovation systems consider the same basic building blocks that are actors, institutions, networks and technology (OECD, 1999). In this section the main components of the NIS in the bio-sector are defined according to their contribution to innovative activities. It begins with NIS actors, institutions, and bioscience knowledge that represent knowledge production side. The national policies are also presented and it reflects the central role of government. Furthermore, the local business environment is discussed as market actor that is related to the demand side.

#### 3.4.1. Knowledge actors and institutional capacity

The research and innovation capacity reflects the overall readiness of the sector to support research and innovation activities that can be commercialised into new products or services. As indicated in R&D indicators, research and innovation infrastructure are in the academia and public research centres. There are no R&D labs or centres in the industry or the private sector. Within the academic sector, public higher education organisations have more sophisticated research laboratories compared to private organisations. There are well-equipped research centres in the government, for instance, the research centres of the MAF. Another example is Oman Centre for Animal and Plant Genetics Resources that was established in 2009 under the supervision of the Research Council.

Furthermore, several research chairs and centres emerged in the public and private universities. For example, University of Nizwa Chair of Oman's Medicinal Plants and Marine Natural Products and Environmental Research Centre in Sohar University. There is a rapid development in research-supporting units, such as incubators, science parks, and free zones or industrial estates. Business incubators are geographically scattered, but the largest



number is found in Muscat, the capital city. Similarly, the Public Authority for Industrial Estates has developed several free zones outside the capital city.

Regarding scientific activities of knowledge-producing actors, publication and collaborative research are the dominant activities compared to commercialisation and academic entrepreneurship. For example, there is a substantial increase in the publication rate in the College of Agricultural and Marine Sciences (CAMS) of SQU with a yearly average rate of 1.5 paper per faculty (CAMS Annual Report, 2012). In 2013, the total number of publications was 235, which represents four-fold increase (63 publications) from 2005 and almost eight-fold increase (32 publications) from 1995. In the College of Science (CoS), 267 publications were reported in 2013 that accounts for 1.16 per academic staff compared to 34 publications in 1995 (CoS Annual Report, 2010). In addition to the change in the total number of publication, research themes also transformed. By reviewing and comparing the key words in the recent publications with earlier work, there was a shift towards applied research.

The collaboration with external organisations includes public lectures, training programmes, workshops and outreach. The linkages with the industry include research contract and consultancy in two key fields that are microbial enhanced oil recovery with the oil industry and environmental assessment with the craft industry. Academics also collaborate with their international peers in academic cooperation programs, conferences, scientific seminars and workshops. It is interesting to note the extensive activities of the student society and their interaction with academic sphere and other institutional spheres, for example, the sport day, student's conference, and student's exhibitions. This reflects the culture within the academia that supports the development of networks within the university and with external organisations.

In addition to these two colleges, there are three other centres in SQU that are involved in biosciences research, which are: the Centre of Excellence in Marine Biotechnology; the UNESCO Chair in Marine Biotechnology; and the Centre of Environmental Research. All these units have been established recently and they share the same mission of promoting applied

research and building national capacity. They also aim to encourage linkages with the industry and international collaboration.

In the public sector, research activities of the MAFW are directed by a five-year plan, which also reflect the development of research management. There is an increase in the total number of research project and publication in both subsectors of agriculture and fisheries. For example, the number of research projects was less than ten in 1988 and there was one published scientific paper. In 2005, the total number of research projects was 82 and the publication was nine papers (Agricultural Research Annual Report, 2006). Research themes also have developed and became more organised. They can be categorised according to the following groups: horticulture and field crops; toxicology; tissue culture and genetics; plant pathology and pest control; soil and water; food processing; and livestock research. By its nature, the research conducted by the MAFW is of applied type and is oriented towards problem solving.

#### 3.4.2. National R&D policies

The NRS, which was formulated by TRC in 2008 by collaborative efforts of local stakeholders from the three institutional helixes, is the main policy document for the management of research and innovation funding. The strategy focuses on four objectives, which are: research capacity, research excellence, knowledge transfer, and enabling environment. For each theme, a set of indicators were used for the evaluation in order to identify the gaps and set a qualitative goals to address them. In general, most indicators showed modest performance on knowledge and innovation outputs, which reflect limited research and innovation capacity.

On the other hand, the Innovation Grand Committee, under the supervision of TRC, formulated the National Innovation Strategy in 2015. The strategy focuses on four pillars that are human capital, economic diversification, Intellectual Property (IP) and institutional and social integration. The industrial policy focuses on long-term goals, which aims to enhance the strategic sectors and no specific policies for the bio-based industry. Successive

Five Year Development Plans and the long-term Oman Vision aim to shift the economy towards self-sustained growth with more roles of the private sector.

Besides, the Foreign Capital Investment Law is considered as one of the important policy initiatives that aim to enhance domestic and foreign investments. Such investments are expected to enhance the creation of job opportunities as well the knowledge transfer. However, these policies aim to achieve long-term objectives and there is a need for more specific policies that address the meso-level and the micro-levels. It was interesting to note that TRC has used the Economic Vision Oman 2020 as the reference policy document for the development of the National Research Strategy

### 3.4.3. The business environment

The business environment for commercialisation activities is a significant factor in the discussion of knowledge entrepreneurship (Siegel and Wright, 2015). It reflects all the factors, internally and externally, as well the institutions that influence business transactions (OECD, 2015). According to the World Bank, Oman is ranked 47<sup>th</sup> out of 185 economies in the ease of doing business index for the year 2013, with no change in its overall ranking from previous years (The World Bank report, Doing Business, 2014). Oman's economic freedom score is 67.9, making its economy the 47<sup>th</sup> including freedom from corruption, labour freedom, and government spending. Oman is ranked 5<sup>th</sup> out of 17 countries in the Middle East/North Africa (MENA) region, and its overall score is above the world and regional averages. Tables 3.1 and 3.2 present the key indicators such as number of procedures, time and the cost of the main stages in doing business.

**Table 3.1:** Summary of indicators of different stages of a business's life cycle (The World Bank, 2014).

Summary of indicator	Procedures (Number)	Time (Days)	Cost (% of income per capita)
Starting a business	5	12	3.3
Dealing with construction permits	15	186	106.2
Registering property	2	16	3
Enforcing contracts	51	598	13.5
Closing a business	34.9 % (recovery rate)	4	4 (% of estate)

**Table 3.2:** Summary of indicators for paying tasks and international trading stages of a business's life cycle (The World Bank, 2014).

Paying taxes		Trading across borders	
Payments (number per year)	14	Documents to export (number)	9
Time (hours per year)	62	Time to export (days)	14
Profit tax (%)	9.7	Cost to export (US\$ per container)	766
Labor tax and contributions (%)	11.8	Documents to import (number)	9
Other taxes (%)	0.1	Time to import (days)	17
Total tax rate (% profit)	21.6	Cost to import (US\$ per container)	890

The national business legislation has developed as several laws and policies were issued (The World Bank report, Doing Business, 2014). For example, Banking and credit laws (Law No. 9/1995 on the Banking Insurance System) that was issued by Royal Decree No. 55/2000, regulate getting credit and support investing. Different stages in doing business (starting a business, employing workers, registering property, and enforcing contracts) are regulated by Commercial Law No. 4 /1976. Royal Decree No. 35/2003 issued Labour Law, and Securities Law No. 53 /1988 regulate securities and stock exchange.

Under the law for the organisation and encouragement of industry, several incentives are granted to licensed industrial units after the recommendation of Industrial Development Committee (The World Bank report, Doing Business, 2014), (Personal communication, Ministry of Commerce and Industry (MCI), 2014). The incentives include exemption from custom duties on import of raw materials, plant and equipment. In addition, government soft loans and subsidised electricity and water charges are granted. Manufacturing companies can benefit from the preference in government purchases of local products. Furthermore, all companies engaged in priority economic sectors (e.g. oil, fisheries and tourisms) are given an income tax holiday period for the first five years from the date of commencement of the project. These exemptions can be extended for another five years.

As far as intellectual and industrial properties are concerned, Oman is a member of World Intellectual Property Organisation (WIPO) (MCI, [www.mci.gov.om](http://www.mci.gov.om)). The regulatory framework has developed and several legislations were indorsed to protect intellectual properties rights of companies and individuals. Copyright and related rights law, are issued by Royal Decree 65/2008 and protects the rights of authors of literary, artistic and scientific works (including software and computer programs). Copy right, which is registered with

Intellectual Properties department, Ministry of Commerce and Industry, span for the lifetime of the author and 50 years afterwards.

The Industrial Properties Rights Law was issued by Royal Decree 67/2008, and protect the rights of registered trademark and names, industrial designs, patents and integrated circuits for local firms, foreign companies, as well individuals (Ministry of Commerce & Industry, [www.mci.gov.om](http://www.mci.gov.om)). Similar to the copyright, trademarks and trade names are registered with Intellectual Properties Department in the Ministry of Commerce and Industry. The protection period is for 10 years, and is renewable. The period protection Patents, industrial designs and integrated circuits is also renewable and for twenty years.

### 3.5. Strengths and Weaknesses of the Innovation System

As discussed earlier, the national innovation system is evolving and several elements are at the infancy stage. The main weakness is in the fragmentation of the roles across the NIS institutions. Furthermore, there is a weak link between research and educational actors and commercial and industrial organisations. This is further enhanced by the lack of an explicit and coherent national innovation policy that address the critical issues such as University-Industry linkages, research funding policies, and enhancement of local culture of experimentation, invention, and knowledge creation in the fields of Science, Technology, Engineering, and Mathematics (STEM). However, there are significant developments in the overall research and innovation capacity such as the establishment of new actors within the national innovation system and the emergence of systemic management of the innovation programs.

#### 3.5.1. The Research Council of Oman (TRC)

The Royal Decree No (54/2005) established the Research Council (TRC) that acts as an umbrella for supporting research and innovation actors in Oman. Before, the finance and management of research and innovation activities were performed within knowledge producers' actors. TRC provides funding and facilitate collaboration between key stakeholders with the focus in building national capacity and achieving research excellence in areas of strategic importance ([www.trc.gov.om](http://www.trc.gov.om)).

The first National Research Strategy (2008 -2020) was released in 2008. It addresses four core objectives, which are: (1) to build research capacity and infrastructure; (2) to enhance research excellence in areas of strategic importance; (3) to foster knowledge transfer between academia, local industries, government, and other actors; and (4) to improve research environment to attract researchers and scholars to conduct research activities in Oman. With regard to the third objective, TRC aims to promote commercialisation through the provision of risk capital and the attraction of technopreneurs and investors. Different funding schemes are directed to six research sectors that are: Social science and humanity, Education and human resources, Energy and industry, Environment and biological resources, Information and Communications Technologies (ICT), and Health and social services. Across the six sectors, TRC is running several Research and Innovation (R&I) Programmes, as follows.

### *3.5.1. The Open and Strategic Research Grant (ORG)*

The Open Research Grant (ORG) allocates small-to-medium size research grants to short-term and mid-term research projects within the fields of sciences and humanities. The main goal of the program is to expand and enhance research capacity in the Sultanate. To achieve this, the program supports networks and interactions of researchers and assists young graduates with financial support for their postgraduate study ([www.trc.gov.om](http://www.trc.gov.om)).

However, the Strategic Research Program allocates medium to large research grants for long-term projects of primary national importance. The program supports projects that respond to strategic needs, ensuring research excellence, and aiming at building national research capacities in strategic areas. The programs recommend solutions to national challenges by generating new knowledge and technology through networks of local and international scholars. TRC is supporting strategic programs (each with total funding of 2.5 M OR) in the fields of energy, water, social development, agricultural sustainability and road safety (TRC Annual Report, 2016).

### ***3.5.1.2. The Research Chair (RC) Program***

The Research Chair program aims at developing local research excellence and establishing ties between Omani and international research organisations. It provides financial resources for the establishment of research chairs at higher education institutions. It contributes to advancing knowledge through focused research, and strengthening the capacity of local institutions to generate and apply new learning. TRC is currently supporting research chairs (each with total funding of 2 M OR) in nanotechnology, biotechnology, medicinal plants and material sciences (TRC Annual Report, 2016).

### ***3.5.1.3. The Researchers' Incentives Program***

The Researchers' Incentives program seeks to increase the level of research productivity and promote interest in research and innovation. It aims to increase the number of active researchers, motivate researchers and postgraduate students to contribute to local capacity building through publication as well commercialisation of research outputs, e.g. licencing and patenting (TRC Annual Report, 2016).

### ***3.5.1.4. The Research Awards***

The Research Awards, which were first launched in July 2014, aim at encouraging researchers to conduct high quality research of national importance (TRC Annual Report, 2016). The Awards enhance the development of the research culture and its output. The award is divided into two categories; the Faculty Mentored Award and the National Research Award (NRA).

The first award is a scholarship-type funding that is granted to students and faculty mentors in higher education institutes to enable them to perform research and enrich undergraduates learning experience. The program aims to promote research culture and to increase creativity among science and engineering students. Annually, TRC is supporting around 100 undergraduate research ideas with total funding of 200,000 OR (TRC Annual Report, 2016).

The NRA recognises the best-published research led by a PhD holder or equivalent, as well by a young researcher (a non-PhD holder). The winner from both categories are receiving

2,000 OR along other support, such as recognition in local media and opportunities to meet industry representatives who are invited in the ceremony.

#### ***3.5.1.5. Innovation Park Muscat (IPM)***

The IPM project is Oman's newest and most ambitious science and technology development. It is one of the major initiatives by TRC to encourage scientific research, innovation and activate collaboration between the academic, private and the diverse industry sectors of local and international communities ([www.trc.gov.om](http://www.trc.gov.om)). It is the second largest science park in the country after Oman Oasis Muscat, which was established two decades ago. Its vision is 'Placing Oman in the global map of scientific advancement'. It provides vital access to outstanding facilities, services and talent, creating an environment that inspires innovators and entrepreneurs to develop extraordinary ideas and companies. The project is in the first phase and focuses on four strategic sectors that are energy, food and biotechnology, health care, water and environment.

#### **3.5.2. Research and Development (R&D) indicators**

The development of national Research and Development (R&D) indicators is considered as a major milestone in the enhancement of the research and innovation activities. It started after the establishment of TRC with the purpose of assessing the current research capacity (Personal communication, Statistics Specialist, TRC, 2014). Since then, TRC acts as the national focal point to collect these indicators and to train the concerned organisation in order to increase the quality of these data.

The data are obtained using UNESCO questionnaire, which focuses specifically on resources that are devoted to research and experimental development. The database includes the indicators about R&D personnel and researchers (Table 3.3 & 3.4), as well the total number of researchers by sector of employment and field of science (Table 3.5). The expenditure on research and development (R&D) is also provided according to the type of R&D activity (Table 3.6), and field of research (Table 3.7).



*R&D personnel and human capital*

According to the database, the R&D personnel are distributed between the government and the academia sphere, whereas the industry has no active R&D staff (Table 3.3). For both the Headcounts (HC) and Full-Time Equivalents (FTE) R&D personnel, the highest number is in the academic sphere where male researchers dominate the field (Tables 3.3 & 3.4). The total number of biosciences graduates has increased since mid-1995 as the enrolment rate in local universities has improved. Moreover, the percentage of Omani students who are funded by the Ministry of Higher Education for abroad study has increased in the fields of science, technology, and innovation-related subjects.

**Table 3.3:** Headcounts (HC) R&D personnel by occupation, sector of employment and gender (TRC Database, 2014).

<b>Gender</b>	<b>Occupation</b>	<b>Government</b>	<b>Higher education</b>	<b>Total</b>
Males	Researchers	208.0	766.0	974.0
	Technicians and equivalent staff	83.0	204.0	287.0
	Other supporting staff	235.0	343.0	578.0
	Not specified	0.0	0.0	0.0
	Total R&D personnel	526.0	1313.0	1839.0
Females	Researchers	94.0	167.0	261.0
	Technicians and equivalent staff	29.0	96.0	125.0
	Other supporting staff	20.0	240.0	260.0
	Not specified	0.0	0.0	0.0
	Total R&D personnel	143.0	503.0	646.0
Total	Researchers	302.00	933.00	1235.00
	Technicians and equivalent staff	112.00	300.00	412.00
	Other supporting staff	255.00	583.00	838.00
	Not specified	0.00	0.00	0.00
	Total R&D personnel	669.00	1816.00	2485.00

**Table 3.4:** Full-time equivalents (FTE) R&D personnel by occupation, sector of employment and sex (TRC R&D Database, 2014).

<b>Gender</b>	<b>Occupation</b>	<b>Government</b>	<b>Higher education</b>	<b>Total</b>
Males	Researchers	193.5	186.7	380.2
	Technicians and equivalent staff	78.7	62.0	140.7
	Other supporting staff	233.8	75.2	309.0
	Not specified	0.0	0.0	0.0
	Total R&D personnel	505.9	324.0	829.9
Females	Researchers	86.8	30.3	117.1
	Technicians and equivalent staff	28.0	29.2	57.3
	Other supporting staff	17.9	48.8	66.7
	Not specified	0.0	0.0	0.0
	Total R&D personnel	132.7	108.3	241.0
Total	Researchers	280.27	216.97	497.24
	Technicians and equivalent staff	106.69	91.25	197.94
	Other supporting staff	251.70	124.05	375.75
	Not specified	0.00	0.00	0.00
	Total R&D personnel	638.66	432.27	1070.93

Furthermore, the employment opportunities for Science and Engineering graduates have improved with the reforms in the Omani Higher Education sector. The main employer is the government and the academia (Table 3.5). The Oman Accreditation Council (OAC), which is a newly formed independent department, has initiated institutional quality audits and program accreditation processes in order to align education and skill development with the needs of labour market. The OAC has implemented three main frameworks; the Oman Qualifications Framework, which identifies the different types of qualifications that are currently awarded in Oman (e.g. certificates, diplomas and degrees). The second framework is the Oman Institutional Classification Framework, which recognises the criteria for categorising different types of higher education institution (e.g. universities and colleges). The third outline is the Standard Classification of Education Framework that describes in all the potential fields of study and employment for Omani students (OAC, 2013).

**Table 3.5:** Researchers by sector of employment and field of science (TRC R&D Database, 2014).

Field of science	Government	Higher education
Natural sciences*	20.00	190.00
Engineering and technology	41.00	157.00
Medical and health sciences	0.00	80.00
Agricultural sciences	249.00	63.00
SUB-TOTAL: Natural sciences and engineering (NSE)	255.00	490.00
Social sciences	47.00	253.00
Humanities	0.00	163.00
SUB-TOTAL: Social sciences and humanities (SSH)	47.00	416.00
Not specified	0.00	27.00
TOTAL researchers	302.00	933.00

\* *The highlighted fields represent the biosciences sector.*

In addition to structured education, the government has a separate budget for training and skill development, which consists of both scholarships for higher education, and on-job technical training. In the academic sector, the training programs are more organised. The number of scientists and engineers in the private sector and industry is limited. Accordingly, training of knowledge workers in these sectors is done in small-scale practice. In essence, training of technical staff in the bio-sector is relatively costly. Most of the needed training is about technical issues like instrumentation, field skills, laboratory analysis, software application (Personal communication, Dean of College of Science, 2014).

#### R&D expenditure

As far as the expenditure on research and development (R&D) is concerned, the main source of funding is the government, whereas the contribution of the industry is limited to oil companies (Tables 3.6 & 3.7). Nationally, the main funding agency is the Research Council (TRC), besides the universities, other government departments and non-for-profit organisations. The total funding for basic research is higher than the applied type (Tables 3.6) and the funding of Natural sciences and engineering is higher than that of Social sciences and humanities (Tables 3.6).

**Table 3.6:** Total expenditure on R&D by sector of performance, type of R&D activity and cost (millions Omani Riyals) (TRC R&D Database, 2014).

Type of R&D activity	Business enterprise	Government	Higher education	Private non-for-profit	Total
Basic research	213,213.0	19,781,415.8	3,611,672.5	3,000.0	23,609,301.2
Applied research	5,889,987.6	1,506,328.1	1,479,484.2	0.0	8,875,799.9
Experimental development	6,267,311.6	70,820.0	1,673,541.3	0.0	8,011,673.0
Not specified	0.0	0.0	10,867,811.5	0.0	10,867,811.5
Total expenditure on R&D	12,370,512.2	21,358,563.9	17,632,509.5	3000.0	51,364,585.6

**Table 3.7:** Total expenditure on R&D by sector of performance and field of sciences (millions Omani Riyals) (TRC R&D Database, 2013).

Field of science	Business enterprise	Government	Higher education	Private non-for-profit	Total
Natural sciences*	0.0	249,927.0	1,907,563.7	0.0	2,157,490.7
Engineering and technology	12,370,512.2	89,120.0	2,047,305.7	3,000.0	14,509,937.9
Medical and health sciences	0.0	13,280.0	2,027,684.8	0.0	2,040,964.8
Agricultural sciences	0.0	19,375,503.0	1,117,077.5	0.0	20,492,580.5
<i>SUB-TOTAL: Natural sciences and engineering</i>	12,370,512.2	19,727,830.0	7,099,631.7	3,000.0	39,200,973.8
Social sciences	0.0	1,629,893.9	1,479,865.9	0.0	3,109,759.8
Humanities	0.0	0.0	1,087,056.9	0.0	1,087,056.9
<i>SUB-TOTAL: Social sciences and humanities (SSH)</i>	0.0	1,629,893.9	2,566,922.7	0.0	4,196,816.7
Not specified	0.0	840.0	7,965,955.1	0.0	7,966,795.1
Total expenditure on R&D	12,370,512.2	21,358,563.9	17,632,509.5	3,000.0	51,364,585.6

\* The highlighted field represent the biosciences sector.

In the academic sector, the main source of funding for both basic and applied R&D is the internal grants and industry grants. In Sultan Qaboos University (SQU), there is another source, which is His Majesty's (HM) grant. The HM grants are very competitive and are directed towards research of strategic importance. An additional funding is available through collaborative research with government bodies like the Ministry of Agriculture and Fisheries Wealth, and the Royal Court Affaires, as well regional or international organisations.

Besides the funding of research and innovation activities, there are several programmes for the support of enterprises development. For example, Self-Employment and National

Autonomous Development (SANAD) Program, which was set up by the government in 2001 with the mandate of providing seed capital for individuals and groups of investors running entrepreneurial projects (Ministry of Industry and Commerce, 2014). Before that, the “Sharakha” entrepreneurial fund, which supports youth projects, was established in 1998. Both of these funding programs focus on a number of ‘Sectors of Opportunity’, which are mainly not technology-based, like hospitality industry, ancillary industries, and manufacturing sector.

In addition to the financial support for entrepreneurs, other programs provide technical and training support. For instance, the ‘*Intalaqaah*’ Fund, which is concerned about the technical aspect of entrepreneurship education and mainly provides training and mentoring services to entrepreneurs. Another example is *GroFin*, which is a multi-national group of specialist in SME finance that provides both risk capital and business development support. Oman Development Bank also provides subsidising funds on collateral basis for entrepreneurs.

Recently, the Public Authority for SMEs Development, which is a government body, was established in 2013 with a central mission of embedding the culture of entrepreneurship in the Omani society especially the youth ([www.pasd.gov.om](http://www.pasd.gov.om)). The PASD supports entrepreneurs and managers by providing funding, training, and consultation. It also coordinates with other funding agencies, like the SMEs Development Fund and Oman Central Bank, to assist entrepreneurs and SMEs owners to get access to both finance and other technical support and advice.

### 3.5 Conclusion

The bio-sector is one of the significant economic segments in the Omani national economy and it exhibits progressive growth. The National Innovation System in the bio-sector is evolving and distinct NIS components are recognised. Three broad concerns are found in the NIS of the bio-sector. First, the overall capacity of the NIS is weak and fragmented. At the macro-level, Oman lacks an explicit and coherent national innovation policy and this applies

to the bio-sector. Finally, there is little information regarding local culture of experimentation, invention, and knowledge creation, particularly in the field of bio-sciences.

This chapter covers the study context and introduces country information and the Omani NIS in the field of bio-sector. The next chapter engages with the epistemology and methodology of this study in addressing the research questions. It provides detailed descriptions of the research inquiry process and explains the rationales of its epistemology and how this paradigm informs the research design and approaches of this study.

## 4. Research design

### 4.1 Introduction

The previous chapters have explained the theoretical framework that this thesis follows and the study context of the bio-sector. Taking into account the research questions (section 1.3), there is a need to adopt a design that can provide a useful approach and can engender significant insights into the study topic. As discussed in the following sections, this study is influenced by the conception of Critical Realism (CR) (Bhaskar, 1978; Bhaskar, 1989; Archer et al., 1998), which is one of the most common forms of post-positivism philosophy. Assuming this stance reflects a need to examine causes that influence outcomes, beyond the direct explanation of the events. As CR is claimed to be relatively tolerant with regard to different research methodologies, the mixed research approach (Creswell, 2003; Tashakkori and Teddlie, 2003) is applied. Such design is advantageous to 'capture the best of both quantitative and qualitative methodologies, as it allows knowledge claims to be based on pragmatic grounds' (e.g., consequence-oriented, problem-centred, and pluralistic) (Creswell, 2003, P 21).

Accordingly, the choice of methodology here derives from two sources, which are theory-driven and with the influence of research questions. Research in knowledge networks in the biotechnology sector tends to employ both qualitative and quantitative methods (e.g. Boschma, 2005; Hewitt-Dundas, 2011; Perkmann et al., 2011; Huggins and Thompson, 2012; Huggins et al., 2014). Then again, the type of research questions implies the need for both types of data. Recognising that all data collection techniques have certain limitations, convergence across quantitative and qualitative sources is attempted through triangulation of questionnaires, semi-structured interviews, and analysis of policy documents (Figure 4.1). The results from one method can be used to develop or inform another means of analysis; for instance, the review of policy documents was used to develop the questionnaire and interview questions, suggesting a sequential procedure. As indicated by Tashakkori and Teddlie, (1998), 'one method can be nested within another method to provide insight into different levels or units of analysis'.

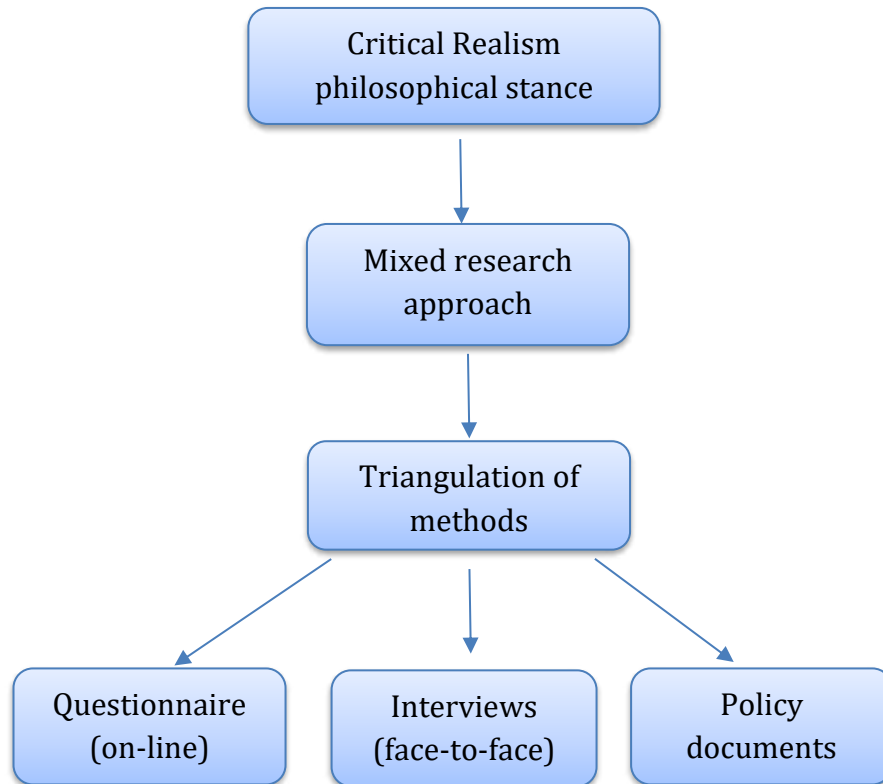


Figure 4.1: An illustration of the research design indicating the philosophical stance, research strategy, and the methods for data collection.

This chapter presents research design that includes three main components: the logic of the inquiry, approaches to research, and methods for data collection and analysis. The first section explains the philosophical principles that drive this thesis, together with the justification for employing the mixed methods approach. Then the chapter explains the identification of the actors through desktop analysis. The next section focuses on the phases of fieldwork that were conducted in Oman during 2014, followed by detailed accounts of the methods of data collection and analysis. After that, the ethical considerations, which are relevant to this thesis, are explained. The last section concludes the research design that this study follows.



## 4.2 Logic of the inquiry

This thesis examines the current commercialisation activities and experience, the past events and transformation of the actors, and perceptions and views of professionals in the main institutional helixes. Initially, the research questions (Section 1.3) were developed to describe the research context as discernible events, and to examine what causes them to occur. They are in the form of ‘what’ and ‘how’, which implies the need for interpretative knowledge with regard to the research topic.

Therefore, the quest here for ‘what’ and ‘how’ events happened cannot be fully addressed through the positivism paradigm (Lincoln and Guba, 2000; Mertens, 1998), which is based on merely scientific-like measurements, correlation, statistical reasoning, and verification. This implies the implementation of appropriate research epistemology that subjects the research phenomena to wide critical examination to achieve the best possible understanding of reality. Therefore, this study is aligned with the Critical Realism (CR) paradigm (Archer et al., 1998), which is one of the most common forms of post-positivism philosophy. As certain types of social research problems call for specific approaches, the CR is thought to suit the complexity of this topic and to contribute to the understanding of the events and their mechanisms, as stated by Bhaskar and Danermark (2006):

[...] critical realism is [...] the ontologically least restrictive perspective, insofar as it is maximally inclusive as to causally relevant levels of reality and additionally maximally inclusive insofar as it can accommodate the insights of other meta-theoretical perspectives. (Bhaskar and Danermark, 2006, p. 294)

Whereas CR is a relatively new orientation in social science research, it is being applied in many disciplines including the fields of commercialisation and entrepreneurship, such as economics (Lawson, 1997), geography (Proctor, 1992; Yeung, 1997), and management (Ackroyd and Fleetwood, 2004). CR is centred on the realist social theory and assumes that social reality consists of social structures that exist ‘independently of the various ways in which they can be discursively constructed and interpreted by social scientists and other social actors located in a wide range of socio-historical situations’ (Reed, 2001). For the purpose of this study, three central features of CR were used to connect the underlying philosophy to the main research tasks; which are research design, field investigation, data

analysis, and causal explanation of the outcomes. These features are: the stratified nature of reality, generative mechanisms, and epistemic fallacy (Bhaskar, 1978; Bhaskar, 1998; Archer, 1995; Danermark et al., 2002).

According to Bhaskar (1998), reality is thought to exist as three domains: the empirical, actual, and real. Whereas the empirical domain reflects experiences and observations, the actual domain contains all events that occurred, even if they are not noticeable. The real domain, which is the deepest sphere, contains all the mechanisms with generative powers that are 'real and distinct from the patterns of events that they generate; just as events are real and distinct from the experiences in which they are apprehended' (Bhaskar 1998, P 41). These mechanisms are reintroduced throughout the course of knowledge enquiry, which considers multiple causal mechanisms and allows for the emergence of competing explanations. The critical realist concept of a stratified reality allows for an analytical examination of the correlation between different levels of reality without collapsing the one into the other (Archer, 1995).

Based on the theoretical framework of this study tackles the commercialisation process from the NIS perspective, the bio-sector is viewed as a self-contained setting that has its own actors (researchers, policy makers, intermediaries, industry and private sector personnel), working in a social network (the research community linkages, university-industry ties), governed by sets of implicit and explicit rules (policy and legal framework). An additional element of entrepreneurial capabilities and culture that determines the nature of interactions and collaboration between the key actors represents another layer of reality.

This aspect of entrepreneurial capabilities is a central component of this study and correlates strongly with the multi-layered context of CR framework, as it explores the institutional capacities and transformations towards the third mission of knowledge entrepreneurship. This transformation throughout the study time is a complex process that is induced by multi-causal set of competing and interacting forces of the actors. The analysis of such driving forces reveals unexpected outcomes which was compatible with the decouple of causal laws from event regularities

In CR, it is not the events that are significant, but rather the generating mechanisms, which are found within the real domain (Danermark et al., 2002). Although there is no causal relationship between the events and mechanisms, these mechanisms are either generative or dormant. When a mechanism exists without a consequential event or with an unexpected outcome, the relationship is referred to as tendency. This study addresses the topic of academic entrepreneurship in Oman, which represents complicated institutional and business climates. When addressing the 'how' research questions, the underlying mechanisms are considered. Particularly with the transformation topic, the review of the evolution in the sector reveals the drivers and the mechanisms of such development. The awareness of the stratified reality, generative mechanisms, and tendencies allows more understanding of the topic further than simple descriptions and responding to 'what' and 'how' research questions.

In view of that, critical realist researchers are required to acknowledge their own fallibility and the fallibility of others during the research process. In addition, the social histories of research objects are thought to affect their experiences and observations (Archer, 1995). Therefore, CR acknowledges that all observation and measurement are fallible, and that all theory is revisable. This implies the importance of adopting triangulation across different sources. Triangulation is referred to as the use of more than one method or source of data in the study so that the validity can be ensured (May, 2001). Denzin and Lincoln, (2000) identify four types of triangulation: data, theory, investigator, and methodological triangulations.

This thesis draws on the mixed methods approach of both quantitative and qualitative methodologies. The concept of mixing different research methods emerged from the original notion of triangulation, with the aim of employing multiple approaches to data collection in the same study (Creswell, 2003). Different sources of information provide corroboration to the findings or the conclusion. According to Yin (1994), the most significant advantage of using several data sources is 'the development of converging lines of inquiry' that increases the researcher's confidence and supports the findings (Yin, 1994, p. 91). The use of mixed methods can also be a means to include significant data that might be overlooked, if a single

method is applied. By utilising the mixed methods, a researcher can both generalise the findings to a population, and extend the knowledge of a phenomenon or concept for individuals.

Such approach is thought to be compatible with the diverse range of actors in the small-sized bio-sector, in addition to the scattered type of qualitative and quantitative data. Besides, it helps to overcome practical difficulties in data collection such as the organisational culture, which was the main challenge in the field. For example, with some actors (i.e. public research centres) it is less complicated to get access to knowledge workers and conduct interviews compared to the academic organisations. The triangulation of research methods allows a combination of evidence collected from multiple sources of data that address the research questions, so objectives of triangulation are achieved, as Fielding and Fielding (1986) state:

Triangulation puts the researcher in a frame of mind to regard his or her own material critically, to test it, to identify its weaknesses, to identify where to test further doing something different. The role of triangulation is to increase the researcher's confidence so that the findings may be better imparted to the audience and to lessen resources to the assertion of privileged insights (Fielding and Fielding, 1986, pp. 24-25).

### 4.3 Identification of the actors: secondary analysis

Prior to the fieldwork, secondary analysis was required to identify the key actors and the schedule for collecting different types of data. It included collection of information and data that can be obtained without the need to conduct fieldwork: for example, government published statistics and reports. It also included searching the internet for organisation profiling to build a picture of the actors, the researchers and knowledge workers, and the types of activity within the commercialisation field. During the fieldwork, the desktop research continued as new information or documents emerged.

Firstly, an internet search was done to identify the main organisations that perform research and innovation activities in the field of biosciences, and the organisational mission, vision and goals were reviewed. A similar search was conducted to review the policymaking actors in the government sector. During this stage, different official documents were downloaded, such as the five-year agriculture research strategy, annual reports, and the SQU

research strategy. Such documents reflect the extent of activities in academic entrepreneurship in the sector. It was useful to have an overview of the existing commercialisation-related policies and national strategies at the beginning of the survey, as it allowed the researcher to carry out the interviews and the questionnaire with fair awareness with regard to the policy framework. Table 4.1 indicates the six types of documentary data and their relevance to the main themes of the study.

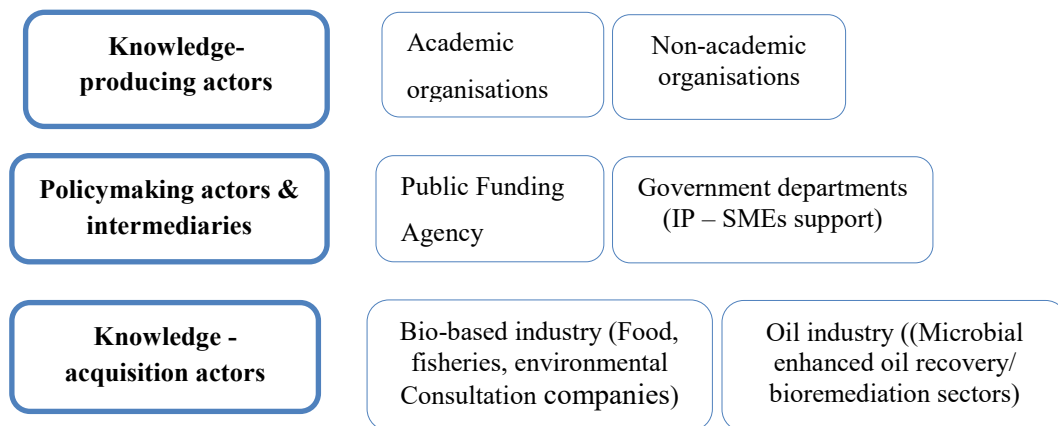
**Table 4.1:** List of documents utilised in the secondary analysis.

Type of document	Relevance to study themes
The Statistical Year Book (2013 & 2014) (The Center of National Statistics and Information)	Entrepreneurial capabilities: Expenditure on higher education and research. Contribution of bio-sector to national GDP, export and employment
The National Research Strategy (2008-2020) of TRC	Entrepreneurial capabilities / policy framework: Funding schemes – National research priorities
Research strategies of knowledge-producing organisations (SQU, UoN, SU, MAFW)	Transformation: Trends in research funding and agenda
Annual reports of knowledge-producing organisations (Every 5 years from 1995 to date)	Transformation & networks: The change in research outputs and the shift towards applied research
The Economic Vision for Oman 2020 and the 8th Five-year Plans (2011-2015)	Policy framework: Higher-level policy and planning documents
The SRI report and the UNCTAD STIP review	Policy framework: The national innovation ecosystem

These documents were used to analyse the study context and the background of the policy framework. Unlike the interviews, these documents can be accessed at any time and are considered as written evidence that save the time and expense of transcribing interviews (Creswell, 2009). These secondary data offer many benefits; for example, no cost is involved

in the collection. Most of these data are collected by public organisations so they are considered of good quality and allow for longitudinal analysis (Bryman, 2004). The main limitation of this method is that some data sets can be complex; also, valuable documents can be protected and unavailable for public access, which requires more time and effort to search out. Furthermore, as the researcher does not collect these data, absence of key variables or information is very common (Bryman, 2004).

Once the collection of secondary data was completed, the key actors were identified. It preceded through the review of research performance of the annual reports of universities and public research centres, as well the statistics of STI Indicators Database (Section 3.2.6). In the database, the biosciences workers are in two categories; the agricultural sciences and the natural sciences. Collectively, the total head count of researchers and personnel in the bio-sector is 412, and the full time equivalent count is 192 (STI indicators, TRC, 2013). It was found that research and commercialisation activities are mainly performed in academic and public research centres. The Government remains the main policymaking actor and the main funder for research and commercialisation. This led to a decision to group the actors into three main groups: knowledge-producing, policy forming and intermediation, and knowledge acquisition actors (Figure 4.2, table 4.2).



**Figure 4.2:** The study setting indicating the three key categorisations of the actors.

**Table 4.2:** List of the key actors in the bio-sector that included in the interviews and questionnaire.

Academic knowledge-producing actors	Non-academic knowledge-producing actors
<ul style="list-style-type: none"> <li>- Sultan Qaboos University</li> <li>- Centre of Excellence in Biotechnology</li> <li>- UNSCO Chair in Marine Biotechnology</li> <li>- University of Nizwa</li> <li>- University of Sohar</li> <li>- Waljat College for Applied Sciences</li> <li>- Higher College of Technology</li> </ul>	<ul style="list-style-type: none"> <li>- Ministry of Environment and Climate Affairs</li> <li>- Ministry of Agriculture and Fisheries Wealth (Research Centres)</li> <li>- Oman Centre for Animal and Plant Genetic Resources</li> <li>- Ministry of Regional Municipalities and Water Resources</li> </ul>
The private / business sector	Intermediary & policymaking actors
<ul style="list-style-type: none"> <li>- Al Rusail Industrial Estates (Muscat)</li> <li>- Sohar Industrial Estate (Sohar)</li> <li>- Knowledge Oasis Oman (KOM)</li> <li>- Petroleum Development Oman PDO</li> <li>- Mabiotech Company</li> <li>- Entrepreneurial Fund (Sharakha, GroFin/Intalaqaah)</li> <li>- Oman Development Bank</li> <li>- Mazoon Environmental and Technological Services (METS)</li> </ul>	<ul style="list-style-type: none"> <li>- Oman Chamber for Commerce and Industry</li> <li>- Ministry of Higher Education</li> <li>- The Research Council</li> <li>- Directorate General for Intellectual Property</li> <li>- The Green Economy Desk help</li> <li>- The Public Authority for Investment Promotion &amp; Export Development (PAIPED)</li> <li>- Self-Employment and National Autonomous Development (SANAD) Program Office</li> </ul>

Therefore, the research was structured to be around this set of actors and a preliminary list of potential interviewees was prepared. In the first group, the actors are further divided into academic and non-academic knowledge-producing organisations. In the academic sector, bioscience departments in the College of Science and the College of Agricultural and Marine Sciences of SQU are included, together with the Centre of Excellence in Biotechnology and the UNSCO Chair in Marine Biotechnology. Two private universities, Sohar University and University of Nizwa, were considered in addition to one private college (Waljat College) and the Higher College of Technology. The non-academic sector included six research centres under the Directorate General of Agriculture and Livestock Research, which are: Plant Production Research Centre, Plant Protection Research Centre, Soil and Water Research Centre, Date Palm Research Centre, Livestock Production Research Centre, and

Animal Health Research Centre. These centres were performing nine Mega research programs according to the Agricultural Research strategy. The seventh public research centre is Oman Centre for Animal and Plant Genetic Resources that is under TRC.

The second category consists of government departments that are responsible for both policymaking and funding of knowledge production and commercialisation. In this category, knowledge intermediation organisations are included. In the third category, two industrial estates were included. They consist of different types of knowledge acquisition actors, which are the bio-based industry, such as food and fisheries companies, and environmental consultation firms. The biologically-related fields in the oil industry were also considered, such as bioremediation and microbial enhanced oil recovery. This categorisation is consistent with the research questions and the theoretical framework. It allowed tailoring of the questionnaire and interview questions to tackle topics that were not previously addressed, such as the change in knowledge producers and the interaction between different actors.

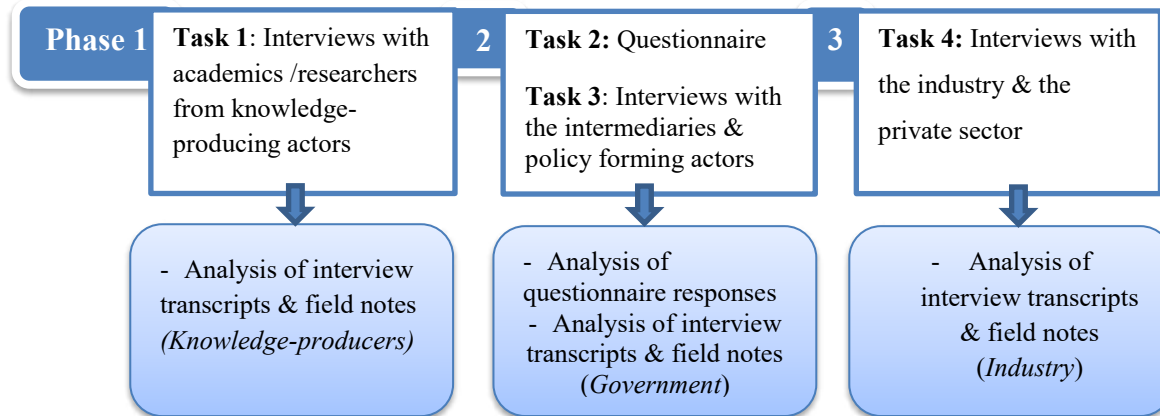
#### 4.4 Fieldwork and data collection

The process of commercialisation in Oman is still evolving, and the data about its current activities are scattered among different actors, whereas some parts of the information are not officially documented. Therefore, the access to knowledge possessors (individuals and organisations) poses challenges in the process of data collection. In order to address these difficulties, two instruments were utilised to ensure collection of more robust data, which were a questionnaire and interviews. A three-phase fieldwork plan that consists of four tasks was designed and a sequential procedure of data collection was followed (Figure 4.3).

The first two phases focused on knowledge production and intermediation, whereas the third phase targets knowledge acquisition actors. The fieldwork started with qualitative methods (interviews and field notes) in which concepts of knowledge production and commercialisation were tested. This was followed by a quantitative method (questionnaire) to study the interactions, as well as a qualitative method (interviews) to examine policymaking and knowledge intermediation processes. The third phase used a qualitative



method with interviewees from the industry. This three-phase fieldwork plan allowed collection of data in a sequence pattern so that the information of each phase informed the next stage (Table 4.3). It also permitted conducting the data collection in focused design so that all types of actors receive good attention and the interactions between them can be explored.



**Figure 4.3:** The three-phase data collection approach.

The categorisation of actors into three groups and the three-phase design are pertinent to the research questions that investigate the actors of knowledge entrepreneurship and in three ways relate to the theoretical framework. Firstly, drawing on the NIS approach, this design offers a wider understanding of the changes that occurred during the study period in each category. Secondly, deriving from network theory, it aims to explore the linkages and interactions between the actors. Thirdly, based on the TH model, the categorisation provides space for the non-academic actors (industry and the government sector). The employed approach is also relevant to the mixed methods perspective, as different types of data can be obtained from the three categories of actors. For example, with industry and government, the issues of collaboration can be better explored through qualitative data from the interviews. While with the knowledge producers, quantitative data about the performance of knowledge production can be acquired. Such research strategy is also able to advance the research on knowledge commercialisation in general and particularly in the case of developing countries.

**Table 4.3:** A summary of the fieldwork phases and the timing of performing the tasks.

Phases of the survey	Timing	Objective	Presentation
Phase 1 (1 task): 1. Face-to-face interviews with academics	At the beginning of data collection process (January - April 2014)	1. To have data from producers about entrepreneurial capabilities & networking that can feed Phase 2.	Chapters 5, 6, & 7
Phase 2 (2 tasks): 2. Questionnaire for academics and researchers 3. Interviews with the public sector	After the preliminary analysis of phase one. (August - October 2014)	1. To discuss policy framework for knowledge production & commercialisation. 2. To broaden the data regarding knowledge networks through quantitative data.	Chapters 6 & 7
Phase 3 (1 task): 4. Interviews with the private sector and industry	Towards the end of the data collection process (November - December 2014)	1. To use data from phase one and two in the interviews with the industry.	Chapters 5 & 6

#### 4.4.1 Semi-structured Interviews

The topic of knowledge commercialisation has gained considerable attention in Oman. The key actors of the bio-sector possess different levels of knowledge and engagement in the processes of research, commercialisation, and policymaking. Accordingly, the study themes and research questions can be addressed by exploring the experience and the perspective of

the actors. As this type of information is not documented or can be attained by observation, interviews are considered the suitable tool for data collection.

As indicated by Kvale (1996), some social events are not 'observable'; communicating to the actors would be one of the most useful methods for attaining and exploring such concepts. Hence, interviewing is 'a valuable method for exploring the construction and negotiation of meanings in a natural setting' (Cohen et al., 2007: 29). More specifically, the data related to the transformation in knowledge-producing actors and the social dimension of networking. As interviews are interactive, they can broaden the scope of understanding of the topics that are less available through quantitative data. That is, the significance of interviewing is not only that it builds a holistic overview about the themes of the study; but also for it allowing the interviewees to 'speak in their own voice and express their own thoughts and feelings' (Berg 2007: p. 96).

The interviews in this enquiry followed the semi-structured type, which is more flexible as 'it allows depth to be achieved by providing the opportunity on the part of the interviewer to probe and expand the interviewee's responses' (Rubin and Rubin, 2005: 88). An interview plan was prepared and it consisted of four themes that covered all areas of the research questions: (1) UI linkages, intermediaries, and proximity; (2) entrepreneurial capabilities; (3) entrepreneurial environment; and (4) policy framework and transformation (Appendix C 2). The plan allowed for in-depth probing of certain themes, while directing the interview to follow the scope and aims of the study.

The interview took place within the three phases of fieldwork (Section 4.4, Figure 4.3), so the data from previous phases were used to inform the following ones. As this enquiry follows triangulation methods, the interview was designed to gather qualitative data regarding the three themes, besides the other sources of data collection methods (documents and the questionnaire). It aimed at getting insights into interviewee's perceptions, together with the other two methods 'providing in-depth information about participants' inner values and beliefs' (Ho, 2006: p 11).

#### *4.4.1.1 Preparation for the interview*

Based on the desktop analysis and the categorisation of the actors, potential interviewees were identified by reviewing the staff directories of the bio-based organisations. For example, academics with a higher position, like Dean or Assistant Dean, were considered. In the government, staffs with long service or diverse work experience in different positions were indicated, as they had access to knowledge that is not accessible to other individuals in the field. It was useful also to visit the key actors, SQU and MAFW, in order to have fair knowledge about the researchers and the labs.

Therefore, the expertise that were sought were not restricted to technical and scientific knowledge, they also included experience with policy-making processes and organisational cultures. A preliminary list of potential interviewees was prepared and as the interviews proceeded, more candidates were added until 'saturation' was reached. According to Morse (2000), the estimation of the size of the sample required to 'reach saturation depends on a number of factors, including the quality of data, the scope of the study, the nature of the topic, the amount of useful information' obtained from each interviewee (Mores, 2000, P. 3). It was planned to have equal numbers of interviews for the three categories (10-15), but as the interviews proceeded different counts resulted, according to the saturation status and the quality of data.

With knowledge-producing actors, new potential interviewees were proposed until the last three interviews, indicating the diverse community of academic and non-academic actors (Table 4.4). The number of interviews in this category was 22, representing different types of knowledge-producing actors. Three retired interviewees who have long service in the public research centres were also interviewed. With the other two sectors, however, the interviewees began to suggest similar candidates earlier, which indicate the limited number of actors engaged in the topic, resulting in 15 interviews from the government sector, and 10 interviews from the industry. Furthermore, there was also the issue of narrative saturation which was observed, together with the recurrence of the themes. Therefore, narrative interviewing was used in such cases, e.g. the retired individuals and some academic staff, by asking them to share their own experience or story about the topic.

**Table 4.4:** The interviews with the key actors of the NIS in the bio-sector, Oman 2014 (Total of 50 face-to-face semi-structured interviews).

Institutional sphere	No. of interviews	Phase of the fieldwork
Academic / Public research Centers (Knowledge production actors)	22	Phase 1
Government (Policy actors)	15	Phase 2
Bio-based industry/private sector (Knowledge-demand actors)	10	Phase 3
Long service retired public sector staff	3	Phase 2
Total	50 interviews	

Potential interviewees were invited to be part of the study by telephone call, as well as emails (see appendix A for the list of interviewees). In the invitation email, a brief introduction to the study along with the consent form (Appendix A.2) was provided. In some cases, potential interviewees asked to include their senior managers in the email to ensure that they were aware of the project and the participation of their employees. In cases of no response, a follow-up email was sent. After receiving approval, appointments were set to conduct the face-to-face interviews.

#### *4.4.1.2 Conducting the interviews*

It is the responsibility of the researcher to ensure that interviews take place in an appropriate setting, which is conducive to achieve rapport with prospective respondents and to encourage positive participation (Bryman, 2005; May 2001). At the beginning, the interviewees were provided with a credible rationale for the research context. They were

assured that their participation was totally voluntary and their contribution would not be disclosed, so there would be no direct risk from their participation.

As attention and interest are more likely to be secured at the beginning of the interviews, early questions were directed towards topics directly related to the core work of the interviewees. Each interview lasted an hour, and it was audio-taped with the agreement of the interviewees, who were informed that they retain the right to stop the recording at any time, as well as to withdraw from the interviews. There were no cases of withdrawal. Additional information that was provided outside of the recording after the interview was noted down by hand.

#### 4.4.2 Structured questionnaire

A comprehensive questionnaire was used to study the patterns of knowledge networks between the key actors of the bio-sector in Oman, with reference to the role of intermediaries and the geography. The questionnaire was web-based, and targeted knowledge-producing actors to gather quantitative data. Administration of the questionnaire online was fast and involved no cost, allowing data to be gathered from researchers located in different geographic areas. Unlike the semi-structured interview, there was less researchers' bias as the questionnaire was filled in the absence of the researcher and all the respondents address the same questions (Bryman, 2005).

This method of completing the questionnaire online was also more practical in giving instructions to the respondents, such as not to skip sections. A significant number of respondents are found to give more honest answers to web-based questionnaires compared to paper-based questionnaires (Bryman, 2005; Denzin and Lincoln, 2013). However, there are two main issues with this method: the difficulty with following up with the target respondents resulting in low response rates; and the items of the questionnaire may be interpreted differently by the respondents, besides the inability to probe for additional details.

The questionnaire used LimeSurvey Version 2.06+ and consisted of four parts: (1) general information about the participants; (2) research activities and collaboration with

other organisations; (3) institutional capabilities and the barriers to knowledge commercialisation; and (4) governance and policy framework (Appendix C 1). Finally the respondents were provided with a space to add their comments, concerns or recommendations about the topics covered in the questionnaire. The questionnaire was constructed using a mix of open questions, closed questions, and multiple-choice questions. The former generated the qualitative data, whereas the rest reports the quantitative data. The inverted-funnelling type of questions arrangement was used, where highly specific areas are investigated first. Certain replication of specific questions was used to ensure validity of answers.

Prior to the fieldwork, a pilot was performed. Sample questionnaires were sent out to selected researchers who were performing research activities similar to the real respondents. They were asked to provide feedback and comments about the following aspects: (1) time for completion; (2) clarity of instructions, layout and language; (3) presence of ambiguous or objectionable questions; and (4) overlooked topics. The respondents who were asked to be part of this pilot include some personnel from public and private universities. These academics were, previously, involved in joint research with the Government and the private sector and they have the experience of working with external organisations. They were not part of the study population and their responses were not included in the analysis. It is not recommended to include the pilot participants in the study population as their experience with earlier versions of the questionnaire may mask their real response (May 2001; Bryman, 2005).

The feedback from the pilot study indicated that the questionnaire was clearly set out, concise and reasonable in terms of length and access on the web. The feedback also indicated that the main areas were covered adequately. The degree of detail was thought to be appropriate, and the type of information sought from respondents was quite realistic. Thus, no major adjustments were made to the tool.

The link to the questionnaire was sent to knowledge producing actors (academic and non-academic) through their organisation's e-mail. In universities and other high-education organisation, the Dean's Office for Research was utilised to circulate the e-mail to academic

staff and their support personnel. Individual e-mails were also sent to the researchers and academics that are in senior positions, e.g. Head of the Department, Director of Research centre. After the distribution of the questionnaire, a timeframe of six weeks was allocated to complete the questionnaire. After that, follow-up was undertaken by both emails and telephone calls with respondents who had indicated willingness to participate but had not returned their questionnaire. A cut-off point was reached after three months, after which no further follow-up was done to get the responses for the questionnaires that have not been returned, or remained incomplete (in 'saved status'). Table 4.5 indicates the responses of the on-line questionnaire.

**Table 4.5:** Responses to on-line structured questionnaire conducted during phase 2 of the field work, Oman 2014 (Total of 46 responses).

Sources of respondents *	Researchers	Response
Academic knowledge-producing actors	<b>108</b>	<b>32 (29.6%)</b>
Non-academics knowledge-producing actors	<b>79</b>	<b>14 (17.7%)</b>

\* Total Head Count (THC) of biosciences researchers is 412, STI indicators database, TRC, 2013.

#### 4.4.3 Field notes

The field notes represent an additional data source that was used throughout the three phases of the fieldwork. They contain the researcher's observations and some of the participants' views that were provided either before or after the recorded interviews. Most interviewees tend to share information more openly at the end of the interview, after switching off the voice recorder. It was important to take notes about this additional information that was shared off the recording. Also, during informal gathering, e.g. Science Cafe events, the researchers interacted and discussed their views efficiently. So the notes were as valuable as the interviews.



## 4.5. Data analysis

### 4.5.1. Secondary data and documents

For the purpose of this research, the documents served as sources of both quantitative and qualitative data. The secondary data and statistics were used to support the qualitative data regarding the evolution of knowledge production processes. In addition, the quantitative data about different indicators were traced throughout the study time to study the institutional transformation towards knowledge commercialisation. Regarding policy documents, public sector reports and strategies, the major themes and the target audience for these documents were identified (Scott, 1990; Silverman, 2001). The contents and function were correlated with interview data that examine how the documents moved between organisations and served different purposes in various institutional spheres.

### 4.5.2. Analysis of interview transcripts and field notes

The qualitative data analysis was performed using interview transcripts and field notes. A professional transcriber processed the audiotapes of all interviews and interview transcripts were reviewed for accuracy against the audiotapes. Audiotapes were transcribed verbatim (i.e., recorded word for word), including any nonverbal or background sounds (e.g., telephone ringing, tunes, pen clicking, etc.). The transcription files were saved after being identified by the following information: date of interview; participant code; interview title; interviewee category; and site.

The coding was done manually following a three-stage process, as explained by Boyatzis (1998); Strauss and Corbin (1998); and Saldana (2009). Manual coding was preferred as it brings the researcher close to the data and it allowed the extraction of possible meanings from the textual data. Prior to coding, the transcripts were screened to 'highlight, bold, underline key words or phrases in the text that stand out upon an initial read' (Saldana, 2009). The research questions were labelled by their topic and this represents the 'anchor codes' (Strauss and Corbin 1998) that the process of codification started with.

The first stage includes taking a broad review of the transcripts, in search of general themes, and it is referred to as 'open-coding' (Strauss and Corbin, 1998). During this stage,

the key themes and sub-themes were identified resulting in a first-level coding. A second sequence of coding was performed with the purpose of recording noticeable patterns of inter-relationships between the topics identified in the first round. This 'axile coding' (Miles and Huberman, 1994) resulted in the second-level coding, which presents the correlations and inter-dependences. In the third stage, data were condensed to identify the core categories. Unexpected emerging themes were grouped separately to be used in the discussion of the findings as supportive examples or ideas.

The coding was done using both a descriptive and *in vivo* coding, depending on the content of the text segment. The former refers to words or phrases that summarise and condense data in textual data, whereas the latter uses portions from the participants' own language (Hatch, 2002). Some codes were used repeatedly throughout the process, when repetitive patterns of actions or opinions were encountered. Codification was stopped when 'saturation' was reached (Strauss and Corbin, 1998). Coded data were then grouped into their respective anchor codes and categories from the codes were produced. The categories were then examined to consolidate the meaning from these data and generate the themes that address the research questions.

Therefore, 41 codes clusters were organised into 19 key categories that resulted into the five major themes of this study (Table 4.6). Drawing on the theoretical framework and the research questions, five themes were generated: entrepreneurship capabilities; institutional transformation; knowledge networking; entrepreneurial environment; and commercialisation-related policy framework. The themes, which are informed by the data gathered, were further divided into sub-categories (Saldana, 2015) according to the type of actors (knowledge-producers, intermediary and policy-maker; and industry).

**Table 4.6:** The outcomes of codification and categorisation of textual data from interview transcripts and field notes.

Key clusters of codes	Key categories	Major five themes
<ol style="list-style-type: none"> <li>1. Laboratory facilities</li> <li>2. Funding issues</li> <li>3. Research team</li> <li>4. Administrative burdens &amp; bureaucracy</li> <li>5. Biosciences researchers &amp; students vs engineers</li> <li>6. Marine biotechnology/MEOR</li> </ol>	<ol style="list-style-type: none"> <li>1. Hard &amp; soft infrastructure</li> <li>2. Human resources issues</li> <li>3. Research niche (marine, MEOR)</li> </ol>	Entrepreneurship capabilities in the three institutional helixes
<ol style="list-style-type: none"> <li>7. Internal transformation</li> <li>8. Trans-institutional effect</li> <li>9. Intermediaries</li> </ol>	<ol style="list-style-type: none"> <li>4. Trends of knowledge production</li> <li>5. Transformational benefits</li> </ol>	Institutional transformation in the bio-sector towards academic entrepreneurship
<ol style="list-style-type: none"> <li>10. Hierarchy structure</li> <li>11. Structural &amp; functional change</li> <li>12. Phases of networking</li> <li>13. Exchange of technical knowledge</li> <li>14. Exchange of tacit knowledge</li> <li>15. Evolution of interactions: UI sub-dynamics</li> <li>16. Evolution of interactions: UG sub-dynamics</li> <li>17. Evolution of interactions: GI sub-dynamics</li> <li>18. Current actor's interactions: modes of linkages</li> <li>19. Current actor's interactions: formal vs. informal</li> <li>20. Selection of partners</li> <li>21. Motivation for networking</li> <li>22. Proximity &amp; networking</li> <li>23. Intermediaries &amp; networking</li> <li>24. Tacit knowledge &amp; sharing culture</li> </ol>	<ol style="list-style-type: none"> <li>6. Characteristics of knowledge-producing organisations</li> <li>7. Actors' bi-lateral relations</li> <li>8. Actors' tri-lateral linkages</li> <li>9. Inter-organisational networks</li> <li>10. Cross-organisational networks</li> <li>11. standard curve of knowledge network lifecycle</li> </ol>	Knowledge networking in the bio-sector: development, dynamics, and geography
<ol style="list-style-type: none"> <li>25. Entrepreneurial opportunities in the bio-sector</li> <li>26. Female bio students</li> <li>27. Entrepreneurship in education</li> <li>28. Employment of bio-graduates</li> <li>29. Job security / safe career</li> <li>30. Political stability and investment climate</li> <li>31. Technology-based companies in bio-sector</li> </ol>	<ol style="list-style-type: none"> <li>12. Business environment</li> <li>13. Entrepreneurial culture &amp; mind-set</li> <li>14. National IP system</li> <li>15. Habitat factors</li> </ol>	Entrepreneurial environment

<p>32. Change in research agenda  33. Policy making process  34. Role of national committees  35. National research &amp; innovation strategies  36. Higher-level planning: Oman Vision 2020, 5-year plans, investment law, IP system &amp; SMEs support  37. Direct policy instruments (funding – research admin )  38. Indirect policy instruments (science parks, infrastructures - HR)  39. Areas for policy interventions: UI linkages – IP – awareness  40. Types of policy interventions: de-regulation - institutional re-structure - entrepreneurial education  41. Replication and learning from success stories</p>	<p>16. Evolution of knowledge-producing process &amp; policy  17. National policies vs. imported policies  18. Vertical vs. horizontal policy interventions  19. Transition &amp; policy learning</p>	<p>Commercialisation-related policy framework</p>
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#### 4.5.3. Analysis of questionnaire responses

The software automatically collected the responses from participants who filled in the questionnaire online. The data were downloaded as a spreadsheet. For participants who filled in the questionnaire manually, the responses were transferred into the spreadsheet. Each question number was put as a column heading and one row was used for each participant's answers. Then a number or 'code' was assigned for each possible answer. The descriptive statistics were done using the tools of Microsoft Excel and frequency tables were made.

#### 4.6. Ethical consideration

The ethical dimension is an essential element in research. The Economic and Science Research Council (ESRC) defines ethical and professional research:

'The ethical principles of integrity, honesty, confidentiality, voluntary participation, impartiality and the avoidance of personal risk to individuals or social groups characterise social science research that is conducted in a professional and ethical manner'. ESRC Research Ethics Framework.

This study involves different techniques for the collection of qualitative and quantitative data. It also deals with human subjects, mainly through face-to-face-interviews, but also via follow-up phone calls and emails. There was a need to address ethical

considerations associated with interaction with participants and data handling. According to Denzin and Lincoln (2000), there are three ethical concerns in this study, which are informed consent, privacy and confidentiality, and accuracy.

Prior to fieldwork, ethical approval was sought from the Research Ethics Committee (SREC) of the School of Planning and Geography (Appendix B). Adequate information was provided to the potential participants to make an informed decision about their participation. In this study, anonymity and confidentiality of participants were maintained, especially when quoting from the interviews. All information, data, and documents were used in a manner faithful to the originals, so that the obtained results will not contain any deliberate distortion or misrepresentation.

#### 4.7. Conclusion

This chapter offered insights into the study design, which includes three elements: the philosophical stances, the research approach, and methods for data collection and analysis. The study is aligned with the Critical Realism position, following a mixed methods design that provides an interactive element to the process of data collection. A sequential three-phase fieldwork was designed and method triangulation was sought using: secondary data and documents; a questionnaire; and semi-structured interviews. The research design was set out to address the ethical considerations. Once the research design is explained, the proceeding chapters engage with the empirical dimensions of this study.

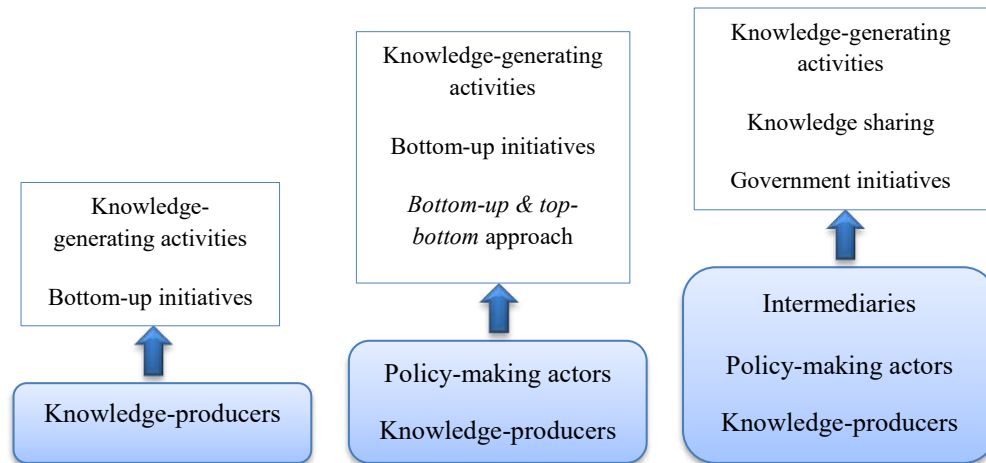
## 5. Commercialisation actors and the transformation to the third mission

### 5.1. Introduction

This chapter analyses the first pillar of investigation which is the commercialisation actors and the transformation towards knowledge entrepreneurship in the Omani bio-sector. It draws on the interview data and addresses the first two research questions, which are: (1) *who are the key actors for commercialisation of the bio-sector within the Omani national innovation system's institutions?* and (2) *how are the commercialisation actors in the key institutional spheres transformed towards knowledge commercialisation and entrepreneurship?* These research questions are inter-related, and represent the first component of the NIS approach; actors and institutions. This chapter analyses the characteristics of the actors within the NIS and examines the role institutions in the commercialisation process. This level of analysis tackles two domains; knowledge generation and the cultural domains of the actors (Freeman, 2000; Freeman 2002). Furthermore, it draws upon the evolutionary perspective of the NIS to investigate the path and drivers for the institutional transformation.

The commercialisation process is performed by the active involvement and support of various actors. Considering the variety of contexts and institutional setups, the actors for commercialisation undertake activities that evolve around knowledge generation, the provision of essential supporting services, and intermediation, with a central role of the government that support the activities of actors (Freeman, 1995; Batholomew, 1997). Hence, the means and intensity in which these actors interact and contribute in commercialisation differ; that is, some actors are directly and exclusively linked to the process (i.e. TTOs) whereas others are involved due to their intrinsic features (e.g. universities and Public Research centres). Such variance requires that the industry, which is the receptor actor, is set to communicate its needs to knowledge-generating actors and to tap into different bases of knowledge.

During the study time, the actors of the bio-sector had witnessed a transformation towards knowledge entrepreneurship, with universities playing a central role as sources of knowledge production. In order to take such a role, universities suggested a trend towards the third mission of knowledge commodification and institutionalisation of knowledge entrepreneurship, thereby undergoing transformation to the entrepreneurial paradigm (Figure 5.1). As transformation proceeded, different actors emerged, as idiosyncratic organisational characteristics are common and present, and their implications require coordination mechanisms. This is where policy making actors take the lead to facilitate commercialisation process through means that links the actor's capabilities to a specific institutional context, and adds more actors for knowledge intermediation.

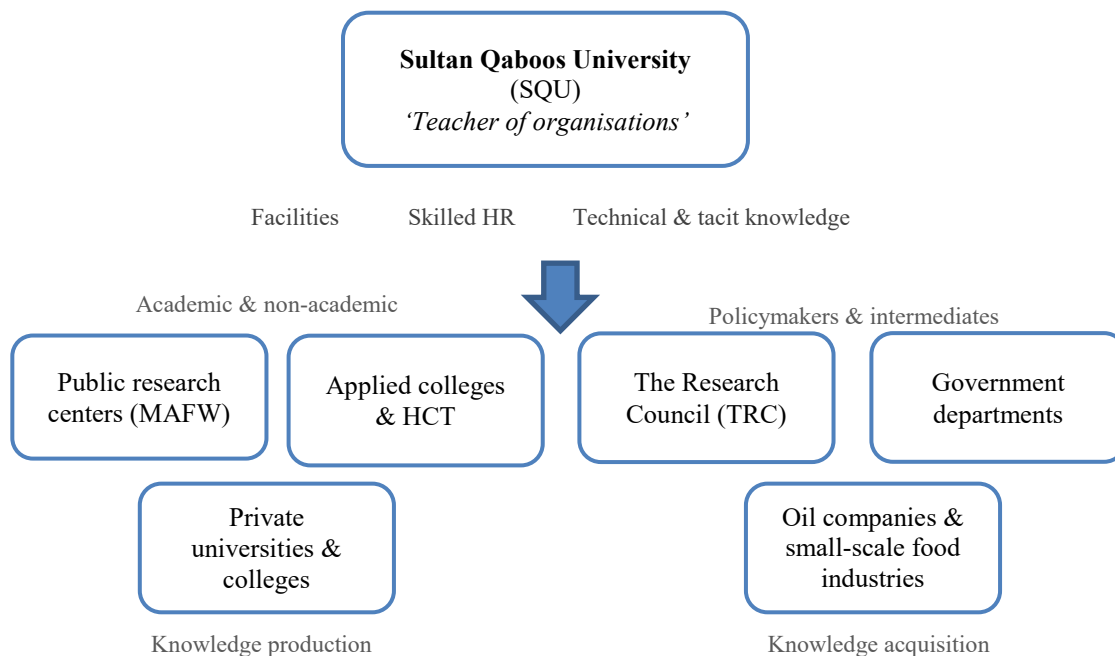


**Figure 5.1:** The evolution of commercialisation actors and their roles (Depicted from the responses of the interviewees).

This chapter consists of three main sections that are organised as follows. The first part presents the key actors for commercialisation in the bio-sector and their characteristics within the institutional setting. The second section provides a comprehensive account for the path and drivers for the transformation towards academic entrepreneurship in the three institutional spheres. It also emphasises the role of individuals and the intermediary actors in the process. Following that, the topic of co-evolution of commercialisation actors and processes is discussed. Finally, the chapter concludes with a summary of the main findings.

## 5.2. Key commercialisation actors of the NIS of the Omani bio-sector

As discussed earlier in chapter 3, actors of the bio-sector are grouped into three categories: knowledge producers, policymakers and intermediaries, and the bio-based industry (Figure 5.2). When these actors are assessed based on their organisational role and degree of influence, four distinctive features emerges: hierarchy of actors, high dynamics, replication of organisational culture, and lack of conformity between a formal organisational structure and its core activities. These characteristics have shaped the role of the actors within the Omani NIS during the transformation process.



**Figure 5.2:** An illustration of the key actors in the Omani bio-sector.

### 5.2.1. Hierarchy of actors

It seems that there is a degree of hierarchy within the institutional sphere and among the three spheres. In the academic sector SQU is dominating the actors, due to the fact that SQU is the main public university with highly equipped laboratories and research centres, together with adequate funding. Among the actors, government actors are considered to have an influential role. There are two possible explanations for this result: (1) government funds remain the main source of finance for research and innovation; and (2) there is no big



role for academia and industry in formulating national policies and strategies for research and commercialisation.

In an ideal system, a sector's key actors are expected to be diverse enough to carry out their role in complementary ways, without a hierarchy. Diversity is normally linked to abundance, yet the actors in the bio-sector are relatively limited. In terms of quantity, the total number of actors in the three institutional helixes is moderate, compared to international case studies. Within its limited actors, the lack of diversity in the sector is thought to be also due to the recursive force exerted by a well-established organisation. In this case, SQU, with its position at the top of the pyramid, drives other actors to repeat its experience, thereby reducing the potential of variation.

However, this hierarchy structure can have some advantages, especially with young developing organisations, which view SQU as a role model in research activities. The influence of one dominant actor has been reported in literature, for instance the study of Holi (2007) about universities in the East of England. These universities are dominated by the presence of the University of Cambridge, which delivers the vast majority of scientific publications, patents, licensing, and spin-out companies in biotechnology. This indicates the positive impact of the presence of University of Cambridge. In a similar vein, SQU has managed to create world-class university degrees (undergraduate and postgraduate) in biotechnology in a relatively short time. In addition, the university is considered an active research performer based on a number of publications in biosciences and biotechnology. It is therefore clear those other actors, especially the public research centres and the private universities are following the same curve, as a learning process. As one interviewee said:

... the majority of the employees at this Ministry were graduated from SQU and we still belong to that university ... we still believe we are a part of it, and I'm proud that I sit as a member in different SQU committees. We learned from their rich experience and their intellectual asset. I think we integrate, do not duplicate, and we don't compete (*Director of Public Research Centre, 2014*).

Then again, this learning process is a unidirectional flow of knowledge and over time it is one of the causes that has shaped the hierarchy. This hierarchy has caused an absence of cross-fertilisation of ideas, despite the fact that other players in the public sector and private

universities are performing well in terms of teaching and research. In addition, when other actors are learning from the experience of SQU, there is also a potential of replicating their errors. With regard to this issue, an interviewee said:

... SQU receives His Majesty (HM) grants for research and innovation since the year 2002 and there is no improvement in commercialisation activities. I think we need to shift the centre of gravity from SQU to private universities; they can take the lead to carry applied research that meets the need of local industry. They do understand the industry better, they are in the market. But they have to do it differently. A new start: They don't need to go over previous flaws (*Director of Regional Organisation, 2014*).

Similar to this situation, the evolution of the tripartite interaction in life sciences was performed in using the analogy of the 'dance hall', as both the music and the dancers shift over time (Powell *et al.*, 2005). They argued that 'organisations with diverse portfolios of well-connected collaborators are found in the most cohesive, central positions and have the largest hand in shaping the evolution of the field' (Powell *et al.*, 2005, p. 1187). Therefore, it can be assumed that the hierarchy status of actors has shaped the type of interactions between actors in terms of knowledge flow and the adoption of organisational practice. With few exceptions, the performance of academic entrepreneurship in the organisations that are at the top of the pyramid indicates the overall performance. As more actors emerge, there is a tendency to dilute hierarchy status and shift the 'centre of gravity' to other new actors. Such drift is enhanced by the continuous emergence or disappearance of actors, which forces the system to adjust to the equilibrium. This leads to the second actor's characteristics, which is the high dynamics of the bio-sector.

### 5.2.2. High dynamism

In the bio-sector, the continuous development of organisation and addition of new actors is observed. As well, there is substitution of actors and a diminishing of other actors. Unlike other sectors, the bio-sector is susceptible to these changes. Most organisations in the academia and the public sector have laboratories and other supporting units, which make it difficult to adapt a new status.

Most of the interviewees thought that there are more negative effects when a new organisation is formed, compared to the case when one organisation is merged with another

bigger organisation. The formation of a new organisation may cause the loss of tacit knowledge and prolong the idiosyncratic phase. In most cases, a new actor was added to the bio-sector normally by up-scaling a department from a bigger, established organisation. For example, the Ministry of Environment was formed basically from the Directorate of Environment that was part of the Ministry of Regional Municipalities, Water Resources and Environment.

In the new organisation, the top management normally changes and the majority of the staff, especially those with long service, prefers to stay with the main organisation. Thereby, the needed tacit knowledge remains within the mother organisation. The situation becomes more complicated when there is physical infrastructure, like laboratories or research centres, as the tacit knowledge is lost. Furthermore, most of the newly-formed actors seek autonomy from the Ministry of Civil Services, which allows them to be independent financially and administratively. As the number of devolved actors increases, the process of research commercialisation becomes decentralised and more challenging due to increasing numbers of actors.

An actual rise in the numbers of actors did not occur in the three institutional spheres (academia, industry, and government) and most of the emerged actors are in the interfaces between the key spheres. These intermediary organisations include funding agencies, SMEs facilitators, technology incubators, and other public sector bodies. These intermediaries help to fill the gap left by underdeveloped spheres, yet researchers do not consider them as active facilitators. This idea leads to the next characteristic, which is the replication of organisational culture in newly established actors.

### 5.2.3. Replication of organisational culture

During interviews, participants used interesting expressions to describe their interactions with other actors within the sector. The term 'sister organisation' was used to describe mutual collaboration between equally formed organisations. The terms 'mother organisation' or 'mother university' refer to the key organisation that was formed earlier and is the source of funding, information or human resources. It reflects the cultural atmosphere

within actors. For example, with management of research grants in funding agencies, as one participant commented:

... The process to secure funds from TRC is also long, they are just like SQU, there is a lot of bureaucracy. There is no real difference between the internal funds and the external grants (*Biologist, Public Research Centre, 2014*).

Accordingly, the organisational culture of a dominant organisation was found to be replicated in the newly formed actors. This reduces the degree of diversity between actors and renders the sector susceptible to repeating the failings of the key actors. Although it is encouraged for positive and productive organisational cultures to be adopted and learned by new actors, bureaucracy is replicated.

#### 5.2.4. Lack of conformity between the formal structure and core activities

This feature is common in all sectors, where the formal view and the title of the organisation is not compatible with the core practice. The actual processes to obtain prerequisites for research commercialisation are fragmented between several organisations, which add to the administrative burden on researchers and investors. This feature affects one of the main resources of researchers and investors, which is time. As one interviewee said:

...bureaucracy is there and I have no time to follow up. The process is very slow.. I think it is the culture of not moving the things fast. Even if they have legislation, and specific departments but you can still be surprised that you need to go to another department or another ministry. I would say, the culture is far more powerful (*Plant Genetics Expert, Public Research Centre, 2014*).

Bureaucracy was a recurrent theme in the interviews, as researchers found it both challenging and time consuming. It was observed that key roles are fragmented and divided between actors within one institutional sphere, but also among the three spheres. While new organisations that are dedicated to a certain task emerge and become part of the sector, some functional aspects of the task remain scattered between several other agencies.

Finally, the roles of the actors were found to be shaped by their characteristics. The key roles in knowledge production are carried out by different actors within the category of knowledge-generating organisation, despite the hierarchy status. SQU is the main actor with high production of both new discursive knowledge, i.e. publications, and tacit knowledge in

the graduates. With regard to discursive knowledge, other actors like the public research centres of the Ministry of Agriculture and Fisheries are considered a competent knowledge producer based on publications and joint research. Similarly, private universities (e.g. Waljat College of Applied Sciences) are also producing highly trained graduates.

### 5.3. The transformation towards knowledge entrepreneurship

The transformation of the institutional spheres towards entrepreneurial activities is an important element in the study of academic entrepreneurship. In the literature, transformation is typically linked to the notion of 'entrepreneurial university' that was first described within the model of the Triple Helix (Etzkowitz and Leydesdorff, 1997). The role of the university has evolved from performing conventional research and education functions to serving as an innovation-promoting knowledge hub, hence the development of the term entrepreneurial university (Etzkowitz, 2008; Youtie and Shapira, 2008). Nevertheless, transformation occurs in the other two spheres as well (government and industry).

The change towards entrepreneurial activities can take both 'bottom up' and 'top down' approaches. For example, in the academic sector the US universities started commercialisation of their research during the late nineteenth century, due to the lack of a formal research funding system (Feldman *et al.*, 2002). However, the entrepreneurial university emerged in Europe as a 'top down' experience (Soete, 1999). This section discusses the transformation in the bio-sector by considering four topics: the internal transformation within each institutional sphere, the trans-institutional influence, the role of intermediary actors and the role of individuals. It allows better understanding of the key drivers and pressure that compelled changes in the organisational environment.

In order to trace the transformation that took place in the three helixes over the study time (1995-2015), it is useful to follow select indicators of the components of knowledge entrepreneurship. In the academic helix, three indicators were identified, which are research agenda, funding, and entrepreneurial structures, e.g. TTO. Two components were assessed for indication of transformation in government, which are entrepreneurial policies, e.g. IP

regime and investment law, and public research centres. In industry, the establishment of bio-firms was evaluated as an indicator of the transformation.

### 5.3.1. Transformation of the academic sphere

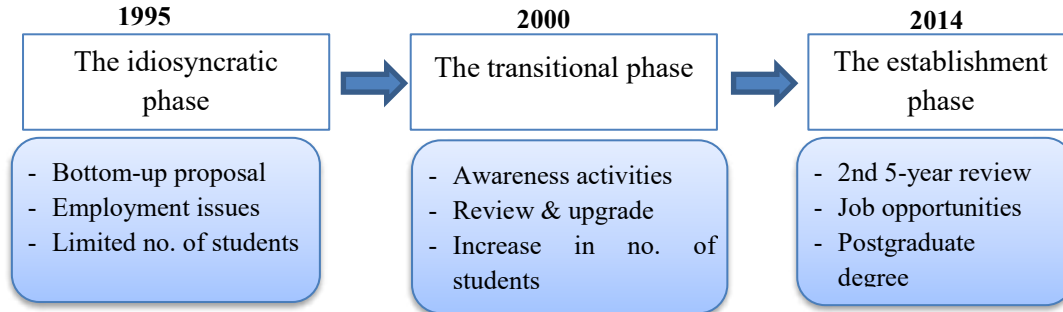
The Omani Government first identified biotechnology as a field of strategic importance in the late 1980s and different public measures were formed to advance biotechnology in the early 1990s. In the academic sector, the Ministry of Higher Education provided public scholarships to study biosciences abroad. The first initiative for establishing a BSc degree programme in local universities was taken by the individual academic staff who came back from postgraduate studies in Europe and the United States of America (USA). This bottom-up proposal initiative took place in the College of Science in Sultan Qaboos University in the mid-1990s.

The interviewees, who have long organisational memories, were asked to share their experiences and opinions about the establishment of the biotechnology degree program in SQU. The responses reflected a considerable change in the structure of the department and its academic staff. Officially, the biotechnology degree was approved in 1997 as a new specialisation replacing the Biology major, which had been offered in the College of Science (CoS) since the establishment of the university. The introduction of biotechnology created a shift in outcomes of the department in terms of the quality and numbers of graduates, as indicated by one participant:

... Now, our graduates are well prepared.. The number of students increased from only 19 students upon its launching [BSc degree] to 60 students per cohort since 2005. The degree plan went through several modifications and it evolved to perform in accordance to the best practices. The MLS [Medical Laboratories Sciences] was taught here for several years, and then the College of Medicine took over. Our focus is in industrial biotechnology and most of the research performed in the department is applied research (*Former Dean of College of Science, 2014, Public University*).

There are three key moments for this initiative, each of which has distinctive features (Figure 5.3). In 1995, the biotechnology degree was proposed, and then five years later the transition stage started and witnessed most of the changes and transformation. The third phase reflects the establishment of the programme, as a critical review of the biotechnology

degree was conducted in 2010 and in 2015, the second five-year cycle of upgrading of the programmes was performed.



**Figure 5.3:** The three key moments in the evolution of biotechnology degree in the academia sphere (*Depicted from the secondary data and the interviews*).

During the first stage, the idea was not clear to all stakeholders and the general understanding at that time was of the link between the degree and job opportunities. The bio-based industry was in the infancy stage, so the Ministry of Civil Services was not sure in which category the BSc Biotech graduates were to be considered. As one interviewee said:

... Of course there were no bio-tech companies at that time... but we couldn't just wait for the industry to establish bio-tech firms and to see the employment opportunities in order to establish our in-house biotech degree. We had to start... the idea was that to strengthen ourselves for the future. Eventually the biotech firms and good jobs will happen (*Biotechnology professor, Public University, 2014*).

This was the idiosyncratic phase of the sector in the academia. The biosciences in general was well established in the CoS since the opening of the university, but their graduates faced difficulties in employment compared to other departments like earth sciences, physics and chemistry. Therefore, the initiative faced challenges in both directions, inside and outside the university. As one of the interviewees put it:

This was not an easy thing at all. When we started to create biotech programme we initially have written several letters. At that time it wasn't difficult to make a new programme and just to convince the academic council and it has been approved, but we wrote several letters to the ministries, especially the Ministry of Civil Services and the Ministry of Man Power, for the new programme. But we don't know what happened to the letters, it was every time whenever we send the letters about the employment of our students, the reply was that they don't know what

biotechnology is. It was exactly like 'Biotechnology from Mars, the employer from Venus' (*Former HoD Biology, Public University, 2014*).

In the transition stage, a dramatic change took place and rapid acceptance of the idea occurred (2000-2010). This was due to the multidirectional effort of the young PhD holders who came back from their studies in the USA, Europe and Japan. Many awareness activities took place, through meetings, national workshops, international conferences and scientific seminars, with regard to the potential of biosciences in addressing economic and environmental issues. In addition, there were different non-formal active groups like the College of Science Student Society (CSSS) and the Biology Group, which organised exhibitions and lectures during busy times, like induction week, open days, student competitions, and the job fair. The main achievement of this stage was the rise in student numbers and the participation of academic staff in joint work with other spheres, like scientific committees, public lectures, and development and review of school curriculum. As one academic stated:

... Well the number of our students has increased tremendously, many of us were teaching hundreds of students. So it was overload on us but we still worked. And there was also our research, community service and public sector joint committees. The department was much more oriented to real biotechnology: A much better situation in biotech (*Biology Professor, Public University, 2014*).

Furthermore, another academic interviewee commented:

...that was a challenge. To overcome that, we thought about marketing, and came up with the idea of conferences. So that was in 2004, we organised an international conference here talking about bio-safety, and what is biotechnology. There were even recommendations from the conference that we have to establish the biotech programmes in Oman for capacity building in collaboration with the international organisations like WHO and FAO, and UNICEF. The following year, again, we organised a conference about food safety, specifically the Genetically Modified Organisms; the threats and opportunities of the GMOs and so on, so that was another attempt. Then when I was the Head of Department (HOD) in 2007, we made another smaller conference in the Department of Biology, we invited international people, and it is about biotechnology and its application in Oman (*Former HoD Biology, Public University, 2014*).

When the programme passed the transition status, the third stage started. It was more stable and was characterised by the 5-year cycles of review-evaluate-upgrade process. International best practices were reviewed and successful examples were visited to gather information for improvement. This stage is very critical as the outcomes inform the top management in the academic sector.



There were major modifications; the core courses remained as they were, but we changed the electives that guide our students to set a direction, either to microbiology, plants, or animals. So by doing this, we do not saturate students with the same type of specialisation. Electives from other departments are also included. They will be different and most probably we may end up having some of them as entrepreneurs, inventors and so on. So that was the idea (*Microbiologist, Public University, 2014*).

These changes took place in SQU, the main public university. One decade later, private universities and other Higher Education Institutions (HEIs) started to include biotechnology in their academic schools, as a separate specialisation within the biosciences. In most cases, the programme was formulated after consultation with SQU. As discussed later, a few cases have developed a biotechnology degree with a different perspective, and they have proved to have a successful programme (i.e. Waljat College). Accordingly, the rate of enrolment in biotechnology has increased in both public and private universities. The total number of graduates who pursue postgraduate degrees (MSc and PhD) in biotechnology has risen, as well. In parallel, employment opportunities in the three helixes have improved.

There has been a continuous pressure worldwide on universities to engage in the commercialisation of research outcomes and play an entrepreneurial role. As indicated by Sir Heap (2008), 'U.K. universities are now classified according to whether they are "research-intensive" or "business-facing", and although these terms do not depict exclusivity, they reflect how innovation has become a strong driving force that enables and benefits industrial and business exploitation.' (Heap, 2008, p2)

Similarly, local universities in Oman are no exception as they experienced such pressure. There was a trend that started by early 2000, to encourage universities to perform as a dual-structure organisation that allows for the quest of both research excellence and research commercialisation together. Especially in technology-oriented disciplines, like engineering, medical and biological sciences.

The interviewees with long organisational memories shared a common view, that the 'historical visit' of His Majesty the Sultan to SQU, in 2002, was the turning point towards more applied research. It was after this visit that SQU started to receive annual research grants under the title of 'His Majesty' (HM) grants for science and medical research. These

grants are very competitive and one of the evaluation criteria is the potential for commercialisation.

It was a 'historical visit' and after that, 2<sup>nd</sup> of May is the University Day that we celebrate every year. I think it was an important event especially after the announcement of HM grant. These grants support applied research that are directed to solve local issues.. It is an additional source of funding and researchers are encouraged to collaborate and work with other researchers from different sectors. This was the 'starting point' in the transformation. Before that, every attempt was an individual effort (*Assistant Dean, Public University, 2014*).

However, the younger interviewees thought that the change was triggered by external pressure, as an adaptation to the global shift towards commercial biotechnology research. It was an attempt to upgrade the 'dormant system' of teaching and research in biosciences. As one interviewee commented:

.. Well there was research at that time... but for the sake of knowledge production only, no consideration of commercial use. Academics were working in an 'isolated island', or as you said; the 'ivory tower'.. but it started to change.. The commercialisation of biosciences research took different dimensions... economists, engineers and even mathematicians... people from different fields became interested and involved in biosciences research. It is not the 'classic science' of classifying animals and plants (*Biotechnologist, Head MEOR unit, 2014*).

Another interviewee said:

.. And when I came back from my PhD study, I felt we were 'out of date'. Biotechnology was everywhere: conferences, workshops and even in the local media. Universities are no longer producing only papers for publication. In other parts of the world, academic staff leaves university to run their spin-off companies with their students and research team. A lot of movement is happening between the industry and the university. So we had to change if we were to maintain our work and image as an academic organisation. It was a global trend and we had to 'cope and adapt' with it (*Genetics Professor, Public University, 2014*).

Taking into account that the beginning of the transformation was in early 2000, which coincided with the historical visit of His Majesty, there was an additional pressure from the local actors after the first movement towards the demand-driven research, in the form of 'expectations' about the issue of solving problems in other institutional spheres. One interviewee said:

...they [stakeholders from the other two spheres] were expecting a lot from academics, I mean the public and the private sectors. It was always there and it crosses all the levels. The first generation of well-educated Ministers were the SQU academics, the image was big and they

expected SQU to solve their issues. And these expectations were the main pressure to find the way to address the issues through research and collaboration (*Assistant Dean, Public University, 2014*).

The institutional environments in academia were in transition as a new culture was gradually established. Not only due to Omani graduates, who joined the department and replaced the expatriates, but also there were the new staffs from different international universities with rich international experience. Some of the new staffs were from the networks made by the Omani students during their higher study abroad. They enhanced the setting up of the new proactive culture from their international experience and knowledge. Also, they introduced different training opportunities within their original organisations, for research technicians or fellow academics. The training courses included wide spectrum fields, like instrumentation, IP rights, and business.

At the university level, three indicators can be considered: (1) the change in research agenda; (2) funding sources; and (3) the emergence of entrepreneurial support units, e.g. TTO. Since the mid-1990s, there has been change in the research agenda in departments of biosciences and related fields, towards applied and interdisciplinary types of research. It occurred simultaneously with the movement to enhance interactions with researchers in other institutional helixes, as the size of research groups increased also. As indicated by one interviewee:

...By its nature multi-disciplinary research is the modern approach, so we tried to be part of that. The idea of nanotechnology, biotechnology, science entrepreneurship, and the idea of two or more departments are working together. The idea of combining our research with oil science, I have never thought that we are very strong in oil sciences. And to this, we need to join environmental sciences with the six departments and definitely with petroleum engineers from the college of engineering (*Former HoD Biology, Public University, 2014*).

Currently, research agenda has become well planned and calls for proposals turn out to be defined by specific themes. Furthermore, the research and innovation agendas are linked to other activities within academic schools, such as student competition and awareness programs. This change was enhanced by the availability of another funding source. In addition to the internal grants, the His Majesty (HM) grants and TRC funds became available to academics, starting from the academic year 2002/2003. Accordingly, the promotion scheme changed to include other criteria, such as community services, collaboration with

industry, and commercialisation activities (e.g. spin-offs, patent, licensing). As one interviewee said:

...So the grants went up because of the new faculty member, the number of publications have increased also, that was very positive. So when I became a dean, that was my task to make it happen... if it is possible. So we tried to make several changes. One of the major tasks was actually to change the promotion scheme. So we made the guidelines for the promotion based on community services and collaboration with industry or commercialisation.. It is not only based on teaching and publication. Research shall solve our problems and answer our needs (*Former Dean of CoS, Public University, 2014*).

The establishment of TTO in SQU is considered a significant milestone in the transformation process. It is the formal route for commercialisation of university research and collaboration with industry. Before TTO, academics were contacting the industry directly and the overall collaboration process was performed in a case-by-case manner. There was no standard procedure for handling the commercial utilisation of research output. As academic entrepreneurship became part of the university mission, the practice of commercialisation was reproduced and TTO became embedded in the university structure.

The academic sector, therefore, re-oriented towards the third mission as a response to internal and external institutional pressures. This transformation occurred via awareness of researchers and stakeholders, change of research agenda and culture, collaboration with other institutional spheres, and setting up of entrepreneurial structures, like TTO. The present findings seem to be consistent with other research, which found that the university has transformed to become entrepreneurial through increasing academic training, technological infrastructure and established interaction with local business actors (*Silva et al., 2012*).

### 5.3.2. Transformation of the government sphere

In a parallel vein, the Government also witnessed a trend of transformation to research commercialisation. This change occurred at the same time of the transformation of the academic sector. According to the Triple Helix model, the Government is the regulator of the innovation process by setting the policies and legislations. Taking into consideration the institutional setting of Oman and the fact that the bio-sector is economically and socially

significant, the role of the Government is thought to be central. The Government is also the main funder for research and innovation activities in the country.

Subsequently, the Government issued three market-oriented policies that revealed the transformation towards external investment and the creation of knowledge driven businesses. These documents are (1) the Foreign Capital Investment Law; (2) the Law on Income Tax; and (3) the Industrial Property Rights. The Foreign Capital Investment Law, which was issued by the Royal Decree RD 102/1994, allows up to 70% of foreign participation in local companies in most of the sectors. And for projects of strategic importance, the percentage of foreign capital investment can reach up to 100%. The Law on Income Tax for companies has been modified so that there is totally non-discriminatory treatment between fully Omani owned companies and other companies incorporated in Oman, despite the extent of foreign participation.

The government sector also conducts research through public research centres. The interest in biotechnology first started in the Ministry of Agriculture and Fisheries Wealth (MAFW) during the early 1990s, simultaneously with the introduction of the biotechnology degree in the public university. The agriculture sector was facing challenges with regard to dates' production, which caused remarkable economic loss (Personal communication with the former Director of the Agricultural and Livestock Research Centres, 2014). There was a need for suitable intervention that could improve the traits of local date palm trees, to enhance production and raise their resistance to disease and pests. Ideally, tissue culture technique, which is based on the applications of biotechnology, can address these challenges.

Similar to the academia, the idea of utilising biotechnology to solve the agricultural issue was also a bottom-up initiative from the individuals in the public research centres at that time. There was also support from the top management. It was proposed to establish a tissue culture lab in an agricultural area in the Interior Region. This region is the second largest producer of dates in the country. The lab was established in collaboration with well-recognised research centres in the United Kingdom and a programme of capacity building was initiated, which is still viable to date. Currently, the Directorate General of Agricultural and Livestock Research is the biggest organisation for the applied research in the

Government. It consists of six research centres for applied research with the potential of commercialisation. The total number of R&D staff is 155 Omanis with BSc degrees in Agricultural Sciences and above, which reflects the vision of the top management. As one interviewee commented:

...we observed that no matter the investment we put in research and lab equipment, I talk about money-wise; unless you have Omanis qualified, these investments will not be sustained for long time. It's a matter of a short-term investment. People are coming here with their knowledge. They work *with* you, not *for* you. They scale up their knowledge, they go back with their knowledge, and if you don't have the one who inherits that one, there is no sustainability at all. So we started in the late nineties to send our colleagues for their post-graduate studies (*Former Director, Public Research Centre, 2014*).

At the policy level, there are different national legislations that regulate utilisation of genetic resources locally in research and for commercial use. The most important public measure is the Royal Decree (RD) No. 57/2004: Approval of Oman Joining the International Treaty on Plant Genetic Resources for Food and Agriculture (PGRFA). The Ministry of Agriculture and Fisheries Wealth was appointed to form a steering committee in order to develop public policy related to the treaty and to define the responsibilities of the local stakeholders (Personal communication with the former Director of the Agricultural and Livestock Research Centres, 2014). Besides, the ministry formed an executive committee for technical collaboration, which consists of members from academic organisations, other public sector organisations, industry and individual researchers.

In addition, the Ministry of Agriculture and Fisheries Wealth have approved other public measures to facilitate exploration and utilisation of genetics resources for research and commercial use. For example, the Ministerial Order which establish the National Information System Mechanism in 2007, in collaboration with national stakeholders. This database allows researchers and other actors, i.e. investors or entrepreneurs, to gain access to the needed information (The former Director of the Agricultural and Livestock Research Centres, 2014). However, the most persist issue is the insufficiency of the current Intellectual Property (IP) regime. There is no national focal point, as all IP responsibilities are distributed among different ministries.

### 5.3.3. Transformation of the bio-based industry

In the industry sphere, all the activities occur in the eight industrial estates under the supervision of the Public Establishment for Industrial Estates (PEIE). With the exception of the petrochemical industry, other sectors including the bio-industry are still in the infancy stage. There are no in-house R&D activities, and the sole means to introduce advanced technologies is via joint venture with international partners. Therefore, the tendency to innovate inside the firm or in collaboration with other local partners is low.

Within the bio-based industry, firms related to marine biotechnology are considered active compared to other sub-sectors, e.g. food, agriculture and environment. Fisheries companies mainly produce fish, seafood and marine added-value products (Personal communication with Director of Al Rusayl Industrial Estate, 2014). Most companies practise traditional fish farming, as these products do not require high technology processing. Currently, new companies adopt high technology to produce sophisticated products (e.g. fish oil, drugs, enzymes, and biopolymers). For example, in 2014 six companies of this category were launched, which reflects rapid growth.

Although most of the bio-based firms were established since the mid-1980s, most local firms are characterised by being diverse about their core business, therefore they operate with low specialisation (The Director of Al Rusayl Industrial Estate, 2014). Additionally, they function in a reactive manner by adjusting their activities to market change. The absence of an innovative attitude has affected the overall performance of the bio-industry, especially the spin off activities.

It is very interesting to note that academia and the government realised the importance of the bio-sector earlier and different measures were taken to embed research and innovation in the sector. However, the industry was not involved in the idiosyncratic phase, which delayed the development of the bio-sector. The key change in the bio-based industry that triggered its recent involvement with the other two helixes is the employment of biosciences graduates. The public sector remained the main employer for university graduates for a long time. As the need for job opportunities increased each year, the bio-based industry and the private sector started to gain more attention and became an

important actor. It takes different forms, e.g. representatives from the bio-industry became permanent members in joint committees with the other two helixes. In addition, HEIs consult the industry regarding curriculum development and use their feedback to improve the qualification and skills of the graduates. As stated by one interviewee:

It was a different role; they [the Higher College for Technology] formed a committee to design the degree for the environmental science. This specialisation is needed in the job market in the public [Ministry of Tourism] and the private sector. I think it was the first time to do so [to consult the industry before the setting of academic degree], which is good, in a sense that graduates are aware of the available job vacancies. Also, there is recognition of the role of the private sector (*Environmental biologist, Private Sector, 2014*).

In addition to the employment issue, the frequency of interactions started to rise as more companies upgraded their capabilities. Thereby, the opportunity for internships and training of university students became available. It is interesting to note the perception of the industry actors with regard to collaboration with other spheres, specifically, the UI linkages. It seems that the culture in the bio-based also started to change. The openness to collaboration and the motivation for networking with other spheres had transformed. As one participant commented:

I don't see a huge change, the industry is still small. Scientists focus on science only.. they are not risk-takers.. They love science and they teach their students to look at science the way they see it. They enjoy being with students. This way they don't realise the economic benefits of their research.. So they don't initiate real collaboration with the potential industry.. We do collaborate of course, we train their students and we work together in some projects, but it is not the partnership that should be (*Production Engineer, Private Sector, 2014*).

Another interviewee said:

The private sector became open to collaborate and they do try, within their capacity, to work with us and the university. Their motivation changed, and more innovation-based firms started to emerge. I guess they want to have more presence. But there is a lack of understanding from other sectors. For example, we asked the Ministry [the Ministry of Manpower] to send appreciation letters to the members of the [...] committee from the industry and the private sector. They declined and they said the Committee Chair should thank all the members after the completion of the task; it is not the duty of the Ministry to send written appreciation letters. Business people are making enough money without the university and the public sector... Just recently, they started to collaborate effectively so they deserve more recognition and encouragement (*Biologist, HIE, 2014*).

The bio-based industry exhibited different indicators of transformation towards a more interactive nature with the other institutional spheres. Throughout the study time, the



sphere was changing slowly and the only active sub-sector was marine and fisheries. Therefore, the most noticeable area of change in the industry and the private sector is in the interaction with other institutional spheres. This can be explained by the rise in the awareness among the actors regarding the involvement of the industry, as well as the fact that more Omanis recently started to run their own firms and initiate different areas of collaboration.

#### 5.3.4. The trans-institutional impact

After the discussion of the transformation in each sphere, it is useful to shed light on the impact of the transformation in one institutional sphere on another. Initially, at the time that the Economic Vision 2020 was released in mid-1990s, the three institutional spheres shared a common understanding and knowledge base about the economic benefits of research commercialisation. The first movement to more entrepreneurial culture was done by the two helixes: universities and government. Industry was lagging behind and it was, therefore, institutionally less powerful than the other two helixes.

Furthermore, the key two helixes of academia and government were indirectly influencing each other and industry. In the Triple Helix model, the spheres are considered 'equivalent', although they are considerably different (Etzkowitz, 2008). Similarly, in the case of the bio-sector, the three spheres were not equal. In the academic sector, the transformation was initiated by SQU, and then it started in private universities and other HEIs. The strength of SQU was in pioneering the change, as the first public university that opened a degree in Biotechnology. It provided the other two helixes with discursive knowledge (publications) and tacit knowledge in the form of skilled graduates, who were the knowledge carriers.

On the other hand, the Government took major public measures to enhance the transformation towards knowledge entrepreneurship. The investment in agricultural and fisheries research centres was huge, as well the development of skilled research personnel in these sub-sectors. In addition, needed policies were formulated to facilitate the process. The public research centres proved to perform research as equal partners to the academic

sector. These centres did not only absorb the continuous influx of the knowledge carriers from academia, they developed a plan for on-the-job training and a programme for capacity building.

Throughout the study time, the industry was a 'silent actor', and the increase in bio firms happened just recently. Interestingly, the influence of one helix on another was obvious with the academic sector and the government. The transformation was initiated at the same time but separately, as well as the response to the institutional pressure to change. The impact had an alternative nature, so at the beginning there was a lag phase and then the impact started. The academic sector was increasingly exerting a compelling effect to consider biotechnology as a new and promising field, especially with employment issues. This direct influence shortens the idiosyncratic phase by increasing the awareness of stakeholders. This in turn enhanced the transformation process in the other two strands (government and industry).

In the idiosyncratic phase, it seems that the Government started the transformation independently from the universities, and yet it was absorbing the experience of the academia to accelerate its own transformation. Then the performance of public research centres started to inspire their counterparts in academia. Interestingly, a similar 'school of thought' has emerged with regard to laboratory management and human resources development (section 5.3.1). The interviewees from both academia and government excluded the idea of 'mimicking or replicating' one another, suggesting 'co-learning' status. After the lag phase of internal transformation, more interaction took place and a 'cross-fertilisation of ideas' occurred, as one participant commented:

... And when researchers started to come together, I mean in conferences, joint projects, national committees, or even public lectures, then useful exchange of ideas happened... Or what we call in biology a cross-fertilisation. Well it does not mean that the two of us were mimicking each other. No. it was a real co-learning process. At one point, we had the same school of thought, but we followed different paths in the change. The university remained the main knowledge producer and the government is our funder, supporter and the policy maker (*Former Dean of CoS, Public University, 2014*).

The transformation to knowledge entrepreneurship in the academic sector and the Government was not totally a response to top-bottom approach. So the similarity of the initiation phase in these two strands allowed for a degree of influence of each strand on the other. Besides, the undeveloped industry strand was indirectly shaped by the development of the bio-sector in the other two strands. Taking into account that the movement of researchers between the academic sector and the Government was more frequent than with the industry, therefore, the transformation in industry was highly reactive and its influence on the other two strands was limited. These findings may help us to understand the current performance in knowledge commercialisation and to suggest the required policies to enhance the role of industry. However, there were effective actors that emerged later, but they had more than an intermediary role throughout the transformation process. Thereby, taking over the role of industry and setting the dynamic equilibrium with the other two spheres, as discussed in the next section.

#### 5.3.5. The role of intermediary organisations

The role of intermediary organisations in the transformation to academic entrepreneurship is an essential element. As indicated in the literature, the intermediaries exhibit a heterogeneous role in the process of knowledge acquisition, knowledge flow and its transfer between the knowledge components, by bridging the knowledge gap and enhancing interactions (Gertner *et al.*, 2011; Tortoriello *et al.*, 2012). Within a range of different activities of intermediary actors, the focus here is on the role of enhancing sharing knowledge and interactive learning and eventually transforming the actors (Doganova, 2013).

In the bio-sector, there are many internal and external intermediary actors with two main features: unequal distribution in the three interfaces and reactive performance. The highest count was found to be in the interface between academia and industry, followed by those between academia and government. The intermediaries between government and industry are the lowest. Within these limited intermediaries, the absence of non-governmental agencies and social organisation puts more burden on the actors, as knowledge-based activities are new to the institutional setting.

Throughout the study time, the emergence of intermediaries occurred as a continuous process, as different intermediary organisations were established and added to the actors of the bio-sector in Oman: most importantly, the Public Establishment for Industrial Estates (PEIE), which was established in 1993, and the Research Council, which was established in 2005. When interviewees were asked to comment on the impact of intermediary organisations on the transformation process, there is a common view that it was a positive role. This is thought to be due to the complementary roles that were taken by these intermediaries, by facilitating flow of knowledge and promoting the interactions between the actors. This in turn enhanced co-creation and testing of new processes. In addition, these organisations provided different kinds of support, such as funding, training or information, which assisted the two helixes to proceed in the transformation towards the new role.

However, a small number of the interviewees considered that the role of the intermediaries was limited. They thought that the transformation was mainly shaped by the internal change in each sphere and the trans-institutional effect. The emergence of the intermediaries in the interfaces occurred through the establishment of the key intermediary organisations, which took place after the first wave of change in the idiosyncratic phase. The process of transformation had been progressing for a considerably long time before the intermediaries became involved. As well, they emphasised the lack of 'real knowledge brokers' which moderated the role of the intermediaries in enhancing the transformation.

Interestingly, the total number of intermediary organisations in the bio-sector is limited and they are characterised by being less diverse. The most important actors are TRC, which is the funding agency, and the Authority for Industrial Estates - both of them are government bodies. The role of these intermediaries in the transformation process was simulating some of the roles of the three spheres. Accordingly, their influence is similar to the effect of the three helixes on each other. For example, TRC is an important stakeholder of the bio-sector as a public funding agency. When it provided funds to the academia or public Research Centres in order to expand on laboratory infrastructure, it was taking the role of industry.

... And these organisations are just government agencies, they have the mission and vision of intermediary body, but they are another public sector entity. We need 'real knowledge brokers'... non-government association or even individuals... so those [TRC and PEIE] are not

literally intermediate organisation, they perform within the government setting and their adding value is limited. I was in a conference recently, and I came across a new idea that is 'science shops' and the concept of bringing people together.. Sharing ideas... this is what is needed from intermediary entity, in my opinion (*Assistant Dean, Public University, 2014*).

In the literature, the role of boundary-spanning actors in facilitating knowledge transfer and the engagement of the academic sector with industry is well defined (Gertner *et al.*, 2011, Schlierf and Meyer, 2013). However, the exact role of the intermediaries, in the context of this study, during the process of transformation is not direct. Taking into consideration that the bio-sector went through phases of evolution, and several organisational and functional changes took place throughout the study time. It is not simple to decide who came first, the actors or the intermediaries, as the sector is dynamic and some actors changed and became intermediary. For example, the funding agency plays a role in the development of entrepreneurial capabilities, such as improvement of laboratories' facilities and training of human resources. This role has facilitated the expansion of research activities and production of knowledge. Therefore, the role of intermediaries is not limited to access to resources and collaborative learning, but it also influenced the positions of the actors and provided the space for transformation.

#### 5.3.6. The role of 'bottom-up' proposals

The institutional configuration in Oman is still evolving and dynamic, where the development of different economic sectors took place due to the planning and management of political organisations. However, in the bio-sector the individual's efforts have contributed to the main milestones, especially during the idiosyncratic phase. This role was further enhanced by the presence of other supporting elements, such as government investment, the support of other stakeholders and comparison with international benchmarks.

The interviewees were asked to comment on the extent of the influence of individual researchers, government personnel and private sector staff on the major changes that took place. The majority thought that the bottom-up approach was a vital method to enhance the growth of the sector. Some interviewees used an interesting phrase: 'knowledge carriers' to refer to permanent or temporary staff who pioneered proposals or new ideas for the

progress of the sector. The main types of knowledge carriers are the new university graduates, well-experienced researchers from other organisations, and international consultants. Among these types, new graduates are more influential as they transmit the technical and the tacit knowledge. As one interviewee commented:

... In 1995 the idea [of the biotechnology programme] was initiated, because at that time biotechnology was viewed as the science of this century. It was a global trend and we wanted our university to include it just like any other good university in the world. Then our graduates can carry the knowledge to their new position at work and transmit the change (*Microbiologist, Public University, 2014*).

The movement of researchers from one sphere to another has also contributed to the development of the sector, especially when a researcher from a well-established organisation with sophisticated facilities is moving to a young, developing organisation. This type of movement is very common in Oman, for instance the movement of academic staff from public universities to the newly established private universities or the industry. By doing so, they avoid the complications of big organisation and other administration burdens related to it. These individuals are more confident to introduce new ideas to their organisations, based on their previous experience, and their efforts are trusted by their organisation. For example, one interviewee said:

... I was lucky to convince them [the top management of his organisation] .. I came from SQU, people trust SQU. So it was not difficult to gain consensus regarding my plan (*Biochemistry Researcher, Private College, 2014*)

Prior studies have noted the role of individuals in disseminating knowledge and introducing organisational changes (e.g. Salter and Martin, 2001; Zellner, 2003). The findings of this study indicate that the initiative for biotechnology in the academia and the public sector was mainly a result of individual efforts. The movement of young PhD graduates, who received their education abroad, into the academic sphere, had shaped the idiosyncratic phase. In a parallel vein, the movement of researchers and graduates into local SMEs is considered a key economic benefit, as it facilitates access to highly skilled human capital (Wright *et al.*, 2008). Therefore, these findings are in line with those of previous studies, suggesting the considerable role of individual actors in the absence of overall perspective at

the higher planning levels. This applies to the initiatives for introducing change in the institutional settings, where the individuals transform faster than their organisations.

Moreover, the biotechnologists who took the initiative for change can be described as 'entrepreneurs', as their role in their organisations is well matched with the real entrepreneurs. Based on the definition of DiMaggio (1988), institutional entrepreneurs are defined as 'actors who leverage resources to create new institutions or transform existing institutions' (DiMaggio, 1988). Two elements of an entrepreneur's role can be indicated; the ability to locate an opportunity and a risk-taking attitude. These individuals pursued the changes as the local circumstances accommodated the proposals of bottom-up nature. Therefore, it is possible to hypothesise that these conditions are less likely to occur in well-established institutional settings.

It is significant to note that in all of these types of individual efforts, there was also the existence of the political will to improve the sector. It was instrumental in speeding up the initiation of major changes, like setting up new laboratories and long-term investment in human resources. When the interviewees were discussing the role of individual initiatives, the majority commented about the 'supportive' environment that persisted at that time. They thought that there was a lot of government investment in the bio-sector, based on the projections regarding its economic and social potential. The guiding plan was the Oman Economic Vision 2020, which recognises fisheries and tourism as economically viable sectors. Therefore, the environment was enabled for bottom-up schemes, as one interviewee noted:

To be honest with you I have not seen appropriate transformation to a level that makes a change based on individuals alone, but we see a complete transformation if you change the leader. So if you see certain ministers for example. They put in a new minister, he can change the whole spectrum of what is happening in that industry, and this can happen in a very short period just because he is passionate, he knows what he's doing, he's courageous, he's taking a risk. So he has the characteristics of a proper leader in that organisation and therefore we can see a very fast change that you are expecting to see. So, transformation coming from bottom up proposals are limited, you may see some initiatives but they are not going anywhere (*Retired Government staff, 2014*).

In a parallel vein, the document Oman Vision 2020 had an impact on the proposals for change, as its aims are promoting economic balance and sustainable growth strategy that is supported by human resource, diversification and private sector development. This document has inspired most of the proposals in different sectors, including the bio-sector. As one interviewee noted:

It is amazing how influential the Economic Vision Oman 2020 document was. In almost every proposal for new idea, the 2020 vision was the reference document and the topic of economy diversification was the main rationale for the establishment of new programs (*Director for Development Planning, Government Department, 2014*).

Besides the supportive environment that helped the development of the bio-sector in academia and the Government, the procedures regarding approval of bottom-up proposals in these helixes were less complicated. At present, the core practices have evolved, and most organisations in the three institutional helixes have developed their plans and strategies. Therefore, this *modus operandi* has left limited room for proposals from individuals or departments. One interviewee commented about a proposal that was submitted in 2007 and was still under discussion during the time of the interview:

Basically, we prepared a plan to include biotechnology in the biology degree plan. It was totally an individual attempt, we are still waiting, it should go through the Ministry's procedures, so it is taking longer time.. It was much easier before (*Senior Lecturer (Biology), HEI, 2014*).

However, other interviewees, especially those with long organisational memory in the government sphere, indicated the role of the Government in the transformation. They assumed that the Governments' investment helped to speed up the development of the sector, as well the absorption of the new proposals. One participant commented:

.... nowadays, commercialisation of biotechnology research has become a norm, biotechnology itself has expanded in all concerned organisation. After the first transition, it became a 'self-replicating' in different field, the universities, the public sector and the private sector. I think the Government took 'catalyst' type of interventions and huge support was there (*Director for Public Research Centre, 2014*).

The development of the bio-sector in Oman is an interesting topic. The major milestones took place in the three institutional helixes almost simultaneously, but with different pace



and by various routes. It seems that the Government has been committed throughout the development phases. The next section discusses the transformation to knowledge entrepreneurship in the three institutional spheres in the bio-sector.

#### 5.4. The co-evolution of commercialisation processes and actors

As discussed earlier, the process of knowledge production in the bio-sector went through different stages that reflect the characteristics and development of local knowledge-generating organisations. The trends in knowledge production are important elements to understand the co-evolution of actors and commercialisation-related processes. Due to the nature of the bio-sector, the process of knowledge production is a complex practice as the organisational capabilities differ among actors. The interviewees were asked to share their experiences about the evolution of the commercialisation activities. The responses indicated distinct phases of change, although there was variation in the narratives regarding the exact timing of noticeable change. In order to study the co-evolution in the bio-sector, four indicators were considered. They include change in research agenda, change in public funding schemes, the role of actors and the institutional framework, and co-ordination mechanisms of the institutional setting.

##### 5.4.1. Change in research agenda

The change in research agenda and priorities reflects the overall tendency of the knowledge-producing actors to pursue applied research. The change in research priority areas can reflect a response to change in the STI policy and to demand from other institutional spheres. At the introduction phase, biosciences research can be described as basic research, and as the sector developed the research became 'demand-driven'. As stated by one interviewee:

In SQU, the research in different biological sciences was general.. The department was small and full-time researchers were limited. It was of 'basic' type, but the process developed. More collaborators [the government] are involved and research topics became more of 'demand-driven' type. They [the collaborators] put funds for research that addresses their needs, so there was a priority. They [the government] encourage the alignment between research topic and the areas of strategic importance and the economic sectors (*Former HoD of Biology Department, Public University, 2014*).

This trend can be observed in CoS and CAMS of SQU, and reflects a normal funnel-type of development. These knowledge-intensive actors started with wide-spectrum areas for research and changed towards fields that are more specific. On the other hand, there is an interesting issue with regard to the development of biotechnology research in the MAFW, which was referred to as 'the inverted funnel'. The Ministry established the Tissue Culture Research Laboratory before SQU and tissue culture research was the only field of biotechnology that was practised. Later on, a general biotechnology lab was formally established. The main reason for the establishment of a lab with very a specific specialisation was to solve problems with date palm trees.

Bio-tech is a broad terminology. Based on my knowledge and experience, if we talk about who has introduced the tissue culture to Oman, I would say the Ministry because the Ministry has established the lab at the beginning of the nineties as I indicated in 1990 (if I got it correct), and tissue culture is one methodology of the bio-tech, so at that time when we say 'bio-tech' we were talking about the tissue culture. Later on, this situation has changed, I believe, it was when His Excellency [...] was appointed. At that time there was Dr [...] who was a famous scientist at Sultan Qaboos University teaching bio-tech courses, he resigned from there and joined the Ministry... and then he established what we call now a bio-tech lab. Formally, the bio-tech lab came almost 12 years after the success of the tissue culture lab. We did it in an 'inverted-funnel' fashion. So again, if we talk about the bio-tech as a terminology, SQU introduced it and then it moved to the Ministry (*Former Director of Public Research Centres, 2014*).

This type of development is very interesting as it reflects several characteristics of the institutional setting and the overall ecosystem in the bio-sector. As described in Chapter 5, the tissue culture lab was established because of both bottom-up and top-bottom approaches. The lab, which works with one application of biotechnology, was established when there was no biotechnology lab within the ministry or in the other institutional spheres. This decision implied the need for frequent consultation and outsourcing processes until the establishment of the biotechnology labs in the academic sector. Nevertheless, this lab remains a unique and successful example in the public sector and the inverted-funnel approach can be replicated in similar fields.

The change in research areas in knowledge production implied the need for a policy framework, which is capable of supporting an appropriate ecosystem for research activities. As the trend was towards more applied research, policymakers were required to

acknowledge the importance of improving the national intellectual property (IP) system. Also, the expansion in research projects reflected in part an increase of joint work that required policymakers to look at mechanisms of enhancing these interactions between key actors. Finally, the rise in total research funding and the sources of funding implied the need for a practical funding policy. Furthermore, different terminology emerged in the strategies and other internal organisation communications. There was a consensus among the interviewees that 'the language' also changed, for example one interviewee said:

When we started the real biotechnology research, we spend some time in explaining some terminology to the admin, they were not used to these expressions.. Like TTO, joint-patent.. Even the translation of the word 'biotechnology' was not simple at that time, when most of the regulations started to change. As the activities developed and more researchers joined, the language changed and these expressions became part of our communication. (Microbiologist, Public University, 2014).

The researchers with international experience played a role in introducing different issues with regard to collaborating with other actors within the organisational fields. The adoption of new expressions in formal communications reflected rapid institutionalisation. The need for well-written bylaws and strategies helped to shorten the idiosyncratic phase.

#### 5.4.2. Change in public funding schemes

In academic entrepreneurship, research funding is a crucial issue as high investments in knowledge have a positive impact on knowledge-based entrepreneurship activities (Audretsch and Keilbach, 2008). As discussed before, the evolution of knowledge production in the bio-sector is assumed to be shaped by the changes in the public funding system. The role of public funding in supporting the development of commercialisation-related policies is viewed from three angles: the adequacy of funding to produce research that has commercialisation potential; the consistency with sector's priorities, e.g. development of potential sub-sectors for economy diversification; and the alignment with higher-level objectives, e.g. national capacity building.

Concerning the first theme, two different opinions are reported. Some interviewees thought that research funding from internal grants and TRC are 'adequate' to support research activities. They supposed that public funding is an essential factor in the evolution

of commercialisation-related policies, providing the examples of upgrading of management of research laboratories, purchase of modern equipment and supporting training of technicians. However, a small percentage of the interviewees said that research in the bio-sector is considerably costly, regardless of the continuous increase in public funding. Interestingly, they thought that the evolution of these policies is shaped mainly by the absence of industry support.

Well, the total funding has increased, and systemic funding emerged...but there is no special consideration to research fields that require more funding. Biotechnology research is expansive, in terms of labs, equipment, chemicals and technicians.. It is becoming challenging if we only rely on public money. The whole scenario would have changed if the industry is actively engaged. The strategies of funding are similar in public organisations, but with the industry, the procedures will be different (*Former Dean of College of Science, Public University, 2014*).

This view is very significant as it highlights an important observation about the roles of the three institutional helixes (university-government-industry/business). Although government support in the form of funding was increasing steadily and exponentially during the study period, it seems that this generous support did not compensate for the absence of the role played by industry. The interviewees shared their own stories to demonstrate that there are additional elements besides financial support, which can be gained from the involvement of the industry in knowledge generation and policy formulation. For example, the identification of research areas was considered an important component as it shapes the process of knowledge production. The government and the academia cannot determine the priority areas of research without the involvement of the industry.

Regarding the second theme, the common view among the interviewees was that current research topics are not properly linked to the development objectives of the sector. They thought that despite the availability of public funds to support knowledge production, the priorities of the bio-sector are overlooked. The interviewees talked about the importance of fisheries and ecotourism as promising sub-sectors for economic diversification. They thought that the development of knowledge production took place in a quantitative manner so that the development of hard infrastructure shall be obvious. However, little was achieved

in terms of the quality of research areas to address the challenges of the sector, as one interviewee said:

...I don't think all research areas have developed equally and the numbers [statistics of annual reports] alone cannot be representative of the development of the process [knowledge generation process]...academics might do it [research] for publication...what about the priorities; the contribution to sectors' development for economy diversification. I think there should be some sort of auditing, or review of the expenditure of this public money and to evaluate the economic return (*Section Head (Training & Scholarships), Government Department, 2014*).

Similarly, the third theme was about the alignment of funding with higher-level objectives. In the evaluation criteria of TRC funds, more weight is put on the elements of training and human resources education. This also applies to the internal grants of the universities. So, research proposals that fulfil this point have a better chance of approval. However, it is difficult to trace the impact of public funding on the development of researchers, technicians and other knowledge workers in the bio-sector.

Therefore, the extent of increase of research funding does not necessarily reflect positive outcomes, e.g. capacity building. In most cases, the huge budgets that were observed in research proposals were due to expensive lab equipment. Accordingly, the rise in total public funding does not present a significant increase in either the total number of research projects or the quality of the outcomes. Nevertheless, the funding policies were shaped by the feedback of researchers during the study period. Sector-specific features were taken into consideration and several modifications were introduced. For example, the issues relating to the ownership of research equipment after the closure of the project. In TRC funding policy, equipment which is purchased through TRC grants is to be owned by the research lab in the organisation of the Principle Investigator (PI). After purchase, the equipment is to be included in TRC's database for research equipment. This database helps researchers to locate and use equipment especially the expensive units.

Finally, the type of institutional response to public expenditure in research was considered by a few interviewees to be one of the drivers for change in the policy for funding systems. They pointed out that in the academic sector; the management of research funding has developed quickly compared to public sector research centres or labs. This is mainly due

to the knowledge and experience introduced by expatriate staff, especially during the early 1990s. In the public sector, however, research funding is managed similarly to any other budgetary items, and this is what halts the proper utilisation of funds. Therefore, it was significant to trace the change in knowledge production from the wider institutional context.

#### 5.4.3. Actors and institutional framework

For the purpose of this analysis, functional change is when functions are shifted from one actor to another, with or without excluding the former actor. However, organisational change refers to the cases when an actor disappears from the institutional sphere or a new actor is included. Since the 1990s, the public sector has witnessed many of both changes, including in the bio-sector. Within this institutional structure, the activities of knowledge generation take place and its related policies are implemented. The changes in the institutional arrangements of the actors affected the evolution of the knowledge production process and the emergence of national policies and strategies.

For example, the MAFW was divided into two different ministries in 2007. Later on, in 2012, they were joined together as before. Also, the Ministry of Water Resources and the Ministry of Environment were dissolved, down-scaled to Directorate General (DG) and joined to the Ministry of Regional Municipalities. In 2007, the DG of Environment was upgraded to a new Ministry under the title Ministry of Environment and Climate Affairs. All these ministries have laboratories and research centres and such change puts a lot of pressure regarding the conflict over these infrastructures and facilities. Research activities usually slow down for a period of time after change, and this not only affects the knowledge production within these organisations, it also influences other organisations in their formal and informal network.

Similarly, when functions are shifted the progress of knowledge production slows down. Such shifts in functions can be within the institutional sphere or in the interfaces. The key effect of both changes (functional and organisational) is to disturb the equilibrium status, which requires inputs to settle down. Two key components were found to be influenced: networks and tacit knowledge. Consequently, more resources were utilised, for instance,

time is required to form new networks and build trust, as discussed in the previous chapter.

As indicated by one interviewee:

I see the development of biotechnology as phases... at the beginning the government and the academia were eager to 'ride the biotechnology wave', so different activities and initiatives happened at that time. Then the momentum has cooled for a while, a lot of changes happened in the academia and the government sector. Research became systematic in the university and new ministries are formed. So more specialised actors became involved and with the support of TRC, there are clear improvements, for sure (Industrial Biotechnology Researcher, Public University, 2014).

In previous section, the characteristics of the actors were discussed and the most critical feature was found to be the hierarchy arrangement of actors. The research outputs of SQU, in the form of publications, were found to be the highest, compared to other knowledge-generating organisations. Other forms of output, i.e. patents, licensing, or spin-outs, were found to be almost absent from most organisations, including SQU. As the research and innovation policies are developing, the modest presentation of commercialisation-related outputs also indicates a lack of policies in the downstream phases of the knowledge production process. When the interviewees were asked about these outputs, and whether the policies are in place, the common view was that the process is in the infancy stage. They thought that the process of knowledge production is still evolving, together with its related policies.

It is too early to talk about commercialisation of research outputs, we need to work on the research process and produce results that can be absorbed by the industry. So, I think it is not because of lack of policy the commercialisation activities are modest. It is the other way round; because the research activities are still developing, the commercialisation policy is not yet ready (*Assistant Dean for Training, Private University, 2014*).

Therefore, although the hierarchical structure of the actors reflected obvious variations in the entrepreneurial capabilities, the commercialisation-related outputs are modest in all actors. The current activities are mainly in the knowledge production process. Different institutional spheres perceive such processes differently. In the academic sector, most of the responses acknowledged the importance of academic entrepreneurship. More efforts are placed to sustain an enabling environment to carry on the process to the commercialisation stage. The development of proper policy framework is gaining attention. It seems that if

there was an organisation with the same facilities as SQU and can buffer the hierarchy status, the performance of SQU would become more productive. As stated by one participant:

...I think there was a lot of expectations from SQU, this is why...it was overwhelming...they did their share. Maybe this university [Oman University that is a newly established public university] can take the lead and start, from the beginning, with market-oriented mind-set. They can use the existing facilities and policies to make a strong start (*Director of Information Management, Government Department, 2014*).

On the other hand, the other two institutional spheres (government and industry) consider knowledge production as one of the official mandates of academia. The general view was the traditional image of academics, who do research for the sake of publication only, because it is linked to their promotion. In public research centres, the production of knowledge has increased as more research projects were performed. Yet, publication remains limited. In the industry, the generation of knowledge is restricted to a few cases, which are normally for problem-solving. Therefore, the development of commercialisation-related policies and strategies is more linked to the academic sphere.

#### 5.4.4. Co-ordination mechanisms

In innovation governance, the co-ordination mechanisms between different components of the NIS are an essential element (OECD, 2005). When this topic was discussed, most of the interviewees acknowledged knowledge production as a 'shared practice'. The adequacy of proper coordination mechanisms to ease knowledge exchange and researcher mobility between the spheres were assumed to lower transactions and provide access to knowledge, people and resources. Therefore, the degree of connectivity between institutional spheres was considered to play a role in the evolution of the knowledge production process and its related policies.

The responses of the interviewees highlighted the inefficiency of current coordination mechanisms, which are considered as key research obstacles. They identified three types of researchers' activities that are affected by ineffective coordination: request for use of equipment, request for information, and on-job-training. They represent the main types of activities within and among the three institutional spheres that face administrative burdens. In Chapter 6, all types of knowledge networks were discussed in detail and in this section



only these three types were presented. The participants considered that knowledge-generating organisations were performing in a way that is similar to other administrative units. In their opinion, research outputs were mainly in the form of publications. Co-authorship is the most common mode of interaction between actors, as it depends mainly on informal linkages.

As I said before, it is all about time waste, things eventually happen but it takes long time... time is an important resource and in order to perform simple request it goes through loops of administrative procedures. This is in my organisation.. it is worse when we contact other organisations, unless if I know people there who can facilitate my request. This is why we normally have delay in the closure of research projects and the submission of the final report. There is an urgent need to have proper co-ordination between all stakeholders.. there is actually a need to reduce these procedures so research activities can go smoothly (*Biology Professor, Public University, 2014*).

In addition to the burdens at the individual level, the inefficient mechanisms are found to be at the organisational and institutional levels. Official procedures that impede the mobility of information and individuals are required for most types of interaction. Unlike other non-technical fields, the scientific work in the bio-sector, including research and teaching, needs more openness that allows for flexible interactions with other spheres. With the importance of information and tacit knowledge, researchers require assistance from other institutional helixes throughout the research process, such as sample collection, field observation, and access to local knowledge.

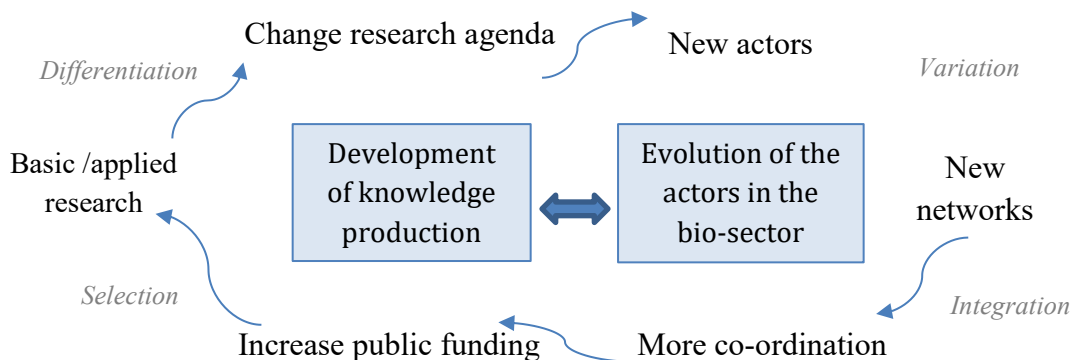
As discussed in the next chapter, researchers and academics mainly use their personal networks to reduce time and effort when they interact with other spheres. The knowledge generation process was considered to survive the lack of connectivity between spheres by adapting different means, in addition to informal linkages. The university-government interface was the most affected. This reflects the lack of policy framework in such areas, indicating slow development.

#### 5.4.5. The co-evolution of pattern in the bio-sector

Based on the above analysis, the change in the actors and activities of commercialisation provide useful insight into the development of the understanding of the co-evolution pattern during the study time. Four drivers are identified, which are the internal perception of

knowledge-generating processes by each institutional sphere; the diversity of public funding schemes; the functional and organisational changes of actors; and coordination mechanisms that set by the government (Figure 5.3).

The starting point was the availability of different public funding sources, which induced a selective approach for more applied research. As knowledge-producing organisations started to pursue 'demand-driven' research, the research agenda in the bio-sector went through a differentiation stage that shaped the direction towards specific 'research niche', e.g. marine biotechnology, tissue culture and EOR. As discussed in Chapter 5, the bio-sector witnessed major organisational and functional changes and yet the sector maintained its stability. The changes include the appearance of new actors, such as research organisations, funding agencies, and policymaking actors. The changes in the actors together with the changes in the research agenda encourage the formation of new knowledge networks and integration of the sub-sectors. Within the existing co-ordination mechanisms, the interactions between actors facilitate the increase in funding for knowledge production and the cycle starts.



**Figure 5.3:** A co-evolution pattern of knowledge production and policy development processes in the bio-sector during the study time (*Depicted from the responses of the interviewees*).

From an evolutionary perspective, these drivers had exerted a selective pressure on the process of knowledge production and its policies, suggesting a status of co-evolution. As research activities expanded to include more applied fields, different issues emerged and implied the need for new policy formulation. In parallel, the changes in the bio-sectors'

actors played a role in the selection of collaborators and changes in the knowledge actors. This dynamic acted as a feedback process, the inputs from knowledge-generating actors selected for the more suitable policies. Therefore, it can be assumed that the current policies and strategies emerged in accordance with the development and changes in knowledge production processes and the dynamics of the actors and knowledge networks.

In academic-based knowledge producing organisations, research management can be seen as a learning process. It went through several stages and the overall process is a result of multi-sources inputs. In addition to the formal outsourcing and consultation, there is the key role of the knowledge and experience of the researchers who had been awarded grants and performed their research in different university systems, indicating the role of tacit knowledge and previous experience. Furthermore, there are other types of knowledge, like technical knowledge and organisational memory. The use of this knowledge as researchers' feedback for the evolution of research policies depends on the degree of openness of the organisation to implement suggestions. Nevertheless, the outcomes of previous experience in funding and equipment purchase have a role in the development of internal policies and strategies.

On the other hand, this status is less observed in non-academic organisations, as research activities in these organisations are lower compared to the university. Another possible explanation for this is that non-academic organisations depend on SQU as their key source of knowledge when it comes to research management, in addition to the outsourcing and consultation, as discussed in Chapter 5. As the 'teacher of organisations', SQU remains the source of policies, tacit knowledge and experience. Therefore, the development of internal policies and strategies is less likely to be linked to the evolution of knowledge production processes in non-academic research-generating organisations.

However, the process of co-evolution in the university was not linear and these findings may be somewhat limited by different factors. Interestingly, the process of knowledge production has transformed during the study time, and yet some stages were found to be overlapped or repeated. The initiation stage corresponded with the introduction of biotechnology in Oman and the development was not steady. This can be partly explained as

a result of the limited research capabilities in both the academia and the public sector. The changes in the institutional setting are considered to have an impact on the overall evolution. In addition, the initiation stage was repeated further down the timeline, with the replacement of expatriates with Omani workers in the academia and the public research centres. The repetition of some phases slows down the development of the knowledge production process as the system enters an 'adaptation phase'. As indicated by one interviewee:

It was not a continuous growth curve.. we started at mid-1990s but the initiation stage was repeated sometime in the early 2000 with the Omanisation policy of positions in university and the government. So the production of knowledge slowed down for a while and then it returned back to normal. The system went in a kind of dormant phase.. it was the normal adaptation to the new situation (*Former Director of Public Research Centres, 2014*).

By assuming that the dynamics of knowledge production is one of the key determinants for the development of commercialisation-related policies, it is significant to identify the key parameters of such dynamics. Among the four indicators, the change in research agenda is considered the most important factor. This change acted at both levels, internally and externally. It had facilitated the internal transformation of knowledge production in the academic institutional helix. It also facilitated the development of knowledge networks to support the new research directions. Academics and researchers started to rethink their research interest and explore new opportunities of joint work with external organisations. Thus, researchers pursued applied research with commercial potential. This is similar to previous work in literature, which demonstrated that the overall research agenda is thought to impact the performance of academics across the research disciplines and their selection of research that can have commercial potential (Antonelli *et al.*, 2011).

It is important to bear in mind that the trigger for selecting new research areas can also be because of individual reasons, e.g. researcher's curiosity or availability of resources. Within the bio-sector, researchers tend to know their colleagues at different organisations and the selection of joint research can be highly determined by these motivations. In the presence of different drivers, it is not simple to determine the extent of the influence of knowledge production dynamics on the evolution of commercialisation-related national policies. Besides, the actors, who use them in their work, can further influence the evolution

process. The next section discusses the interactions between the knowledge-producing actors with the current policy framework, which includes the process of policy formulation and the main commercialisation-related policies, and national strategies.

## 5.5. Conclusion

This chapter discussed the first component of the NIS that is actors and institutions for commercialisation in the bio-sector. It presented the typology of actors and analysed their key characteristics: hierarchy of actors, high dynamism, replication of culture, and lack of conformity between formal organisational structure and its core activities. These features have shaped the role of the actors and resulted in a variation in institutional capabilities.

Based on the evolutionary perspective of the NIS, the evolution occurred in all institutional spheres simultaneously but not equally, as the changes were more evident in the academia and the public sector. During the study time, knowledge-producing organisations have developed their entrepreneurial capacities in terms of soft and hard infrastructure. In parallel, commercialisation-related activities evolved and more actors emerged, suggesting a co-evolution development. Four drivers enhanced such co-evolution that is: the internal perception of knowledge-generating process, diversity of public funding, functional and organisational changes of actors, and coordination mechanisms.

Most of the major changes were first initiated by individuals, who were not necessarily in leadership positions, as bottom-up proposals in both the academic and the public sector. It is interesting to note the complexity of human component in the process of transformation, as knowledge carriers who proposed the changes and guided decision-making. Especially during the idiosyncratic phase, the role of knowledge carriers was profound. Despite the effect of the positive political will at that time, the transition was shortened due to individual's efforts to grow awareness of the stakeholders within their organisations and among other institutional helixes. It suggests a multi-level process that utilised knowledge, organisational practices, culture, and the encouraging setting in the three helixes. This individual-induced transformation is unique, as the whole experience cannot be simply replicated at present. Such initiatives lost their effect with devolved government agencies.

## 6. Knowledge networks in the bio-sector

### 6.1. Introduction

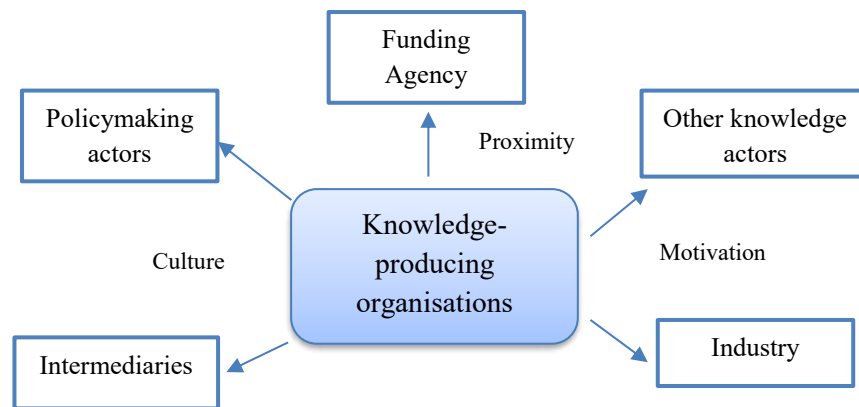
This chapter aims to explore the interactions and knowledge networks between the actors in the bio-sector and addresses research questions 3 and 4, which are: *What are the modes and dynamics of knowledge networks in the bio-sector? and What is the influence of network resources, spatial proximity, and intermediaries on knowledge networking in the bio-sector?* It is informed by the series of interviews, the questionnaire and the field notes and discusses the issues of networks from three perspectives. Firstly, the chapter considers the sub-dynamics of bi-lateral linkages and the motivations for trilateral interactions. Then, the main types of interactions and the dynamics of the networks are indicated. Thirdly, the roles of both proximity and intermediaries are discussed, and mechanisms of selecting partners are explored.

In essence, knowledge networks refer to the different types of relationships between the actors (academia, government and industry) through which knowledge is either diffused or jointly generated (Balland *et al.*, 2014). Since the generation of knowledge has been acknowledged as a social, interactive process (Lawson and Lorenz, 1999), the comprehension of knowledge networks is central in studying different innovation activities, such as academic entrepreneurship. Within a sector, the performance of commercialisation activities of one actor depends mainly on access to knowledge and resources held by other actors (Gulbrandsen *et al.*, 2011; Perkmann *et al.*, 2013). According to the Triple Helix model, the institutional spheres of university, industry and government are thought to take on each other's roles in addition to their traditional roles, thereby reducing barriers and increasing the links between the three spheres (Etzkowitz, 2008).

Within the concept of 'valuable' university–industry linkages (Giuliani and Arza, 2009), the main forms are joint patents, joint publications, inter-organisational job mobility, advisory boards or joint committees, and joint participation in research and development (R&D) projects (Salter and Martin, 2001; Abreu *et al.*, 2009; Bishop *et al.*, 2011). Network analysis examines knowledge relationships at various levels, such as individuals,

organisations, regions and nations (Gilding, 2008; Crespi *et al.*, 2011), in addition to knowledge intermediation or brokerage (Hargadon and Sutton, 1997). In this chapter, different levels of knowledge networking are considered, which include formal and informal linkages as well, individual, inter-organisational and cross-institutional linkages are discussed.

In this chapter, the bi-lateral and trilateral linkages between the key actors are studied, in order to allow better understanding of the development of these networks, their motivations, and dynamics. The first level tackles the bi-lateral sub-dynamics and the opportunities for collaboration between the key spheres, which enhance the learning and transformation of the actors. The second level is the dynamics of trilateral relations as a significant process that shape the knowledge networks in the bio-sector. From this level, the analysis is extended to include external factors, e.g. proximity and intermediaries, in order to map the extent to which actors are influenced by cultural and social dimensions. The phases of interaction during knowledge networking represent the third level of the analysis. By adopting this perspective, the driving forces for selection of partners can be identified and, consequently, a better understanding of the existence of joint phenomenon, e.g. co-development and co-evolution, can be achieved.



**Figure 6.1:** An illustration of the contextual framework of the chapter (Depicted from the responses of the interviewees).

This chapter is organised as follows. The first section reviews the main activities of the actors in the bio-sector and the motivations for interaction between knowledge-producing

organisations and external organisations. In the second section, the modes of interaction between the actors are discussed, with special reference to university–industry/business linkages. The dynamics of knowledge ties between the actors are presented in the third part, followed by the roles of both proximity and intermediaries in knowledge networking. In the last section, mechanisms for selection of partners in the bio-sector are discussed. The chapter concludes with a summary of the main findings.

## 6.2. Motivation and barriers to interactions in the bio-sector

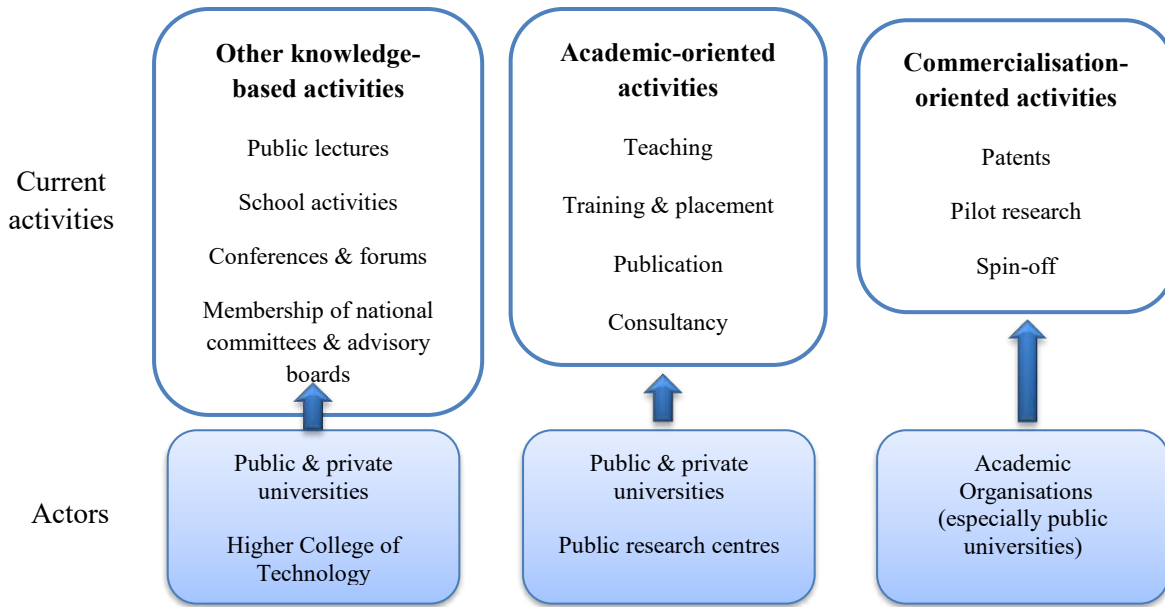
### 6.2.1. Activities of actors for commercialisation

Before the discussion of the motivations for knowledge networking at the bi-lateral and tri-lateral dynamics, it is significant to review the current activities in the bio-sector. These activities allow better understanding of the rationale for the development of knowledge networks and the barriers to networking. According to the Lambert report (2003), key barriers to university-business interactions in the UK are an over-emphasis on IP in collaborative research projects and a lack of clarity on the primary aims of collaborative research. In the context of this study, the main concern is clarity over the purpose for collaboration, as discussed later (Table 6.2).

Based on the interviews and questionnaire responses, activities can be categorised into three groups: academic-oriented; commercialisation-oriented; and other knowledge-based activities (Figure 6.2). Within each category, different activities are performed, whereas those related to commercialisation are limited. Some activities are distributed across all actors, e.g. the category of community-based activities. However, limited actors perform certain activities, for instance the academically oriented and commercialisation.

Previous studies emphasised the role of university activities in enhancing linkages with other actors. Drucker and Goldstein (2007) indicated that particularly knowledge-based activities, such as teaching and basic research, have substantial positive effects on a variety of measures of regional economic progress. In the bio-sector, most of the sector's impact and contribution are from knowledge-based activities, in the form of skilled graduates, publications and tacit knowledge.





**Figure 6.2:** The categories of main activities which are performed by the actors in the bio-sector (*Depicted from participants' views*).

This pattern of activities reflects the characteristics of the actors within the institutional setting, i.e. fragmentation of processes and the hierarchy structure (chapter 5). It originally indicates the differences in the organisational capabilities among the knowledge-producing actors. For example, limited actors perform activities related to IP protection as this process is highly fragmented between different government departments (chapter 7). In addition, training is mostly done by the public universities, although public research centres and laboratories are more relevant because perform more experimental and fieldwork. However, training activities are closely related to the use of common facilities, and are done by actors with sophisticated organisational capabilities.

### 6.2.2. The bilateral academic-industry relations

Historically, the academia and industry have existed as two separate institutional spheres, with academia as part of the government (Former Dean of CoS, 2014). As discussed previously, the major milestones in the development of the bio-sector seem to have shaped the co-evolution of the three sub-dynamics, and driven the relations into new regimes. In this respect, three institutional and functional changes are recognised: the transformation of the biosciences departments in the universities, the transformation of the public sector

research centres and labs, and the establishment of the Research Council as a key funding and governing body for national research and innovation activities.

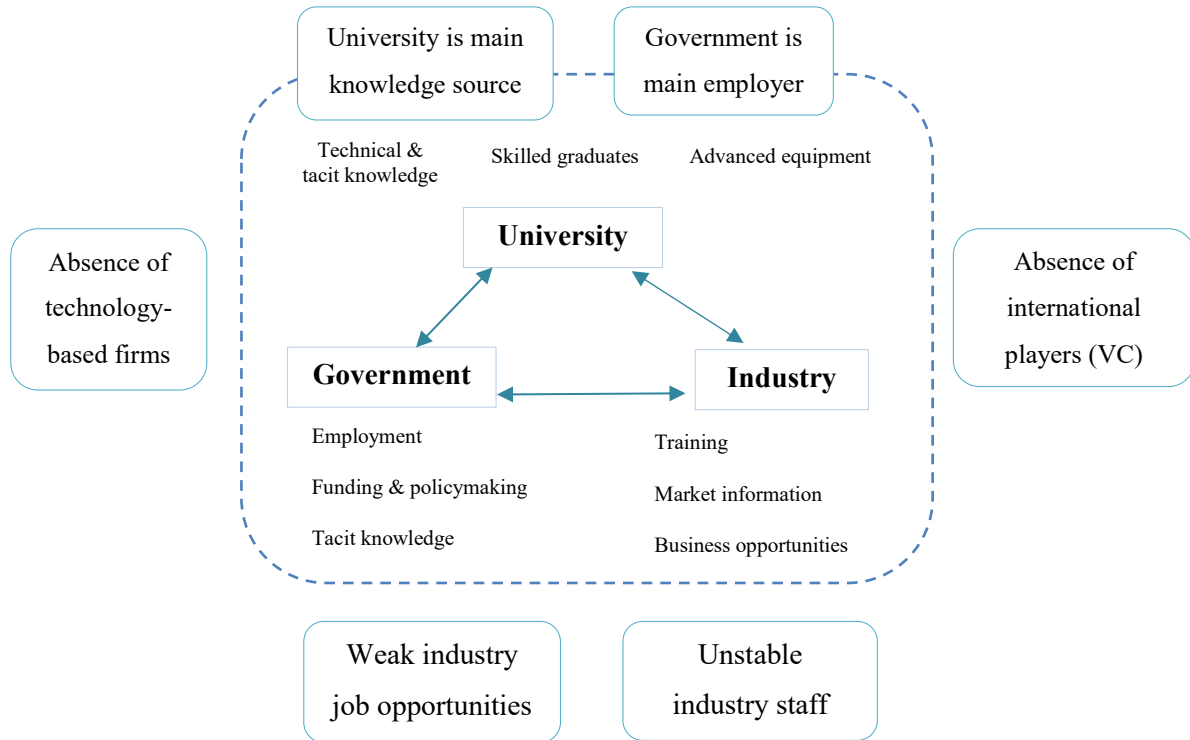
However, these transformations affected the university-industry (UI) linkages more than the other two sub-dynamics (university-government and industry-government). Universities and other HEIs are the 'knowledge possessors' and the suppliers of skilled graduates. The key entrepreneurial capabilities within the academia are: advanced facilities; technical and tacit knowledge; and skilled graduates. On the other hand, the industry offers the other two spheres the following: training; market information; business opportunities, tacit knowledge, and employment. Finally, the Government provides the other two spheres with funding and policy, employment opportunities, and tacit knowledge (Figure 6.3).

Interestingly, the UI sub-dynamic is shaped by the fact that 'university is not the first source of knowledge for the bio-industry and the industry is not the main employer for university graduates' (Former Dean of CoS, 2014). The three main sources of knowledge in these firms are the Omani Standards (OS) that are developed by the Ministry of Industry and Commerce, the internal documented knowledge and consultants' reports (Personal communication with Director of PAIE, 2014). The Government remains the key employer for university graduates, who seek well-paid jobs that are not offered by the bio-based industry. As indicated by one interviewee:

One of the key challenges in the bio-sector is the loss of skilled graduates due to the lack of good employment opportunities in the academia and the industry, together with the absence of technology-based companies. The 'weight of the industry' in the sector is undermined by its inability to provide sustainable employment to the university graduates (*Biotechnologist, Public University, 2014*).

Furthermore, the fact that most of the industry staffs are expatriates, and hence they are not stable, plays a central role in the low interaction with the other two institutional spheres (Director of PAIE, 2014). The staff change more frequently compared to their counterparts, which results in short-time networks at the personal level. Staff may leave their firm for other firms or for neighbouring countries for better payment. More sustainable networks

are with newly formed firms, which are run by their Omani founders. Therefore, the entrepreneurial capabilities have limited influence in this sub-dynamic.



**Figure 6.3:** The motivation for the bilateral dynamics of the actors in the bio-sector.

Another significant factor is the absence of advanced bio-based companies that perform in-house R&D activities. Therefore, they do not benefit from the available funds from academia or the Government. Consequently, the bi-lateral interactions between the academia and the industry occurred in less pace compared to the academia and government bilateral. Academia and the public research centres share the practice of performing research and producing knowledge and, besides, the definition of applied research, which is more relevant to the industry, is not similar in both parties, as stated by one interviewee that:

..Ok.. What type of research is done by the university? They call it applied research... but it is 'not applied enough' in our perspective.. We look for different level of details... academics are waiting for us to knock their door, it never work like this... the university is important part of the equation, they cannot be replaced. But, the type of the knowledge they produce is important, the publications they make, even the mind-set of their graduates. University

graduate have different perception of the work in companies in the private sector (*Production Director, Private Sector, 2014*).

Therefore, the university-industry bi-lateral exhibits low interactions. The key factor is the independency of the industry from the academia regarding knowledge source, and the absence of employment opportunities for university graduates in the industry. The low opportunities in the bio-based industry shifted the bilateral dynamics towards the government.

### 6.2.3. The bilateral academic-government relations

Until the recent transformations in the government and universities, the latter were functioning as part of the government. Several institutional and functional changes took place from mid-1990s and allowed for more differentiation between the academic sphere and government. As a result, there has been a trend, from the late 1990s until very recently, for the bioscience's public sector employees to leave their jobs and join the university. Very few have joined as academic staff, while the majority were either technical or administrative staff.

However, few academics joined the public sector. The main type of such movement was the appointment of academics in high positions in the public sector, such as ministers or undersecretary. A Royal Decree issued these promotions and it was very common during that time to witness ministers with academic backgrounds in different fields, including the bio-sector. Interestingly, this historical background has shaped the university-government bilateral.

In the absence of strong actors from the industry sphere, the interdependence between the government and universities has deepened. Whereas the Government is both the main source of funding for research and teaching activities, and the main employer for university graduates, the local universities are the main source of knowledge for the Government. Simultaneously, each party was attempting to develop its capabilities and competing for resources, i.e. skilled personnel and well-equipped labs. An example is the establishment of the first biotechnology research lab in the public sector, which was carried out by the MAFW. Throughout the setting of the lab, the Ministry outsourced the needed technical assistance

from international consultants. In addition, the department of biology in the CoS has established the CARRU as a state-of-art analytical unit, without consulting the public sector.

#### 6.2.4. The bilateral government-industry relations

In the government-industry bilateral, the government is the key policy-making actor and accordingly this sub-dynamic is characterised by the hierarchical and uni-directional nature of interactions. It is limited to collaboration with regard to policy and regulatory issues, including consultation, problem solving, and joint committees. The key driving force is the absence of both high-technology firms and international players as investors.

As the three institutional spheres perform in an isolated manner, it is not simple to identify which network builder initiated the interaction. In any sub-dynamic with the academia as part in the interaction, the university acts as the 'buffer organisation' to enable such linkage. This is due to the high entrepreneurial capabilities of the academic sphere in comparison to the other two spheres. Furthermore, the bilateral links across institutional spheres in the bio-sector are also determined by the intensity of interactions among actors within each institutional sphere. As one interviewee said:

We cannot say there is no collaboration, but with biotechnology companies, it is less actually, not that much. We work more with our colleagues in the public sector. In microbial technology, there is some collaboration because only one pharmaceutical industry is here. The infrastructure for bio-based industry is not in place yet. I don't mean to compare, but too many industries are well established in Dubai.. One of my students is now there  
(*Industrial Biotechnology Researcher, Public University, 2014*)

Therefore, the main drivers for bilateral interactions can be summarised as the variation in institutional capabilities among key actors, individual initiatives, and the degree of openness and organisational culture. It is clear that actors started to collaborate with their counterparts from the other institutional spheres to get access to more resources, such as funding, equipment and knowledge, indicating the role of institutional capabilities in initiating bilateral dynamics.

The role of individuals emerges as the sector witnessed migration of skilled personnel from one organisation to another. These individuals joined the new organisation, but

maintained their contacts in the previous organisation. When a collaborative element exists, the initiative for networking takes place depending on the degree of openness to network. This does not only apply to staff mobility between organisations, it also applies to freshly graduated students who joined an organisation and facilitated interactions with their previous academic staff in the university. As one interviewee commented about their students in the oil industry:

You see actually now the base work with the oil industry has started.. we got some of our students got employed there.. and now they proposed good ideas for join-research in waste management. We should appreciate them, they initiated the first steps, and they educate their company so we are throwing this oil in the environment. It should not be like this it should be degraded. Now companies are coming and approaching the university. So where we are lacking is the intersection between the interests of all stakeholders, but now I think once this common benefit identified, we can work together. And as more interest emerges, more stakeholders are invited and included. So at the beginning, oil industry and industry-academic relations strengthen and other sector can join later with the progress. So maybe here we will start this multi-stakeholders collaboration (*Biotechnology Professor, Public University, 2014*).

Therefore, the sub-dynamics of bi-laterals played a central role for the evolution of the tri-lateral linkages. These sub-dynamics acted as a trigger for more interactions, as in any bilateral links, one party can be more active and proactive, e.g. the university. Academics from SQU were the common party with both the industry and the public sector in the bilateral interactions. During bilateral interactions, the collaboration with other actors in tri-lateral or other forms of coalition develops as the motivations for partnership emerge.

Therefore, there are different motivations for an actor to initiate collaboration with other actors. With regard to the responses from the universities and other HEIs, the highest frequency of collaboration is due to two factors that are almost equally: the organisational perception of networking with other organisations, and the personal motivation for keeping research up to date (Table 6.1). The frequency of responses giving the reason of securing more funding is also high, and following that is another personal reason, which is the support of a professional network. The lowest frequency is for the motivation of using advanced equipment, which is expected with this type of knowledge-producing organisations, as they have advanced labs and equipment. On the other hand, the use of advanced facilities is the

highest motivation for non-academic knowledge-producing organisations, and collaboration for securing more funding is the lowest. Interestingly, the other three motivations are almost the same frequencies, which are of both personal and organisational origins.

**Table 6. 1:** The frequency of responses of knowledge-producing organisations with regard to the motivations for collaboration.

Q1: What are the motivation factors that enhance you to collaborate with other researchers from external organisations in your field?	Universities and other HEIs (N= 32)		Public Research Centers (N=14 )	
	Yes (%)	No (%)	Yes (%)	No (%)
My institution is giving more weight to working with the public sector and/or the industry	93.8	6.2	78.6	21.4
Collaboration with other organisations keeps my research up to date and allow pilot of the results	93.7	6.3	71.4	28.6
Collaboration with other organisations allows using of advanced equipment	46.9	53.1	92.9	7.1
Collaboration with other organisations create external source of funds	81.3	18.7	35.7	64.3
Collaboration with other organisations strengthen my professional networks	68.8	31.2	71.4	28.6

During the interviews, the interviewees elaborated on their motivations and different themes emerged with regard to personal motivations. In most cases, researchers seem to look for partners with good knowledge (technological and tacit) in order to improve their research projects and to get them published in referred journals. This is consistent with other studies, which indicate that university researchers maintain strong working relationships with industry to gain scientific knowledge in addition to technological knowledge (Hemmert, 2016). The following examples indicate the different personal motivations:

Well to be honest with you the first motivation I would say is personal... whenever you contact other people to do research with them, you want to improve your research. So that's the first motivation. Second, unfortunately... we can't do research in Oman without specifically, in my case, I can't do research without contacting other people, because all of my research includes specimens. You know, I am not going to get the samples unless I get the contact... for instance SQU. So in order to get things going I have to contact people and collaborate with them (*HoD Microbiology, Private University*).

Another interviewee said:

Being a bio-technologist puts a lot of demand on academic to expand their knowledge and expertise... I mean new knowledge... outside the textbooks or conferences. This knowledge is derived from working with the industry or the public sector. We need to reach this kind of people and include them in research or simply invite them to give a lecture to our student (*Head of MEOR Research Unit, Public University, 2014*).

On the other hand, the interviewees consider the organisational perception of the collaboration with other actors as a key motivation to networking. Currently, most organisations encourage inter-organisational linkages, as well as cross-institutional collaborations. The interviewees mentioned different examples of organisational incentives for collaboration with external organisations. This reflects the degree of awareness at managerial levels. However, personal drivers tend to be the most significant motivation. It is not simple to separate the two drivers, because it is difficult to specify where individual initiatives end and formal organisational influence begins. As stated by one interviewee:

As far as the institution is concerned... whether they value this kind of interaction? Of course they do. In our strategic plan, our main objective is to widen collaboration with other institutions... so they do value this kind of collaboration and a lot of support is there. I can say that I am collaborating with other biologist as part of my duties, it became a routine, and even the assessment of academics considers this topic (*Former HoD Biology, Public University, 2014*).

In addition to the influence of organisational vision, the interviewees talked about the support from their organisation to initiate collaboration with the industry. For example, workshops and conferences funds or job fairs that brings the potential employers together. These events allow academics to display their areas of research and its application in the industry. As indicated by one interviewee:

I am planning to conduct a workshop or even a series of seminars at the end of each year throughout this project. I am going to invite the company people... some key people and we can show them how much we are producing and the cost... so it may initiate something in their mind. The department is supporting these initiatives (*Industrial Biotechnology Researcher, Public University, 2014*).

Based on the analysis of the motivations, possible barriers to networking are identified and grouped into two categories; external and internal (Table 6.2). The former



span across the three institutional spheres and includes the quest for resources as well as structural and cultural issues. The internal elements are within the organisational or the institutional spheres, and include the availability of resources and interactive capabilities. The deficiency of resources is a common factor within and across the three spheres. This includes lack of time due to teaching burdens, limited funding, and deficiency in some skills for collaboration, e.g. identification of potential collaborators. This is more obvious in small organisations and is in line with previous studies about barriers to networking that highlight the lack of knowledge about potential partners and possibilities for mutual interaction (Abreu *et al.*, 2008). At a firm's level, the key difficulties are in estimating the market demand for their products or service, and it is in line with other studies (Subramonian and Rasiah, 2016).

**Table 6.2:** Barriers to linkages grouped into external (across institutional spheres) and internal (organisational or within one institutional sphere) elements. (*Depicted from interviews data*)

External elements (resources, structural & cultural)	Internal elements (resources & interactive)
Deficiency of stable & long term funding for collaboration	Deficiency of collaborative/networking skills & leadership for strategic linkages
Lack of incentives / rewards for networking	Difficulties in identifying potential collaborators
Absence of active boundary-spanning actors	The 'teaching & training loop'
Lack of the environment for ' <i>cross fertilisation of ideas</i> '	Lack of role models & successful examples
The quest for 'equity in the collaboration'	
The diversity issue vs the 'silo mentality'	

On the other hand, the structural dimension has an impact on the motives for collaboration due to the absence of vital intermediary actors in the interfaces. Several cultural issues are also significant, such as the lack of an environment for sharing ideas and knowledge exchange, together with the perception of collaboration as a process that implies equity between all actors. Furthermore, some interviewees thought that the main barrier is the 'silo mentality' that is present in some departments and prevents initiatives for collaboration, indicating the influence of cultural dimension of the actors.

### 6.3. Modes of knowledge-based interactions in the bio-sector

Based on the questionnaire responses and interviews data, seven types of collaboration were identified: joint committees; co-authorship; collaborative research; consultancy and problem solving; use of common facilities and exchange of resources; community-based collaboration; training, exchange programmes, and internships (Table 6.3). Most of the interactions between knowledge-producing actors and external organisations are in knowledge-based, as well as society-based, activities. The responses indicated low interactions for the purpose of commercialisation and academic entrepreneurship. This is in line with current literature, which indicates that university researchers engage with industry in multiple knowledge exchange mechanisms; the most important of these involve people, such as consultancy, contract research, joint research, or training, as compared to patenting or spin-out activities (D'Este & Patel, 2007; Abreu *et al.*, 2008).

There are different driving forces behind these interactions, which are: the need to form 'knowledge alliances' to compensate the lack of facilities; the power of internally generated knowledge and the tacit knowledge of individuals; the overlap in research areas in knowledge-producing actors; and the dominant organisational and institutional culture. These drivers are related to the motivations for collaboration that were discussed in the previous section. They exert selective pressure on the actors and the existing network, and shape the main types of interaction.

**Table 6.3:** The percentage of responses from knowledge-producing organisations with regard to the main types of collaboration.

Q 2: What is the main mode of collaboration with other actors?	Universities and other HEIs (N= 32)	Public Research Centers (N=14 )
Joint committees	87	79
Co-authorship	31	14
Collaborative research	48	20
Exchange of resources	36	62
Consultancy and problem solving	73	34
Training, exchange programmes, and internships	82	38
Community-based collaboration	17	13

As the institutional capabilities vary, actors with low research and innovation abilities form different types of partnership with actors with sophisticated hard and soft infrastructure for knowledge production. Furthermore, actors pursue access to tacit knowledge possessors, who are limited within the bio-sector, as well to the internally produced knowledge in non-academic actors. Networking also helps knowledge-producing actors to consider the overlap in some research areas. For example, the agricultural research centres perform field research that targets farmers to educate them, whereas CAMS participate to get access to the data with regard to post-harvest techniques. Finally, as the actors collaborate while having competing interests, the cultural element plays a central role in the selection of modes of collaboration. For instance, some academic knowledge producers prefer more 'prestigious' collaboration modes with the government such as committees or high-level meetings. On the other hand, they focus on the scientific-based collaboration modes when links to the industry or similar academic actors.

### 6.3.1. Joint committee

National joint committees are the most common type of interaction, as they contain representatives from different spheres. The responses of both types of knowledge-producing organisation (academic and non-academic) with regard to this type of interaction are high. The committees are usually formed under the management of a host organisation from the public sector. Networking happens not only between the committee members during the committees' task, but also outside the work of the committee, suggesting the role of informal linkages. This type of interaction is characterised by the absence of the selection of partners as the host organisation contacts the relevant department at other organisations and requests representative nominees. Although formal contact is the main type of interaction between members, yet informal and personal linkages play a central role. The committees function for a limited time and members can be further invited to join other committees, focus groups, or research teams. Thus, previous experience plays a role in future collaboration. As the predominant culture of these committees is formal, the commitment is considered high, compared to other collaborative work.

As this type of collaboration represents an important means of networking in the bio-sector, it will be discussed in detail in two later sections: 6.5, with regard to proximity and section 6.7, which is about the selection mechanism. The key driver for such interaction is the search for capable partners. In these committees, the quest for technical and tacit knowledge is the main objective to invite members from different organisations.

When the interviewees were asked to comment on their experience with national committees, the common view was positive. Although these committees are demanding in terms of time and commitment, members from academic and non-academic actors spare time to participate. They indicated the importance of these committees in introducing individuals to the fields and actors of the bio-sector. They thought that despite the fact that most of the committees are duplicating the work of other committees, it is the 'committee's atmosphere' that is benefitting.

### 6.3.2. Co-authorship

Although the overall output of knowledge production in the bio-sector has increased throughout the study time, the rate of co-authorship did not represent a clear trend of increase. The scientific publications continue to include academics from different departments within universities and from other academic organisations. It was observed that in collaborative research the extent of contribution from other knowledge-producing organisations is limited to the type of 'in-kind contributions'. Also, the contribution can be mentioned in the acknowledgment part of the publication.

The ideas that emerged when this topic was discussed with the interviewees are that publication is critical to researchers from academic-based knowledge-producing organisations, whereas it is considered as added-value in non-academic actor. Therefore, the co-authorship is more common with partners from the academic sector. In the public sector research centres, most of the research activities are directed to produce evidence-based policy implications. Also, the research outcomes are utilised for extension, whereas scientific publication is not at the top of priorities. This pattern is based mainly on informal linkages and is linked to the tendency to collaborate in joint research, where academic actors use the finding for publication and other partners use them for other purposes.

### 6.3.3. Collaborative research

Researchers from academic-based knowledge-producing organisations are more likely to be involved in joint research within the academic sector and across the institutional sphere. Researchers from non-academic organisations participate in collaborative research at a modest rate. Both types work with industry in limited cases. The absence of industry as a strong actor has diminished collaborative research. The research partnership between academia and the public sector has different areas of interest, which are away from commercialisation and academic entrepreneurship.

Although the local bio-based industry has limited joint research with the academic and public sectors, researchers from the academic sphere mainly initiate the existing joint research. As there is no clear strategy of enhancing such collaboration at the policy level,

most of the initiatives are based on informal linkages. These interactions are also weakened by the limited role of intermediaries.

#### 6.3.4. Consultancy and problem solving

Consultancy is an important type of interaction between the actors in the bio-sector. Academic organisations are more involved in consultation than non-academic actors are. However, the outsourcing from international consultation firms reduces the significance of consultation in the development of knowledge networks. For example, when the industry contacts the university to nominate a suitable consultant for their case, this formal contact reduces the chances of establishing sustainable networks with industry. As stated by one interviewee:

We don't really have consultation activities with the industry...they call our office, they come through the official channel. They contact the university... But this is only when there is a problem or something important. Also, we approach them if we seek any request.. But we normally prefer to do it through proper international tendering. It is not that we don't believe in our people, but it is the system that requires the utilisation of best available knowledge from international experience (*HoD Biology, Public University, 2014*).

Similarly, the public sector seeks consultation from academia in some areas. Although consultation is an important route to exchange tacit knowledge, there is no active interaction in this regard. In addition, the public sector and industry's lack of awareness of the research work of academia plays a role. In the cases of consultation work, informal linkages are utilised to initiate the interaction.

#### 6.3.5. Training, exchange programmes, and internships

These interactions that are based on Human Resources (HR) development are very common in academic and non-academic knowledge-producing organisations. The key objective is to develop the skills of students, technicians, and researchers. Informal linkages play a role in these interactions as they facilitate the formal contact. It is very common to have knowledge workers who are participating in different exchange programmes for training purposes. Yet, there are different routes for training, such as sending the trainee directly to the knowledge possessor, or through academic programmes like a PhD. The following examples present

these ways of training, which include both formal or structured learning through academic programmes and other ways of transferring tacit knowledge. One interviewee said:

Let me comment it's like a route of exchanging and transferring knowledge from one institution to another. For example if they are sending their student to you, or new employees, if you are receiving these kind of people and train them for certain time or even you go there and train people. This is the type of interaction in which knowledge can be transferred, and especially the tacit knowledge (*Director of Innovation, Government Department, 2014*).

Another interviewee commented:

Well, two things here. Number one, I know that Sultan Qaboos can train technicians for instance. Let's say that University of Nizwa has a technician... two or three technicians they want to learn more about PCR for example, one technique in molecular biology. They can do training and stuff, so that's one thing. The other thing that is also known is that they accept PhD students from different institution meaning that students from Nizwa University they can do their PhD with Sultan Qaboos University, they will have two monitors to supervise them, one from this institute and the other from the other institution, like core supervision (*Biologist, HEI, 2014*).

Therefore, this type of interaction is not always related to the institutional capabilities and the hierarchical structure of the actors. In most cases, the tacit knowledge possessors can be found in any actor. These interactions are very useful in enhancing future collaborations at organisational level, based on previous experience.

#### 6.3.6. Use of common facilities and exchange of resources

This type of collaboration is very common in non-academic knowledge-producing organisations, where institutional capabilities are lower than in academic organisations. During collaborative research, researchers get access to advanced lab equipment and they are exposed to more technical and tacit knowledge. This type of collaboration is normally initiated informally and then the official contact and request take place. Therefore, researchers who have limited personal contacts in other organisations may hesitate to pursue this collaboration opportunity, as stated by this interviewee.

Does it [collaboration by using common facilities] exist? Yes, it exists. But whether I use it or not, no I don't use it, but I know people use the facility... especially, let's be clearer here, with well-equipped organisations. Only Sultan Qaboos University, the university that has the equipment and the facility and the infrastructure that they can do research

now. The central labs of the [...], they do have almost everything but using those facilities you must go first through long bureaucracy. You know, it's not just as easy as, 'I want to use,' it requires a lot of informal contacts to get the official approval. Many researchers save huge money in their grants by using sophisticated equipment from other labs, so they can use the money for conferences, or training of their technicians... but I have never experienced this, and I've never tried (*Microbiologist, Public University, 2014*).

Some interviewees thought that using common facilities should be the predominant culture to reduce the replication and fragmentation in the bio-sectors' resources. As one interviewee said:

It is the way that should be... what is going now in terms of labs and facilities is not sustainable. The number of researchers and technicians are limited, so there is no point to build labs in every ministry and university. TRC is establishing database of equipment and it will be public so researcher can locate them. And equipment that is purchased via TRC grants is owned by the host institution of PI, but it can be shared by other researchers. This is what is needed so resources can be directed elsewhere, for example HR development (*Director of Research, Government Department, 2014*).

These perspectives reflect the current fragmentation in utilising resources, which focuses on the hard infrastructure. According to the size of the knowledge workers in the bio-sector, the idea of centralising research labs is considered more suitable. The cultural atmosphere that depends upon personal communication prevents actors with few contacts from utilising such facilities. The centralisation of such facilities may enhance the transfer of tacit knowledge, as more interactions will take place.

#### 6.3.7. Community-based collaboration

Community-based collaboration activities in both types of knowledge-producing organisations are limited to certain actors. These activities are mainly linked to personal motivations with no organisational rewards, so there is no clear trend. The activities include training of science teachers, running mobile exhibitions for the public, public lectures or participating in radio and TV programmes. Most of the interviewees from academic-based organisations are not active in this field, as they have a high load of teaching and research. One interviewee said:



Well unless we consider the teaching and research, I do not have any other extra occupation... a volunteer activity or so. The load is very high here, so with a society-based activity like lectures or awareness seminars, No, unfortunately I am not too much involved in that side (*Biology Professor, Public University, 2014*).

However, academics from public and private universities had a common view about the role of awareness in increasing the tendency to study biosciences among school students (male and female). Before the establishment of a biotechnology degree in public and private universities, only female students were attracted to study biosciences. Most male students preferred to study engineering or medicine. The total number of students has increased and the share of male students has improved. Public lectures given to students in high schools and to the public have bettered the perception of the field and its' future employment.

Biology is becoming now popular and students are really attracted to the department. We used to have around 220 to 250 students for the past three years, with an average of thirty five students in each section, but this time we have 370 students... all the sections were full this semester in biology courses. So that's why I'm busy and I'm very happy that it's a big group. Usually girls are attracted towards biology always... but know more male students in biology. Thanks to the awareness lectures, the job fair, and all the visits and presentations (*Industrial Biotechnology Researcher, Public University, 2014*).

In such activities, a lot of preparation and coordination are needed which involve actors from the bio-sector and other sectors. Although these activities are not considered wholly the mandate of knowledge-producing organisations, they add to the individuals' experience who perform them. They are also powerful tools and contribute to the overall marketing of the field of biosciences. In addition, some interviewees thought that community-based activities are more effective in enhancing interactions between actors, especially among 'like-minded' individuals.

#### 6.3.8. Formal versus informal links

After the discussion of the main modes of interaction, it is relevant to consider the role of formal and informal links in facilitating these interactions. As universities develop a dual structural organisation, which supports pursuing both research excellence and research commercialisation at the same time, mechanisms for the transfer of knowledge via

collaboration with local industry are enhanced by providing technical support via formal and informal linkages (Bramwell & Wolfe, 2008; Bekkers & Freitas, 2008; Chang *et al.*, 2009). Knowledge generated during formal interactions can also be transferred via informal networks (Azagra-Carrea *et al.*, 2016).

With most of the interviewees from the academic and non-academic actors, it was a common view that the informal linkages are more influential, not only at the individual level. Members who utilised their professional linkages and contacts formed most of the successful committees and focus groups. The formal route is time-consuming and may result in less effective 'mix' of partners. As indicated by one interviewee:

Absolutely, the informal links are the preferred ones. Unfortunately this is what we are lacking here in the middle east in general is that we don't put formal communication as a serious item and we depend on our friends and contacts... even if you go on the ministry of health website you don't feel that there is a way that you can communicate people. You don't know them, you don't know what they are doing actually unless somebody tells you what they are doing. This is number 1. Number 2, this didn't happen for me but I imagine that it wouldn't be easy to just pop up on people and just say ok hey I want to do research. That's not easy, because unless people know you and you know how to say it, they will not probably take it seriously. So personal communication is crucial here and you know one brings the other you know, and so on (*Biochemistry Researcher, Private University, 2014*).

One researcher, who considered that informal linkages are too risky, in some cases, expressed an additional view. It was interesting to note this perception as the issues of misuse of trust, as well as the impact of an accident in the research labs, were mentioned. For instance, informal linkages can be utilised to use lab equipment and the consequences can be unbearable when the equipment is damaged. This situation also applies when individuals from organisations work in other labs, based on personal connections, to carry out parts of their experiment. The interviewees who talked about these topics recalled their experiences and commented on the limited benefits of informal linkages. They thought that these linkages could be utilised to save time and efforts in searching for compatible partners. However, all the practical steps in any collaborative work have to go through proper formal channels. As noted by one interviewee:

Lab work is the most unpredictable task... accidents can happen even if all safety precautions are taken... the equipment can go down... calibration can be totally wrong... anything might happen. I can allow a colleague to come to my lab unofficially and do certain test, but if anything happen, who will be blamed. If everything comes through official channels, the insurance will cover the costs (*HoD Biotechnology, HEI, 2014*).

The discussion revealed the awareness of informal linkages and the extent of its utilisation in the knowledge-producing process. Within the institutional setting of the bio-sector, it is significant to understand the informal interactions between actors at the individual level. Taking into account the small population of actors, the actual knowledge workers (academics, researchers, research and teaching technicians, and field technicians) are mostly co-workers and previous classmates. However, the informal linkages alone are not practical and instrumental, as there is always a need for official endorsement.

#### 6.4. Network typology and dynamism in bio-sector

After the discussion of the main types of collaboration between the actors, this section presents the network typology by identifying the key collaborators for each actor. As shown in Table 6.4, the highest frequency of collaboration of academic knowledge-producing actors is within the public sector research centres and labs, followed by interaction with other biotechnology related departments within the organisation and across other universities and HEIs. Interestingly, collaboration with the local bio-sector is moderate and it is almost the same as the linkages with regional and international organisations.

**Table 6.4:** The frequency of collaboration of academic-based knowledge-producing organisation with external organisations (%) (N = 32).

	<b>4 On-going collaboration</b>	<b>3</b>	<b>2</b>	<b>1 No collaboration</b>
Other biotechnology/biosciences-related departments within organisations	6.3	59.4	34.3	0.0
Other biotechnology/biosciences-related departments in other universities or HEIs	15.6	56.3	28.1	0.0
Public sector research centers or laboratories	31.3	43.7	25	0.0
Private sector or the industry	6.3	38.1	65.6	0.0
Regional and international organisations	4.1	36.5	59.4	0.0

On the other hand, non-academic knowledge-producing organisations exhibit an interesting pattern of collaboration with external organisations (Table 6.5). The highest frequency is in the work with other biotechnology-related departments within the organisation, followed by collaboration with universities and HEIs. With a high frequency of collaboration, these organisations are interacting with both other public sector centres or labs, and international and regional organisations.

**Figure 6.5:** The percentages of the frequency of collaboration of non-academic knowledge-producing organisations with external organisations (%) (N = 14).

	<b>4 On-going collaboration</b>	<b>3</b>	<b>2</b>	<b>1 No collaboration</b>
Other biotechnology/biosciences-related departments within organisations	42.9	57.1		0.0
Universities and HEIs	64.3	28.6	7.1	0.0
Other public sector laboratories	35.7	50	14.3	0.0
Private sector or the industry	28.6	42.9	28.5	0.0
Regional and international organisations	42.9	42	15.1	0.0

#### 6.4.1. Phases of knowledge networking

Based on the frequency of collaboration and the main types of interaction, the phases of knowledge networking are designed. The interviewees were asked to share their

experiences and stories regarding the initiation and dynamics of knowledge networks with other actors. When this textual data is analysed and compared, distinctive phases can be identified. It was interesting that one interviewee from the academic sector used the analogy of bacterial growth curve to explain the phases of networking with external organisations, as indicated that:

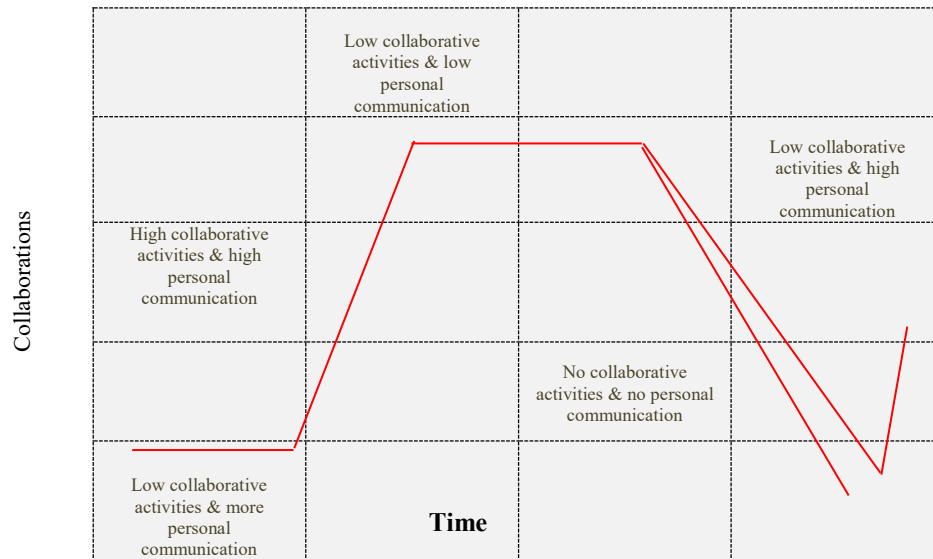
It [the interaction with external stakeholders] is not uniform or has standard momentum... it goes through different shapes.. Or phases; just like the *E.coli* [Escherichia coli bacterium] growth curve. At certain stages, we see frequent collaborations; especially when the stage is related to the interaction with funding agency or other government body. It differs from case to case, in some cases the initial stage is quiet, and in other cases the introductory phase is very dynamic. Generally speaking... there are phases that depend on the nature of research... the type of all stakeholders... the resources... the degree of commitment and of course the leading organisation (*Microbiologist, Public University, 2014*).

When this model was compared against the responses of the interviewees, two or more of the phases were recognised. The formation of networks between the actors seems to be a multi-phase process (Figure 6.4). As described by the interviewees, the phases are shaped by several factors such as the role of informal linkages and the availability of resources. In addition, the cultural dimension plays a role, for example, large organisations with a long history of collaborating with external organisations retain networks after the completion of collaborative work. Small and emerging organisations face some challenges in this regard.

The introductory phase is the characteristic phase of network initiation when the actors first collaborate. This phase can also happen with long-term collaborating partners after a substantial institutional or functional change. According to the interviewees, it is critical to identify the network initiator or builder. The nature and position of the initiator decides the length of the introductory phase. For example, when an influential actor initiates collaboration with a less influential partner, the initial phase is reduced.

In this stage no actual collaboration takes place, rather the actors adjust to the partnership environment and look for the opportunities. Both formal and informal linkages play a role in bringing the actors together. As this stage is the result of the different mechanisms for selecting partners (Section 6.7), the type of selection mode also influences

the length of the initial phase. For example, collaborations, which are based on previous successful engagements, tend to have a shorter lag phase.



**Figure 6.4:** The phases of knowledge networking in the bio-sector (Depicted from interviews data).

In the active phase, more interactions occur and the partners work closely to achieve the objectives of the collaboration. The networks develop between the key actors and more actors from both sides are included in different tasks. As indicated by the interviewees, it is in this phase that both parties expand their personal contacts from the connections of the other party. This indicates the influence of personal relationships and this phase determines the future of the networking process after the stationary phase.

As collaboration becomes *modus operandi* practice, the networking process slows down and enters an inert status, which is the stationary phase. This happens towards the end of a research project or any joint work with multiple actors. The length of this phase depends on the nature of networking process, such as whether it was initiated through formal routes or if more resources can be gained if the network exists. For example, when a follow-up project is suggested, the funding might continue for the benefit of all partners. After this phase, the network either is renewed or declines.

Network renewal or decline phase is the last phase in network formation and it takes either a re-generation or decline status, depending on the nature of the initial networking. A long stationary phase also indicates the ultimate network decline. From the interviewees' point of view, there are several reasons for network disintegration, such as the absence of key actors or the 'network builders' in the case of multiple partners; lack of resources or funding; and unachieved goals or project failure, which tend to increase the distance between actors.

The interviewees thought that currently the rate of network renewal is higher than the decline levels. The knowledge-producing organisations have adapted to the endogenous conditions and more sustainable knowledge networks have emerged, e.g. the partnership between CAMS and the Agricultural and Livestock Research Centres that resulted in several collaboration outputs.

#### 6.4.2. Exchange of knowledge: is it phase-dependent?

As the process of networking exhibits distinctive phases, it was relevant to pursue another level of information, which is the link between these phases and the process of knowledge exchange. The interviewees with long organisational memory tend to talk about their own stories and refer to the frequency of interactions as 'the peak interval' and the 'quiet periods'. By referring to Figure 6.3, the 'log phase' is the peak interval, when actors interact and knowledge is shared and exchanged. This is because the maximum collaborative activities take place in this phase. However, some interviewees thought that during the stationary phase that is the 'quiet periods' more personal contact takes place. These informal interactions facilitate more knowledge exchange, especially the tacit knowledge of individuals, as one interviewee said:

I don't think that the knowledge or the experience that anyone gains over the years can be transferred in a workshop, classroom or lab session. For one reason is that... it's very hard to transfer this knowledge in a linear donor-recipient model ... this type of knowledge can be only transferred through personal contact in collaborative research activities. That's why the linkages are very fundamental in our field. During active research time, we just need to finish the tasks and get things done... But during quite times, knowledge possessors, indirectly, make this knowledge be accessible by the PI

[Principle Investigator], the research team, collaborators from other organisations, and students, of course (*Assistance Dean, Public University, 2014*).

It is clear that the process of knowledge networking goes through different phases, which determine other elements of the collaboration. For example, the exchange of tacit knowledge and the selection of partners. As the bio-sector is relatively small, the phases of networking are considered significant in defining the future of collaborations between actors, i.e. the selection of partners based on previous experience. The position in the networking curve reflects the nature of interaction and the intensity of formal and informal linkages.

## 6.5. Proximity and knowledge networking in the bio-sector

This section discusses proximity is an important element in networking and is inspired by the perspective of clusters research that considers knowledge networks as 'uneven and selective, they are not pervasive and collective', whereas the transmission of knowledge between actors is not necessarily facilitated by geographical co-location (Bell and Zaheer, 2007; Ponds *et al.*, 2010). Yet proximity remains the key driver of tie formation. This thesis follows Boschma's (2005) fivefold classification of geographical, cognitive, social, institutional and organisational proximity. The first type of proximity, which is geographical, was addressed in the questionnaire, whereas the rest were discussed in the face-to face interviews. This classification allows better understanding of the role of proximity on the performance and dynamics of knowledge networks.

### 6.5.1. Geographical proximity

This type of proximity is the most known form and it is related to the co-location of more than one actor, which enhances interaction and tie formation. The Omani bio-sector is geographically dispersed throughout the country, with some agglomeration sites, e.g in Al Rusyal Industrial Estate in Muscat. This site can be viewed as the antecedent for the biotechnology cluster, as it contains all the elements to support the origination of the cluster. It contains many of the bio-sectors' actors, such as the Al Rusyal Industrial Estate, SQU and Waljat College, three private universities, the Innovation Park Muscat, the Knowledge Oasis and other governmental departments and labs.



In the questionnaire, participants were asked to identify their partners within the local area (10 mile), within the region, and with other regions. The responses are 32%, 46%, and 29% respectively, which indicate fair levels of collaboration at all levels. During the interviews, two different views regarding the perception of geographical proximity emerged. The first opinion is the perception of co-location as the key factor to trigger ties formation, whereas the second view considers geographical proximity as a complementary factor. The interviewees with the second opinion were asked to elaborate on other proximity types. In both cases, the interviewees were asked to share their experience or story in support of their ideas.

When the importance of co-location was discussed with the first group, other factors came into the conversation, indicating that geographical proximity cannot be considered as the main trigger. For example, they indicated that informal linkages further enhance tie formation between actors sharing the same location. They also pointed to the role of sharing similar interests and fields of work. Interestingly, these two factors are related to two other types of proximity, which are cognitive and social. Therefore, the location factor alone was not sufficient to sustain networking between actors. For instance, one interviewee commented on neighbour organisations that organised a workshop and did not inform other actors or invite them. These workshops are not related directly to the core business but they were in the same field of biosciences.

We have not been contacted, or invited to participate... you know our culture, if you don't know them personally, official things go slowly. We are here in the same place and we came to know from others through personal communication. I think being in the same location is not necessarily beneficial (*HoD Biotechnology, Private University, 2014*).

In essence, biotechnology firms, which depend on external individual scientific collaborations, are expected to grow closer to the innovation (Hohberger *et al.*, 2015) in order to get access to knowledge and resources. Previous research has emphasised the role of co-location (Agrawal & Cockburn, 2003), and spatially mediated knowledge transfer from university research to firms by retrieving localised knowledge spillovers, especially when linked to the presence of science parks (Abramovsky and Simpson, 2011). However, the findings here indicate that the social context of the actors in the bio-sector plays a major role in diminishing the advantage of co-location. The interviewees discussed the topic by comparing their

experiences internationally and concluded that the limited advantages of geographical proximity can be due to the endogenous culture. Most actors are cautious and reactive when it comes to establishing new linkages and sharing. The small size of the bio-sector makes it theoretically easier for actors to interact when they are located in the same local area. However, the cultural factors reflect the underlying reason for the inadequacy of co-location to enhance interactions and the selection for long-distance collaborations. In literature, long-distance interactions occur at firms' level for obtaining high absorptive capacity and in the absence of high-quality local universities (Garcia, 2016).

### 6.5.2. Cognitive proximity

This type of proximity was found in the knowledge networks of the Agricultural and Livestock Research Centres, as they share the same 'knowledge base' (Nooteboom, 1999). The interviewees emphasised the importance of working within a community of practise regardless of the geographical location. These public research centres collaborate with their partners in Oman and within the Middle East region. They consider the co-location as an 'added value' that can promote more collaboration. As one interviewee stated:

Well proximity is just an added value, we don't need to be in the same place to work together.. And in our case, the most successful collaboration is with an international centre which we called ICRDA, which is the International Centre for agriculture research in dry areas. We have started with the collaboration with this centre in 2000. Of course late nineties, but that collaboration was strengthened in 2002 and we have managed with them and through them to introduce and develop and improve the... what they call the soil-less technique for growing vegetable crops. They are called soil-less techniques for growing vegetable crops in greenhouses (*Director of Public Research Centre, 2014*).

Locally, the research centres work closely with SQU and their collaborations result in different outputs, for example, co-publication, joint research and joint committees. In addition, several researcher movements are from these centres to the academic sector and other governmental bodies. The centres collaborate with regional organisations and research centres. The interviewees consider this collaboration as an example of 'fruitful networking' for learning, especially in the area of laboratory techniques and management of research funding. This is consistent with previous work where geographical proximity to particular knowledge sources is important for learning and innovation, as described in literature on industrial clusters (Fritsch and Slavtchev, 2007; Giuliani, 2007).

It is only the case of agricultural research centres, which is compatible with the concept of cognitive proximity. Other knowledge-producing organisations, e.g. SQU or private universities, did not consider this type of proximity. With the academic sector, the collaboration with regional or international organisations is limited and is done through the International Relations Department. The universities are working with other actors based on the cognitive proximity but in a 'salient mode', as one participant commented. Normally the academics connect with other organisations that are working in the same field and they exchange ideas. However, the hierarchical structure of the actors imposes obstacles on such collaboration. Academics are maintaining their position at the top of knowledge-producing actors, regardless of the cognitive proximity situation. Therefore, they utilise the ideas from other actors and get access to tacit knowledge possessors. The actors in academia and industry pioneered the 'open innovation' perspective by enhancing linkages with other actors. This is similar to the historical performance of the biotechnology industry as suggested by Cooke (2005), who argues that biotechnology purely leads the 'open innovation' to overcome intra-firm knowledge asymmetries, the case that is emulated by other industries.

### 6.5.3. Social proximity

All interviewees considered this type as a significant dimension of proximity, indicating the importance of the informal linkages between actors (Uzzi, 1996), e.g. following a previous successful collaboration (Breschi and Lissoni, 2009). As discussed in section 6.3.8, the informal linkages play a major role in the establishment of knowledge networks at the inter-organisational and cross-institutional levels. Taking into consideration the small size of the bio-sector, individual researchers, public, and private sectors' workers are mostly associated with personal relationships.

The interviewees thought that the informal relations are an essential element to trigger network formation in addition to the geographical location. They gave examples of the importance of personal relations in simple tasks that can be done directly through formal channels, e.g. invitation to participate in workshop. Due to this situation, the researchers normally tend to introduce new members in the research team to their contacts to save time

and effort during research activities. This tendency, in turn, adds to the 'saturation status' of the actors, when research teams are working with the same partners for a long time in different research projects.

#### 6.5.4. Institutional proximity

Institutional proximity of the actors in bio-sector is indicated in two aspects. The knowledge-producing actors work under regular rules and incentives and function in the same social subsystem (Etzkowitz and Leydesdorff, 2000; Ponds et al., 2007) of the three institutional spheres. Accordingly, there is a shared knowledge regarding the standards of biosafety and bio-ethical dimension of research. As well, the actors are co-located in the same country (Gertler, 1995; Hoekman et al., 2009), which indicates the second aspect of the institutional proximity.

However, the interviewees expressed their view on the institutional proximity as a pre-established fact that does not practically bring actors together. This type of proximity applies to knowledge-producing organisations in the academia and the public sector, whereas the private sector is not very involved. In addition, collaboration of actors from the three spheres with international actors from the international biotechnology industry is limited. Therefore, in the absence of influential international actors, there is no direct advantage the institutional proximity. Besides that, the three institutional spheres are not performing with symmetrical contribution in knowledge-production processes, so institutional proximity is low, as they are not operating in the same social sub-systems.

#### 6.5.5. Organisational proximity

About the organisational proximity, several examples were found, as in the cases of the CoS and CAMS of SQU and the six public research centres of the MoAFW. The interviewees discussed inter-departmental collaborations from different points of view. The first view was the lack of collaboration in most cases, regardless of the fact of belonging to the same organisation. The second opinion was about the perception of most individuals about the outcome of such collaboration.

The participants thought that inter-organisational linkages could be more practical, in some cases, compared to the inter-departmental collaborations. They discussed the bureaucratic procedures, which require formal routes, especially when computerised systems are in use. Furthermore, the organisational culture and style of management plays a role in organisational proximity, as one interviewee compared working efficiencies under two different managements:

... And it really depends on the management... the current [...] encourages mingling of departments and collaboration. So we started to work closely with others with less admin obstacles. I don't think it is up to individual's choices, the culture and management figure this practice. Previously, we faced a lot of difficulties to work to other technicians from other departments (*Research Technician, Public University, 2014*).

However, some interviewees have an interesting perception about organisational proximity, which does not consider it as a fruitful form of collaboration. This because of the way they interpret the internal organisational knowledge. It seems that low organisational proximity can be partly due to the individual avoidance to operate with partners from the same organisation. Therefore, organisational proximity in the bio-sector is high when there is more encouragement from the top management and more acceptance of it at the individuals' level. These views are indicated by the limited role of geographic and organisational proximity in the selection of collaborators, which is in line with other studies. For instance, in a study of knowledge-intensive business service firms in rural locations, by Johnston and Huggins (2016), the findings indicated that the formation of university–industry links is the result not only of spatial factors but also of prior experience of collaboration.

#### 6.5.6. Proximity and network convergence

In order to examine the role of different types of proximity on network convergence, the interviewees were asked to comment on the role of the proximity in specific modes of interactions. Three types of collaboration were considered here: the national joint-committees that represent a centrally organised process; consultation and problem solving which represents a highly divided task; and participation in different research teams for joint

research that represents an underlying competitive relationship. The rest of the interaction modes are less linked to proximity.

Participation in national joint-committees involves several partners and the process is organised by a single actor, which is the host organisation. Co-location and other types of proximity, such as social relationships, increase the interaction between committee members outside of the main task. The formal meeting of the committee always occur in the same place, so there is no role for geographical proximity. However, other types of proximity can be considered instrumental to enhance actors' collaboration and network convergence.

The interviewees thought that when they collaborate with other actors in a centrally organised task more interactions are enhanced. This is partly because most of the administrative and management tasks are not the responsibility of the members, so there is no extra load on them. In addition, the outcomes of such collaboration are shared between all the members, so there is no risk of being responsible for 'un-achieved goals'. These elements allow members to explore other opportunities for collaboration and strengthen existing networks.

The interviewees expressed different views about the second type of collaboration, which is problem solving. There was a common view about the role of proximity when the actors are involved in a highly divided activity. As the task is divided between different actors, and all of them are contributing to the main body. This type is slightly different from the joint committees, as the task is performed in different places (research labs, public research centres, etc.). The interviewees thought that proximity plays a role in such tasks, as actors can benefit from co-location, and this in turn increases network convergence. However, some interviewees thought that when the tasks are divided between the actors, geography has a limited role. Therefore, these tasks put more distance between actors, regardless of the geographical proximity.

Finally, the role of participation in different research teams for joint research was considered as an example of competitive tasks, where actors are competing for the same resources, i.e. funding. As the biotechnology community is small, researchers participate in

different research teams. For example, a co-PI in one research project can be the PI of another project, so there is an underlying competition for funding. Interestingly, these actors can have more than one form of proximity. In this regard, the interviewees had a common view, which reflected the limited role of proximity in network convergence. The collaborative elements are 'masked' by competition, as the funding sources become a limited resource, but shared between multiple actors. This situation puts more distance between the actors and reduces network convergence. Therefore, these findings confirm, on the one hand, that cognitive and organisational proximity are equally important for knowledge-producing actors; and the idea that social, organisational and institutional proximity can contribute to the development of effective interactions between actors (Oinas and Malecki, 2002). On the other hand, geographical proximity is not a prerequisite for effective knowledge interaction between the actors (Ratinho and Henriques, 2011).

## 6.6. The role of intermediary actors

It was significant to shed light on the role of intermediaries in the interfaces between the three institutional spheres. In the questionnaire, participants were asked to comment on the frequency of utilising intermediary organisations or individuals as a facilitator for establishing networks or any other activities related to commercialisation. Most of the responses show that researchers use TRC as their key intermediary organisation, in addition to its role as the main funding agency (Table 6.6). Following TRC, the Chamber of Industry and Commerce and the Industrial Innovation Centre are most frequently used, use of the Industrial Estates was moderate, and TTO does not seem to be used as a key intermediary actor. Personal and informal means are the least frequently used.

These outcomes reflect the influence of actors' typology (chapter 5) as the academia and the government are the key players, with limited role of the industry and the private sector. Therefore, the frequency of using different intermediaries by the knowledge-producing organisations is unsymmetrical and mostly for funding purpose as both network builder and additional source of information about other actors. All the responses indicated TRC as an intermediary actor, but at various ranges. Some intermediary actors, such as TRC, are interacting more closely with knowledge producers. Furthermore, the total number of

intermediaries in the bio-sector is limited, and the diversity is low. Currently, all the intermediaries are either units within an organisation, e.g. TTOs, or separate government organisations, e.g. TRC. The distribution of these intermediary units and organisations is not balanced in the interfaces between the three institutional spheres. This effect is further deepened by the absence of the private sector and non-governmental organisations (NGOs) in the boundary spanning.

**Table 6.6:** The percentages of frequency of response of knowledge-producing organisations, with regard to the use of intermediaries for collaboration.

Intermediary organisation	Always (%)	Very likely (%)	Moderately likely (%)	If opportunity permits (%)	Never (%)
The Research Council	6.3	56.3	28.1	9.3	
Chamber of Commerce and Industry		31.2	25	40.6	3.2
The Industrial Estates	3.2	21.8	40.6	28.1	6.3
The Innovation Centre		31.2	25	34.4	9.4
Technology Transfer Office (TTO)		18.8	37.5	31.2	12.5
Other means (Personal communication)			50	34.4	15.6

However, regardless of the high frequency in using TRC as the main intermediary organisation, researchers expressed different views regarding its role. Researchers thought that some roles are not yet carried out by TRC, either because of the non-readiness or because they are not its mandate, making it challenging to consider TRC as an intermediary organisation. As one interviewee said:

I think actually the main intermediate organisation between us and the government or the private sector is TRC... they are trying to facilitate this point... for example they are trying to put this database [the Researchers' Directory] for researchers and so that whenever I have an idea and I look for collaboration I search and it gives me the type of people who are interested in doing the same work. But I don't know how complete that database is? I haven't used it, but I know they are doing... they are asking people to put their information for this specific purpose (*HoD Biotechnology, Private University, 2014*).

In parallel vein, another interviewee commented:



I don't think they are really doing programmes to boost these collaborations... you know we can't consider them as that [intermediate organisation] right now... but absolutely, I work with the funding and support of TRC... like conferences, and open research grants (*Microbiologist, Public University, 2014*).

When the interviewees were asked to identify the 'intermediary actor', which can facilitate the interactions between the three institutional helixes and promote the commercialisation process, interesting responses were recorded. The common view was that governmental bodies (existing or to be formed) can play an effective role, when less administrative and bureaucratic burden are assured. As indicated by one interviewee:

If you ask for my opinion, I would obviously say the ministries; if bureaucracy is reduced... they have the power and facilities...so the ministries can be good intermediate organisations. Ministry of Higher Education can play this role generally, or with the help of specific ministries like the Ministry of Oil and Gas... they can do the same thing with companies and SQU...the Ministry of Health can bring together the academia and the pharmaceutical companies or with the university hospital, and so on (*Biotechnology Researcher, Private University, 2014*).

Other interviewees expressed the importance of shifting the role of knowledge intermediation to individuals or non-for-profit organisations. For example, one interviewee suggested:

Anyone other than the government... Anyone can be a good intermediary between the academia and other sectors... Companies, business associations, social societies, even wealthy individuals, or 'recombinant' of some of these bodies... If they have the passion for research and technology, they can fill the gap... It will be under the category of 'Waqf' [Charity], wealthy people put a lot of waqf for non-scientific activities which are not really at the priority list.. they can better directed to support uptake of young researchers and supporting spinouts. So I think anybody that has money and the passion to support research, can act as 'brokers' between the industry and the academia (*Former Dean of Research, Private University, 2014*).

These diverse responses reflect a fair level of awareness among researchers. Although the government was considered as the suitable actor to play the role of intermediary, the interviewees talked about the bureaucratic burdens. The view about non-governmental actors was more practical as the private sector is small and there is a need to activate their role by using intermediaries from their side. It is interesting to note

the view of enhancing wealthy individuals to act as knowledge brokers between academics and industry.

### 6.7. Mechanisms for selection of partners

The analysis of the mechanisms for selecting partners contributes to understanding of network transformation and the role of both network resources and the cultural features of the actors in the bio-sector. The questionnaire asked to specify how helpful the parameters for selecting partners are, via 4-scale multiple-choice questions (Table 6.7). In the interviews, participants were asked to identify the means of selecting collaborators during different stages of knowledge production. They were asked to share their experience and recall the way of commencing the linkages with potential partners in both one-to-one engagements and multi-actor projects.

**Table 6.7:** The percentages of frequency of response for knowledge-producing organisations, with regard to the modes of selecting partners for collaboration (N = 46).

Q: How helpful do you think these factors in the selection of collaborators	Extremely helpful	Significantly helpful	Partially helpful	No help
Sharing interest, e.g. availability of funds (from the public sector & industry)	30	8	6	2
Availability of compatible partners	36	9	1	0
Access to physical infrastructures (research labs, incubators, technology parks)	12	22	9	3
Access to information and tacit knowledge	15	21	10	0
Organisational logistics (mentoring, networking, and outreach)	26	14	6	0
Culture & mind-set	4	31	8	3
Previous engagement (trust & interdependence)	19	11	9	7

As shown in Table 6.7, the highest percentage of responses was for the 'availability of compatible partners' followed by 'availability of funds' and 'organisational logistics'. 'Previous experience' was moderately considered, as well as 'physical structure'. The parameter of culture and mind set was considered significant. These responses reflect the issue of entrepreneurial capabilities of the actors, as the main driver for collaboration is the quest for shared resources (skilled HR, funding, and other logistics).

In order to study the mechanisms for selecting collaborators in bio-based knowledge networks, it was important to consider the key modes of linkages, which include the following: joint committees; consultancy; training; co-authorship, collaborative research and use of equipment. These types of interactions reflect both the formal and informal routes. Several assumptions were taken into consideration when this topic was discussed; firstly, the diversity of actors in the three institutional spheres together with the small population of academics and researchers. The second assumption is the low reliance of the industry on university research. Equally important is the ecosystem in which these knowledge networks develop and perform, including the dominant culture in the public sector and the national policy framework for research and innovation in the bio-sector.

The interviewees expressed a variety of perspectives, as they suggested the selection mechanisms and the rationale of adopting such approaches. Some participants indicated that there is little role for selecting partners in formal linkages, such as in joint committees where members are officially selected. Similarly, other interviewees reported the influence of intermediary actors, for instance the funding agency. A recurrent theme in the interviews was a sense amongst interviewees that common interest, previous experience and trust are the key determinants for selecting partners. Interestingly, some interviewees suggested an additional topic related to the role of other components in the existing networks, such as research topic or certain individuals. This issue was particularly prominent among the participants with long work experience and organisational memory. Therefore, five selection mechanisms emerged from the analysis: pre-determined; influence of intermediary actors; interest-related; trust-based method; and the 'reversible' selections.

Within knowledge networks, prior studies have noted the importance of knowledge-based factors (market-related as well as science-related) that drive composition choices of partnership for commercialisation (e.g. Belderbos, *et al.*, 2004<sup>a</sup>; Belderbos, *et al.*, 2004<sup>b</sup>; Bercovitz and Feldman, 2007; Bercovitz and Feldman, 2011). The present study is designed to explore the mechanisms for selecting collaborators and the drivers for such selection. The five mechanisms indicated in the previous paragraph match those observed in earlier

studies. As indicated in the coming sections, this analysis highlights the drivers of each mechanism and the role of organisational culture in the bio-sector.

### 6.7.1. The pre-determined partnership

The term pre-determined indicates the mechanisms for developing knowledge networks that result from a prior selection of actors by an authoritative body. It is the most common type of interaction in the public sector, e.g. the joint committees. In such committees, the members are selected and invited officially to participate in specific tasks. The role of each actor is decided, and the task has a time limit. Depending on the nature of the task, a follow-up committee can be formed for the implementation stage.

Participation in joint committees is very common among the actors of the bio-sector, including the academic staff. The most common purposes of these committees are: problem solving; formulation of national policies and strategies; and educational objectives, i.e. training or curriculum development. The committee members are diverse and represent two or three institutional spheres. Once the meetings take place, the members interact in smaller sub-committees or focus groups. Most of the future collaborations between the members are mainly shaped by the success of these interactions, as one interviewee stated:

At the beginning we meet different people.. People we did not select them. We work together and after that we can decide whether to collaborate further or not. I think these committees are very useful to explore potential partners (*Biotechnology Professor, Public University, 2014*).

Therefore, this experience enables them to decide and select their partners in other forms of interaction, especially in one-to-one engagements. The committee, basically, commences the formation of professional networks among the members, whereas the members benefit from the interaction with new mix of people in the field, as well as the stakeholders. Such partnership can be instrumental in the formation of knowledge networks in specific developmental stages for individuals and organisations. Some participants thought that membership of joint committees can be useful during both the early and advanced career stages, especially with academics and researchers. At the early stage, an

individual needs to explore his peers in the field and to establish contacts from other institutional spheres.

I gained a lot from them [the joint committees] at the beginning, when I came back from my PhD... At that time, it was useful to know who is doing what in the field. But with time, they became a burden with all this teaching and administrative loads. But I still maintain fair presence in national committees (*HoD of Applied Sciences, HEI, 2014*).

Some interviewees thought that this benefit can be also at the organisational level, e.g. participation in national committees allows newly formed organisations to introduce their presence in the sector and make other actors aware of their mission and objectives. When the new organisation was formerly a part of an established organisation, more awareness is required regarding the roles and responsibilities of the new organisation. One interviewee commented on the advantage of the presence of experienced members in these committees:

It really depends on the members. I mean if you meet the 'right mix' of people.. the committee has to include well experienced members so that the new comers can benefit from their experience and contacts. They can introduce you to key people from their networks. So you don't only communicate with the committee members, but from resourceful people outside the committee (*Director of Regional Organisation, 2014*).

Interestingly, some participants thought that the networks, which resulted from the participation in national committees, are more sustainable. As the partners came to work together under the umbrella of the public sector, it reflects high credibility and trust develops swiftly that enhance rapid future collaboration. Furthermore, they considered these networks as 'organised networks', compared to other types of linkages that are based on informal contacts. This this perception has the advantage of high commitment from members as the collaboration commences in an official setting. It seems to be a common awareness that is gained among co-members, so they tend to pool resources and work together even beyond the original task.

On the other hand, some interviewees argued that the advantage of joint committees is limited due to the 'status of saturation' which prevails in most of the public sector's committees. Some interviewees used this term to describe the situation of members who

already know each other and continue to utilise existing networks to perform shared activities. As one interviewee said:

I don't really see these committees as facilitators for future collaborations... in most cases, the selection of members is based on the professional networks of the Chair, or they contact the well-known individuals, so other good people are overlooked. And in the sector the same individuals are found in different committees. In our scientific language it is a 'status of saturation', the same people are in every technical committee in the sector (*Senior lecturer, HEI, 2014*).

Accordingly, two key issues emerged, which are the indirect means of national committees in selecting partners and its role in the expansion of knowledge networks; and the limitation of this role. In the absence of most modes of interaction between the actors, the joint committees provide a platform for actors to communicate and decide thereafter on future collaboration, specifically in one-to-one-engagement. At both the individual and organisational levels, the participation in national committees offers more opportunities to cooperate, which has a positive impact in the formation and expansion of knowledge networks.

However, this role is limited by the saturation factor, which is a characteristic feature exhibited by the bio-sector. The small population of actors and the practice of selecting members in the public sector contributed to the saturation status. Hence, it can be assumed that the benefits from the participation of such committees are limited to members at early career stage and newly formed organisations.

#### 6.7.2. Influence of intermediary actors

This mechanism is similar to the pre-determined means, as the type of collaborator is decided by formal procedure. The main influential intermediary actor in the bio-sector is the funding agency; TRC that encourages inter-organisational collaborations, so opportunities for securing funds are related to the degree of collaboration under the term interdisciplinary research. In order to fulfil this criterion, the PI identifies potential collaborators and contacts them prior to the submission of a research proposal. The roles of such collaborators are identified in the proposal, despite the fact that in practice these roles might differ.

Furthermore, the tendency to support interdisciplinary research is also found within one organisation through internal grants. Researchers became more interested in identifying potential partners, so informal linkages dominate this selection. This is because the resources in TRC and academic actors are not helpful to guide researchers in selecting partners. For example, one interviewee commented on his experience with a program in TRC called 'the Researcher Directory'. This program allows a person to search a database of individual researchers and research equipment in all academic and research organisations in Oman. It seems that researchers are looking for other than the informal links for selecting partners for collaborative research.

I did not use it. I don't think the program is working.. I mean the database is not searchable yet.. One thing is... it's not doing the database, it's about the people using it, you know. So unless they have the awareness programmes about this database and unless people started to use it we can say that they are playing their role.... Connect researchers and bring them together (*Biologist, HEI, 2014*).

In a parallel vein, The Research Centres of the MAFW organises an annual forum to exhibit the research activities of their research centres. In the forum, most of the governmental bodies and actors from other institutional spheres are invited. This event offers an opportunity to meet with researchers from different fields in the bio-sector. Hence, it can be utilised to identify potential partners outside the researcher's own network.

We have organised a national conference last year for this purpose. It was funded by three stakeholders which are FAO, SQU, and TRC and all the partners and stakeholders were invited to that conference and this is where we present, and we discuss. It's a platform for all of us, so we meet each other, as you said about the motivation for interaction, it's there. People are meeting each other, exchanging their expertise; they are getting to know each other. They sometimes get the opportunity to sit together away from the sessions and talk about the future collaboration. How can they write a proposal, submit it to the donors, how can they implement, how can they... this what we call informal meetings. Until they come to an agreement. Once they have agreed, they either write to the others or others write to us and we start to take the formal interaction for such a kind of collaboration so that's an added value for such a thing like this (*Senior Official, Government Department, 2014*).

Although there are other intermediary organisations that support multi-actor research and innovation activities, yet, funding organisations are the most influential actor. Similar to the pre-determined mode of partnership, the collaboration here is determined by the

regulation of the funding body. Any future link depends on the outcomes of the first engagement, especially when partners are not from a personal network. Taking into account the small bio-sector community, this type is also subjected to the 'saturation status'.

### 6.7.3. Interest-related selection

As research activities in the bio-sector are diverse and costly, research work requires different expertise such as fieldwork and collection of specimens, laboratory analysis, and biological data interpretation. It is very uncommon for one actor to have all the elements: equipment, chemicals, skilled technicians and knowledge. Therefore, different actors come together because of shared interest and this type is the most prevalent means of selecting partners in the bio-sector. It is well established in most modes of actor's interactions, including co-authorship, use of equipment, sharing resources, consultation, training, internships and secondment schemes.

This mode of selecting partners is essentially based on informal contact prior to formal engagement. Interestingly, informal linkages play a limited role once the collaborative work becomes established, as the partnership turns to be path dependent. For example, the Research Centres of the MAFW is best described as a 'strategic alliance' to the College of Agricultural and Marine Sciences. The first generation of biosciences researchers and technical staff initiated collaboration. The current research teams continue to collaborate without the need for informal linkages.

The dominant actor leads the engagement, suggesting a mutual but non-symmetric dependence. This pattern might change throughout the engagement time, which results in different status, depending in the development of actors' capabilities, i.e. research facilities, skills and tacit knowledge. These factors shape the two main elements of this selection mechanism that are trust and interdependence, rendering the engagement close to an equilibrium status. For instance, Research Centres of the MAFW and the CAMS of SQU started their partnership in biotechnology research from the mid-1990s. At the beginning, this engagement was non-symmetrical and was based mainly on informal linkages. As these research centres developed in facilities, HR skills and knowledge, the inter-dependence



increased and trust is developed as the relationship became deepened. As one interviewee said:

... And as you know that the Director General of Agricultural and Livestock Research is the biggest organisation for the applied bio-research in the whole country and this organisation is actually active and involved with different stakeholders. I mean if we go back to the history, since the nineties.. Well it was established quite earlier, probably mid-eighties.. The Ministry has managed to scale up this organisation, and then the growth of all the infrastructure, the capacity building of our staff, R&D facilities, our linkages with regional and international organisations.. All of these changes.. So in conclusion I would say the nature of interactions has changed. We can offer 'in-kind contribution' to academics; I think we are in a better situation right now (*Director of Public Research centre, 2014*).

Therefore, the development of entrepreneurial capabilities in one actor determines the dynamics of the selection of partners within the knowledge networks. In the absence of strong industrial receptor who can take the role of exploiting research results commercially, research partnerships take place mostly between the academic and the public sector. These partnerships pursue either exploratory research derived by researchers' interest or research that contributes to the development of public policy. The 'in-kind contribution' is the main share of the public sector, providing access to facilities (e.g. lab equipment), services (field technicians for samples collection), as well as the expertise of research workers. A common view amongst the interviewees from both academia and the public sector was that in-kind contribution is the most favourable input to a research partnership. This is because this contribution is equivalent to some tangible elements that could have utilised part of the fund. Thereby, the sharing of facilities and expertise builds-up the relationship and increases the probability of future partnership, e.g. follow-up research or implementation of outcomes.

#### 6.7.4. The impact of previous collaboration

Talking about the selection of partners, issues relating to interdependence and trust were particularly prominent in the interview data. Although all of the selection mechanisms depend primarily on trust, some interviewees indicated that trust is a central element that is hidden by other network components. For example, consultancy and co-authorship interactions depend on the previous experience of the two parties. Although the decision to work together with a previous partner depends solely on the outcomes of the first

engagement, the interviewees thought that it is the trust between actors, which shapes the decision, not the success or the failure of the first experience. One interviewee commented as follows.

.. and after the [...] project, I have never been contacted. I don't feel it was a real team work.. I don't think we developed 'satisfactory' level of trust and commitment...actually I did not know how far they will stay committed to the original goals of the project.. So it is about trust not the outcomes of the collaboration... I know cases of teams with history of missing deadlines and low achievements, but they are still collaborating (*Plant Genetics Expert, Public Research Centre, 2014*).

With the same line of thinking, other interviewees considered a limited impact of the first engagement, if any. They expressed the view of separating the cases, as most collaboration is based on the 'availability' of potential partners. Also, they thought that lack of trust is normally linked to the individuals managing the project, e.g. PI, Committee Chair, etc. For example, one interviewee commented on the role of previous experience at the individual level:

I don't think that the previous collaboration has a huge impact at the individual level... because we cannot blame one person for the failure of a whole project or any type of scientific work. Of course we all like to be part of successful projects...so it depends on the individual role in the previous project. I tend to agree that we cannot trust those at the management level again when a project fails to deliver good results. But I don't mind to partnership with other members based on their expertise and skills (*Biology professor, Public University, 2014*).

Taking into account that the total number of knowledge-producing actors is limited, the hierarchical structure of actors with SQU at the top has shaped the behaviour of knowledge production processes. Although it can be part of a learning process, there is a tendency to 'mimic' the top organisation, particularly among the young ones, resulting in low diversity. Therefore, during the process of knowledge production the interactions within one sphere and among the three spheres share similar cultures of practice. As one interviewee commented:

Well... you know biotechnology is still a new area of research here.. So it is important to remember that we cannot be very selective... we normally work with 'available' partners. Sometimes the other researcher is excellent in his field and I need his input

even if there is a history of no good achievements. It is more convenient to take it on a case-by-case basis (*HoD Biotechnology, Public HEI, 2014*).

Therefore, the previous experience has its limitation in the selection of partners. For example, the membership of SQU in national committees is a regular practice, regardless of the outcomes of the previous involvement of SQU. Similarly, private universities and other HEIs seek collaboration with well-established organisations, e.g. in the form of use of equipment, training and co-publication. Consequently, the inter-organisational links do not seem to be affected heavily by the previous experience throughout the process of knowledge production. Especially in one-to-one engagements, knowledge possessor maintain uni-directional pattern with knowledge recipient parties, suggesting consecutive selections of similar partners.

#### 6.7.5. The 'reversible selection'

The 'reversible selection' is the last mechanism for selecting partners and it was mentioned by some interviewee to highlight the role of other collaboration components such as time, type of knowledge, and cultural issues. At different stages of network evolution, these factors become significant and determine how actors interact, which is beyond the selection of collaborating partners. In a similar line of thinking, Padgett and Powell (2012) presented the link of actors and the network with reference to time. They stated that 'in the short run, actors create relations; in the long run, relations create actors' (Padgett and Powell, p. 3, 2012).

At the idiosyncratic phase of the bio-sector, most academic researchers were expatriates who managed to set up the first linkages of the university with external organisations. These linkages evolved and more actors were involved. For example, academics from the fields of ecology and environmental sciences worked closely with Petroleum Development Oman (PDO), the Ministry of Environment and the Ministry of Water Resources. These actors changed throughout the study time and many informal networks disintegrated. Yet, interaction between the actors continues to take place, resulting in different outcomes, such as joint publications, employment of graduates, and consultation.

At both the individual and organisational levels, the established knowledge networks in certain fields exert a selective pressure on the actors. More collaborative works are found in well-known networks. In addition, other linkages and interactions have adapted to perform in such a way that is similar to the established ones. For example, the MEOR research unit is working with an important stakeholder, which is the oil sector. The unit is relatively new and consists of many stakeholders. Yet, the unit is considered as a success story in the sector.

We worked with SQU since mid-1990s.. We worked together in both field-based and lab-based research. In fact, one of labs in the Centre [the Centre for Food and Environment Laboratories] was designed by SQU professor. Most of the team are now in the MEOR research and it is performing very well. It is with the oil sector so when relations are well established. There is no longer selection for partnership (Senior Official, Government Department, 2014).

Another interviewee said:

In any project, a part should be done through official contact... I mean we have no selection over that.. For other parts, we try to get access to people or organisation with the tacit knowledge and experience, and they are limited in our field... so sometimes the topic of research selects for the partners... and also here we have no selection over that. And this is what I meant when I said we need to increase the pool of knowledge so we can have the options for selection. In the current situation, we don't select partners literally (Epidemiologist, Public Research Centre, 2014).

In addition to the type of existing network and the topic of research project, cultural issues influence mechanisms for selection. For example, it is a common practice to include female researchers in joint work or committees. It is a culture within the institutional setting which encourages equal participation of both genders. However, the total numbers and ratios of female and male workers in the bio-sector are not uniform to allow fair representation of both genders. At the individual level, some invitations for collaboration are done according to these considerations, indicating the role of cultural values within the institutional setting.

#### 6.7.6. Network transformation and selection mechanisms

As discussed in chapter 5, the sector witnessed changes that had an impact on the network dynamic and resulted in continuous network transformation. Such status, in turn, has affected the selection mechanisms in three ways: the preference for formal contact; the learning process; and the perception of partners. When a change is first introduced to the

sector, a lag phase begins where actors adjust to absorb the new situation. It was a common view among the interviewees that when a new organisation is formed, actors tend to follow formal contact for a certain period. After this introductory phase, formal and informal linkages emerge and go through the different phases of network development. Most of the new networks were re-established from previous linkages, taking the advantage of previous experience and proven trust. Therefore, the trust-based mode of selecting partners plays a central role when changes at the macro-level cause transformation of networks.

Although, in the bio-sector there are several examples of established networks that proved to be fruitful, and are viewed by other actors as sources of learning. Yet, the dynamics of the sector had an impact on the learning process as new actors emerge and some actors are replaced. The changes normally alter the behaviour of knowledge-producing organisations, and the 'availability' of skills and tacit knowledge of individuals. According to the hierarchical structure of actors, SQU remains the main source of knowledge and experience in the bio-sector. However, one of the private colleges (Waljat College for Applied Sciences) had introduced the biotechnology degree under the Engineering School, which is different from SQU. This change was not noticeable at the beginning and as the graduates started to join the local job market, more attention was directed to the college.

In addition, although the colleges' graduates are of high technical and theoretical quality, most of the positive impression was due to the general perception of the 'engineering flavour' in the degree (Personal communication with Biotechnologist, Private College). Even with SQU, the biotechnology graduates from Waljat College are preferred. Currently, the Waljat College by itself is considered as a source of learning for newly formed organisations. It does not seem that the college replaces the previous actors, yet the emergence of a successful actor encourages other actors into partnership. The mechanisms for selection and the rationale for collaboration change totally. This example reflects how the changes in the learning process affected knowledge networking and the selection of partners.

Finally, any institutional or functional change alters the availability of experienced staff. When two organisations are merged, the possibility of losing skilled personnel is high, and consequently informal networking is affected. For example, when the Ministry of Water

Resources was merged with the Ministry of Regional Municipalities in 2001, most of the skilled engineers, hydrologists, and laboratory personnel left the public sector for the oil industry (Personal communication with HR department in the Ministry of Regional Municipalities and Water Resources). Interestingly, when two public sector organisations are merged or divided, the technical staffs tend to leave for another institutional sphere, which affects the 'availability' of tacit knowledge possessors. This in turn affects the selection mechanisms.

Finally, the transformation of knowledge networks makes it challenging to identify 'right partners', in cases of network transformation due to considerable changes such as institutional or functional change. Such changes may result in a merging of two organisations, for example, and consequently inter-organisational networks disintegrate. New partners are to be replaced, especially when the functions of the former partner were shifted to a new organisation. For example, the Ministry of Agriculture and Fisheries Wealth was divided into two ministries in 2007. Therefore, academics who were collaborating with the Directorate General of Agriculture found themselves collaborating with a Ministry of Agriculture, after the Royal Decree, as one interviewee stated:

It is not a simple equation.. With these rapid changes, there is no clear definition of the 'right partners'. In scientific work we have to partnership to get thing done. So it is rather an endeavour to find 'complementary partners'... It is sometimes confusing.. We work with our partners at the Directorate General and after the Royal Decree they became a separate Ministry...And it does not always turn positive to the partnership (*Microbiologist, Public University, 2014*).

Therefore, selection mechanisms, which are usually based on shared interest, are affected by the network transformation. Most importantly, the impact of such transformation is noticeable with certain types of interaction and at specific phases of networking. The selection of partners changes accordingly, as different elements disturb the system and exert pressure on the actors. The predominance of a specific mode of selection is a result of such pressure and its adaptation.

## 6.8. Conclusion

This chapter has discussed knowledge networking between actors in the bio-sector. The bilateral sub-dynamics acted as the main sources of variation for the selection of current trilateral and other multilateral interactions, determined by both the intensity of networking activities and openness of other actors. The main modes of interaction are: joint-committees, co-authorship, collaborative research, consultancy and problem solving, use of common facilities, training and community-based collaborations whereas commercialisation-related activities are very limited. Taking into consideration the variation in the institutional capabilities, the actors with less research and innovation capacity are driven by both personal and organisational stimulus, for example to get access to advanced equipment. Actors that are more sophisticated are mostly motivated by personal reasons, such as recognition and getting access to tacit knowledge.

The typology of knowledge networks in the bio-sector is multi-level and dynamic. For academic knowledge-producing organisations, the inter-organisational networks are active, whereas cross-institutional networks are more effective with non-academic knowledge-producing organisations. The process of networking exhibits four distinctive phases: introductory, active, stationary and either the decline or regenerative phases. In each phase, different levels of networking and engagement of informal linkages are involved, suggesting phase-dependent pattern.

The impact of proximity on knowledge networking is a multi-level topic, as the perception of proximity differs with the actors. The Boschma's (2005) fivefold classification of geographical, cognitive, social, institutional and organisational proximity was used and social proximity plays key role to enhance the importance of the geographical co-location. The role of proximity in enhancing network convergence is noticeable at the organisational level. Intermediary organisations have limited roles, whereas the main characteristic is being part of governments' departments and units. The limited number and diversity of the intermediaries in the interfaces play role in the modest interaction of the actors and the intermediaries.

The mechanisms for selecting partners within the bio-sector are triggered by different factors, such as the availability of compatible partners, funds, and organisational logistics, in addition to previous experience and the role of culture and mind set. Five modes of selection are identified: pre-determined, influence of intermediary actors, interest-related means, role of previous experience, and the reversible selection. In all these mechanisms, the underlying factors are trust and inter-dependence between actors, as well as the role of strong actors, i.e. the funding agencies. The impact of network transformation affects the selection of partners by altering the preference for formal contact, the learning process, and the perception of partners.



## 7. Entrepreneurial support and government initiatives in the bio-sector

### 7.1. Introduction

This chapter addresses research question 5 which is: *What are the implications of commercialisation capabilities and government initiatives on the transition to knowledge entrepreneurship?* It tackles the broader context of commercialisation and draws on interview data. It discusses the entrepreneurial support within the national system of innovation and includes both the hard and soft entrepreneurial infrastructure. The entrepreneurial capabilities of a sector reflect its tendency to innovate and are determined by several elements, such as hard and soft entrepreneurial infrastructure, support mechanisms, Policy framework and the social characteristics of its actors (Fini *et al.*, 2011; Hewitt-Dundas, 2011; Perkmann *et al.*, 2011).

Hard entrepreneurial infrastructure includes suitable research laboratories and incubators, funding, effective IP regime, and commercialisation structure like TTO (Cooke, 2002). However, soft infrastructure includes national policies, commercialisation skills, entrepreneurial mentoring, and training programmes. Moreover, entrepreneurial capacity can be further influenced by cultural traits, as recent evidence has shown that there is a significant link between enterprise activity and the overall community culture (Huggins and Thompson, 2012).

Commercialisation policies constitute an essential element of the governance of innovation systems and play an important role in promoting successful knowledge entrepreneurship (Doganova, 2013). The creation of academic spin-offs has become a central aspect of contemporary innovation policies (OECD, 2005). According to OECD (2005), 'governance concerns the systems and practices that government use to set priorities and agendas, implement policies and obtain knowledge about their impacts and effectiveness' (OECD, 2005, p.23). Within the context of the NIS, governance refers to the national institutional structures and processes that government employs to shape policy decisions. A successful governance framework to support innovation comprises of three

main components: institutional and legal frameworks; coordination bodies and mechanisms; and policies and strategies (OECD, 2005).

This chapter consists of three parts and is organised as follows. The first section discusses the hard infrastructure that support commercialisation and its implications on knowledge production. The national commercialisation-related policies are analysed in the second part from four perspectives: (1) The process for the formulation of STI policies; (2) the status of commercialisation policies and strategies in the bio-sector; (3) the government approach in setting policy instrumentation for entrepreneurial support; and (4) emulation of foreign policies. The third part examines the entrepreneurial culture, with special reference to government initiatives for the development of academic entrepreneurship. The chapter concludes with a summary of the main findings.

## 7.2. The hard entrepreneurial capabilities for commercialisation

Prior studies have noted the importance of both the support systems at knowledge generating institutions (funding, collaboration and networks, TTOs) for academic entrepreneurship and the absorptive capacity in the industry to uptake academic breakthrough inventions (Nieto and Quevedo, 2005; Fabrizio, 2009; Perkmann *et al.*, 2011; Pries and Guild, 2011). Drawing on the NIS components (OECD, 2005), three elements are examined: research finance, HR and entrepreneurial skills, as well as the business environment. Although these themes were more relative to knowledge producing organisations, it seemed that other actors were influenced indirectly. Interviewees were asked to talk, from their own experience, about the key organisational capacities that had a positive input in facilitating research and commercialisation activities. They were encouraged to mention two to three influential competences that were needed to get their research to commercialisation stage.

### 7.2.1. Research and innovation finance

Most of the interviewees thought that adequate finance is still lacking for both research and commercialisation activities. In the absence of venture capital (VC) and limited industry

funds, the government remains the main funding source for research and innovation in the bio-sector. Researchers thought that expanding funds for applied research could enhance the capacity of knowledge generating organisations, by providing advanced lab equipment and training to knowledge workers.

...We have excellent research ideas for commercial application, but we are restricted to the internal grants. HM grants are very competitive, and TRC grants take so long. The industry can fund us if we have promising preliminary results. We need funds for the pilot study, until we have solid evidence of commercial application (*Biotechnologist, Public University, 2014*).

The majority of interviewees suggested that the government can play the role of VC, especially during the first years of spinouts. When these interviewees were asked what the possible benefit was for the government, other than capacity building or any long-term objectives, only a small number indicated that part of research outcomes, for instance in marine biotechnology, can be directed to public policy and service industries. Hence, the government will benefit from the knowledge, produced by research in biotechnology, in formulating evidence-based policies for the development of the bio-sector.

Some interviewees suggested an indirect role of the government through attracting international bio-manufacturing companies to Oman and supporting projects at pilot stage. Furthermore, it could support emerging start-ups by providing public debt financing. Some interviewees who have wide international experience expressed another perspective; they articulated the idea of collaborating with the international biotechnology industry. Therefore, local actors contribute to the research team and the international support the spinouts, whereas the government plays a part after that in the retention of these companies. However, the interviewees thought that it is more useful to develop and upgrade the bio-industry to enhance its absorptive capacity for biosciences knowledge. As one interviewee said:

Academics are talking about funding... funds that are more public. It is not sustainable. If they want to achieve long-term advancement in innovation, the industry should come aboard. The government needs to upscale the industry and the industry will take over. Government funding alone will not be enough for commercialisation (Director of regional organisation, 2014).

Interestingly, some interviewees thought that the funding is available and the main concern is the management issue. It seems that academics were performing in fragmented ways, so that research outcomes did not reach the industry in a suitable time, as most of the topics are duplicated with no priority orientation for research. As mentioned by one interviewee:

Personally, I don't think the funding is inadequate for research. There is a need to reorient the funds. Departments need to have priority areas for research. We need to form good teams. We also need to see follow-up projects where different team takes the project to a higher level of research. It is not only about funding, we need an overall healthy research environment (Microbiologist, Public University, 2014).

However, the fragmentation in research topics can also be due to difficulties with the administration burdens in awarding research grants. Thereby, researchers do not get access to funding for follow-up stages or piloting. The participants raised the topic of bureaucracy in the management of research funding frequently. It applies for both internal funding and external grants. As one participant said:

...Also there is a lot of bureaucracy involved in terms of managing those grants. So you have a bigger grant, and then if you were to utilise the funds to conduct the research there is a lot of bureaucratic managerial elements that are mixed up, so they would basically pull over the scientist from his role as a scientist to become an administrator, ok? There are several forms you have to fill in and so on (Biotechnology Professor, Public University, 2014).

The fragmentation had a negative impact on less researched topics, rendering them underdeveloped. The majority of the interviewees considered the lack of attention to some research themes within the bio-sector, which makes it difficult for them to be established. As one interviewee said:

Marine biotech, bioremediation, and microbial enhanced oil recovery are doing fine. SQU, MAFW [the Ministry of Agriculture and Fisheries Wealth]...MECA [the Ministry of Environment and Climate Affaires]... and oil companies are supporting them. But what about industrial biotechnology or biosynthesis, well, we need a balanced view. Yes, these fields are not a national priority, currently, but they can be of interest after some time and they do matter elsewhere... This is the trend globally and we have international collaborators... so other fields need attention and development too (Assistant Dean for Training, Private University, 2014).

A possible explanation is that the bio-sector is small and yet diverse, and exhibits a type of stakeholder-induced development. It seems that the key players in the marine and

fisheries are supporting these sub-sectors more resourcefully than others are. Hence, the advances in some fields might be linked to the economic viability, which underlie them compared to other fields. Consequently, the participants thought that there is a need for more awareness among stakeholders to support the development of wide-spectrum fields. Thereby, the industry can get access to information and infrastructure of the other two spheres, and more interaction can take place.

The situation in the private knowledge-producing actors is more severe. With the exception of SQU and agricultural and fisheries research centres, the facilities of the remaining actors are considered modest. The interviewees from private universities mentioned the importance of lab facilities. For example, one interviewee said:

Biotechnology is an expensive science.. Well we actually need is a building with centralised core facilities for molecular biology and biotechnology, including functional genomics, proteomics, bio-control, DNA sequencing, transgenic, and bioinformatics facilities. It is necessary to include research laboratories, lecture theatre, bio museum, offices and other support facilities. We also need entities for pilot activities, bioreactors, and simulation units (HoD Biotechnology, Private University, 2014).

The idea of shared research facilities is not new; there are such facilities in SQU and University of Nizwa (UoN). However, these facilities call for more attention to the type of linkages and interactions between actors, which determine access to knowledge, equipment, and field support services. The replication of units is very common and researchers are aware of the issue. In practice, they do share research equipment based on informal communication. This collaboration is not because of the 'state-of-the-art' equipment, rather the experience and tacit knowledge within research technicians and other personnel. However, it seems that the availability of resources to purchase equipment did not practically improve research and commercialisation performance. The most interesting correlation with this aspect was the resource curse or the paradox of plenty, as mentioned by one participant:

....Lab equipment is a big issue, the PI [Principle Investigator] ask for fund to purchase new equipment.. the same equipment is purchased by another PI from another organisation or even another department in the same organisation... the government is investing in infrastructure and resources are directed to build new labs and new equipment... and after all no research

outcomes [patents, spin outs, ..etc.]. This is a real example of resource curse (Research technician, Public University, 2014).

On the other hand, other participants reported the importance of soft infrastructure and the way of developing the hard infrastructure. In their opinion, it is not the infrastructure itself that affects the academic entrepreneurship, but there are other hidden factors, such as time. One participant said:

...we don't have all needed infrastructure at once.. I mean if the equipment are ready, the technician will be unavailable.. And so on and so forth. It is more difficult with applied research, ideas might change with time.. Industry problems change... We need to develop infrastructure in such a way that knowledge production does not take so long time (HoD Biotechnology, Private College, 2014)

While the hard and soft infrastructure are considered as the key challenge within the processes of knowledge production and commercialisation, the interviewees thought that the way that the policy making actors are working on the infrastructure development is what really matters. For instance, one participant said:

That's true, we don't have all the advanced labs and facilities for piloting, but with money they should have been solved long time ago. Do you know that Oman started to pursue biotechnology in mid-1990s, almost at the same time with other Asian countries like India, Malaysia and Singapore? Look at their progress and look at us. We do have the money, our oil-based economy can support such advanced labs, but we didn't. This is because of the method they [the policy makers] followed in the development of the infrastructure. There was a lot of replication and fragmentation and it is still going on (Microbial Genetics Expert, 2014).

Therefore, the infrastructure theme is double sided; on one hand the inadequacy of the hard and soft infrastructures pose challenges on knowledge-producing actors. On the other hand, there are hidden factors within the theme that are overlooked by the policy makers.

### 7.2.2. Human resources and entrepreneurial skills

Oman utilises academic institutions both locally and globally to achieve its undergraduate and graduate status in biosciences and biotechnology. There are two issues about the HR capacity, which are the low number of biosciences graduates and loss of graduates due to unsustainable employment. The vacancies for bio-graduates are limited and the employment opportunities are mainly in the Government, as indicated by one interviewee:

Now there is also another problem, which I clearly see here in Oman, is the employment sustainability, and this is a major issue. For example, you have an active researcher who sits in his research lab and you have a sustainable project here, ok. The project starts from year one to five years, it is continuous and it is expandable. The problem here in Oman is this process of recruitment. The contracts for researchers like me or any scientists; it is based on three years, ok. So for me it's not really feasible to apply for a research grant on the third year, because who know, I might leave. Now, the same problem actually applies not only for expatriates, it applies for Omanis as well, and the reason behind it is that the salaries are just too low (Biology Professor, Public University, 2014).

Until recent reforms in payment schemes, there were substantial differences in the privileges (salary package, incentives, and allowances) for technical staff between knowledge-generating organisations. University staff used to receive better payment than their counterparts in the public sector. This issue caused a 'migration' of biosciences personnel from the public sector labs and Research Centres to other organisations within the bio-sector institutional spheres. In some cases, the employees joined organisations that are not related to biosciences, such as oil companies or commercial banks. Such cases have severely affected the entrepreneurial capacity of knowledge-generating organisations caused by the permanent loss of tacit knowledge.

I would say the salaries are not sustainable for people to stay in the country. I will give you an example. The excellent veterinary research centre with all advanced equipment, I think that they have spent over maybe twenty million Omani Riyals (\$51.97 M) on this facility, and then you have a mix of ex-pats and Omanis working there... and all of a sudden during the last year many people have left. We are talking here about head of departments, head of units. They left because the salaries are not attractive for them anymore. Now you can imagine you have a project and the government has spent a certain amount of funds and then people just leave (Epidemiologist, Public Research Centre, 2014).

Moreover, the movement of biosciences personnel away from the bio-sector has reduced the research capacity of knowledge-generating organisations by increasing the on-the-job training time for new employees. Such migration does not only apply for well-experienced staff, it also occurs with good biosciences graduates who find permanent jobs outside the bio-sector spheres. In the discussions of human resources, the theme of entrepreneurial skills came up. This theme was related to the lack of entrepreneurial training for bioscience graduates. The common view among the interviewees was that the key actors in the bio-sector overlooked the need for an entrepreneurial training program. Academics called for

more attention to the need of training scientists as the current elective courses are not enough, more focus on the 'business of biotechnology' is required. These findings have important implications for developing an effective workforce employment and training system. It is also critical to develop a plan for retention of competent human resources and valuable tacit knowledge.

### 7.2.3. The business environment of the bio-based industry

The business environment in Oman takes advantage of the country's strategic location, economic resources, and political stability. Additionally, other elements and market-oriented policies can support knowledge and technology driven businesses. For instance, Oman has joined the World Trade Organisation (WTO) and it is a founding member of both the Gulf Co-operation Council, as well the Indian Ocean Rim Association. The Government has also liberalised the investment law and the law for income tax for companies has been modified, providing good regional and international linkages that can be enabling the business environment.

Ideally, Oman can utilise regional bio clusters for the development of the local sector, for example the big pharmaceutical knowledge and expertise in India that is based on marine biotechnology. In addition, most interviewees thought that the effective way to increase entrepreneurial capabilities of local actors is by developing partnerships with strong regional and international biotechnology actors.

## 7.3. National commercialisation-related policies and strategies

This section discusses commercialisation-related policies from two perspectives of the OECD (2005) governance framework of NIS: the coordination bodies and mechanisms; and policies and strategies. Firstly, the policy formulation process is explored to examine the role of policy-making actors. From this level of analysis, the role of the policy framework in supporting commercialisation is examined. Hence, the policy shift towards promoting applied research and academic entrepreneurship can be emphasised, as well as the role of antecedents and the actors in the three institutional helixes. In a parallel vein, the interdependence between policymaking and other processes or actors can be detected.



Drawing on the TH model, innovation and economic development can be achieved through the leading role of the university and in the hybridisation of elements from university, industry and government (Etzkowitz, 2008). Thereby a new institutional and social set-up is generated for the production, transfer and application of knowledge. Along with the neo-institutional perspective, three key arrangements in the positioning of the three institutional spheres can be recognised. The first configuration is when the government plays the lead role in driving academia and industry, but also limiting their capacity to initiate and develop innovative transformations. A laissez-faire configuration is when there is limited government intervention with industry as the driving force. The third arrangement is when the three spheres have balanced roles, working in partnership to provide an optimal space for innovation (Etzkowitz and Leydesdorff 2000).

In the bio-sector, commercialisation-related policies and strategies are still developing and the current emphasis is on sector-specific policies. Within the existing National STI policies, three types were considered: the National Research Strategy (NRS), the National IP system, and the higher-level development plans. The interviewees were asked to comment on the degree of awareness of these policies and the extent of interactions within the overall framework for knowledge commercialisation. This allows better understanding of the national support mechanisms and the role of local stakeholders and their interest regarding commercialisation support.

### 7.3.1. The policy making process in the bio-sector

The policy making process in the institutional setting is very interesting, as it is divided between two government entities. The main governing body for science and technology is the Research Council (TRC), which is relatively a new organisation. For higher level national planning, the responsible planning actor is the Supreme Committee for Planning (SCP), which is also a newly-formed organisation. Previously, the Ministry of National Economy was responsible for planning. Two main views emerged from the analysis of the policy documents and the interviews: firstly, the absence of a complete policy framework for commercialisation; secondly, the perception of the policy makers with regard to university research and its economic and social returns. Regarding the first theme, the current policies

for commercialisation of university research are fragmented with no sector-specific policies, as stated by one interviewee:

The policies need to be more explicit and the inputs from both, the research performers and the industry are required. For example, in the field of genetic resources research, more modification in the IP system was considered critical. In drug development research, the bioethics and bio-security issues are significant. So if the policy aims to successfully increase the impact of biosciences research, there is a demand for specific measures that are applied for biosciences (Microbial Genetics Expert, Public Research Centre, 2014).

Furthermore, the words 'science', 'technology' and 'innovation' were not found in the Economic Vision and other economic planning documents throughout the study time. Despite the fact that the topic of economy diversification was found to be the predominant objective since early 1990s, the role of science and innovation was not highlighted, which reflects low awareness of the importance of these sectors. This can be explained as a result of limited communication between the key institutional spheres and the non-academic policy making actors, therefore, they have different perspective about the economic and social returns of research and innovation. In addition, the absence of the National Innovation Strategy, which is currently under preparation, increased the fragmentation of efforts. As indicated by one interviewee:

There is no mention of 'science', 'technology' and 'innovation' in all the policy documents, the vision 2020, and the five-year plans up to the eighth five-year plan. The coming plan [ninth five-year plan 2016-2020] will include issues of research and innovation in the economically strategic sector, like tourism and fisheries. This is a good movement. The National Innovation Strategy is also prepared by TRC and myself and other staff here [the Supreme Council for Planning] are part of it. The preparation of these documents is done at the same time as the Economic Vision Oman 2040 is formulated. Hopefully, the Vision 2040 will be more practical and of use for all stakeholders: the academic and non-academics (Director of Development Planning, Government Department, 2014).

There was a common view among policy makers about the academic sector, which for a long time was considered as part of the government sphere. Especially with public HEIs, it was not clear that these organisations were perceived as part of a different institutional helix (the academia). At the higher-level planning, it seems as if the policy making actors were performing on-behalf of the academic sector, indicating a gap in the representation of the academic sphere in the policy-forming process. As indicated by one interviewee regarding the need for awareness to allow more of a role for knowledge-generating actors.

I think academic people are under-represented at policy forming committees... well it is improving now, but you talk about S&T policy from mid-1990s. I think academics should have been involved; they can have positive inputs and can 'boost' the process. Most of us were educated abroad and we have the knowledge, also we have our connections and networks. But academics speak better about academic world, and the challenges that face academics. So, more awareness is needed and more involvement is required (*Assistant Dean, Public University, 2014*).

In parallel, another interviewee said:

Before we recommend changes in the procurement policy, as it is a major research obstacle in technical departments, we need to call for 'National Research and Commercialisation Policy'. The current procurement policy was set for general purchase, not for lab equipment and supplies. They [policymakers] have to put different procedures for purchasing research and teaching equipment, not only the purchase process, the whole norms of operation related to research work in universities. Because of this long procurement process, researchers became frustrated, they make them sit there doing nothing. They have to look at the research in different ways. You know, some voices are calling to minimise research funding in SQU because its core business is teaching. If they do so, then what is the difference between SQU and the Applied Colleges of the Ministry of Higher Education? (*Genetics Professor, Public University, 2014*).

Coming back to the process of policy formulation, there are common characteristics that are shared in most policy formulating processes within the institutional helix of government. National joint committees are practically the main functioning units that perform the formulation of national policies and strategies. In most cases, a representative of the policy-making actor chairs these committees. The members are delegates from the concerned organisations within the institutional sphere and from other spheres. In big committees, smaller technical sub-committees are formed to perform specific detailed tasks, and they report to the Chair or the Deputy Chair of the main committee.

The most important feature with this procedure is the issue of consensus building in taking the decisions. Most committees' Chairs pursue this attitude, and this brings to light the issues of stakeholders' relationships and impact. Within the institutional setting of the bio-sector, there are stakeholders with high influence and impact. Several reasons can be behind their position, for instance SQU is the first public university with state-of-the-art facilities and laboratories, therefore members from SQU can be more influential. It is not the scope of this study to do stakeholders analysis; rather the relationships between stakeholders and their impact on the formulation of commercialisation-related policy are

discussed only. This leads to a central question: who are the real or strategic policy making actors with regard to funding of research and innovation? Accordingly, it is significant to recall that the bio-sector is small and yet diverse, with its actors distributed throughout the three institutional spheres. More attention shall be directed to the relations between these actors and their impact on the policy making process.

The influence of stakeholders' linkages is an essential element, as it has a multi-level effect on the process of policy formulation. At one level, the representatives of the stakeholders in the national committees can either enhance or inhibit the process of consensus building within the committee. At another level, the linkages may have an effect on the dependency of policy formulation processes on other actors for gaining access to information or possessors of tacit knowledge. Similar to previous research (e.g. MacAdam et al., 2012), these findings reflect the importance of stakeholders' relationships within commercialisation-governing institutions, specifically from the funding opportunities' perspective with the availability of different funding sources.

When the topic of entrepreneurial support was discussed, most interviewees pointed to the challenges imposed by the absence of complete commercialisation policies and they called for more intervention from the government. For example, one interviewee said:

You know how these committees work.. it depends on the members and their affiliated organisations. For example, SQU people are more influential than members from a Ministry or a company. It also depends on the chair person.. Some can take risk and adopt new ideas; others prefer to reach a consensus for 'quick wins' or the 'low hanging fruits'. There are certain issues that remain unsolved, like the funding problems and the procurement process. After the closing of a committee, a follow up committee for implementation is formed and so on and so forth with no tangible results. I hope the committee can come up with answers or solutions, or anything else other than just recommendations (Retired Government staff, 2014).

Another interviewee commented on some of the recommendations that were produced in some joint committees:

It is easy to write it [the recommendation that call for change in a policy] in the final report, but in reality it is not that easy. The committee has no power to change a policy. It took us many years to change the [...] bylaw because of a part in the law that was issued by a Royal Decree. The law was changed by a Ministerial Order of the Ministry of Finance, and not through the committees. The government is the main player, so why not giving them the lead to set the agenda and adopt the policy. There is no harm in setting committees for different tasks, but I

cannot expect major changes based on the recommendations alone (*HoD Applied Sciences, HEI, 2014*).

Therefore, the policy formulation process is an important factor with three fold impact: firstly, the growth of the gap between knowledge-producing actors and policymaking actors. Secondly, the process overlooks sector-specific issues as the support for knowledge commercialisation and academic entrepreneurship differs across research fields. The third dimension is the influence of stakeholders' relations, which implies the need for moderation measures. Although there is co-evolution between the development of commercialisation-related policies and the evolution of the knowledge production process, the overall policy framework remains functionally incomplete. In addition, the existing policies lack sector-specific details, as described by one interviewee.

### 7.3.2. The National Research and Innovation Strategies

The availability of national research and innovation strategies provides guidance to increase the support of research and commercialisation activities. Two significant strategies were considered: the National Research Strategy (NRS) and the National Innovation Strategy (NIS). Regarding the NRS, some participants considered the document resourceful, but the general view was that the strategy is sophisticated and directed only to a specific audience (i.e. researchers). Unlike the Economic Vision Oman 2020, which 'travelled' through the three institutional spheres, the strategy got less attention among non-academic actors. In addition, some participants thought that the strategy is very ambitious and that more realistic goals are needed. For example, one interviewee indicated that:

It is difficult to compare between the two documents [the Vision 2020 and the NRS]. They serve different purposes, but I think the Vision has been used by all the organisations as the main reference for their work and new initiatives. The strategy document is very long and only researchers and academics can be interested to read it. I do not think the industry sector can find it really useful. It is very sophisticated. The vision is also long, but it is more realistic (*Director of Innovation, Public Funding Agency, 2014*).

Another interviewee said:

The Vision 2020 document did not receive the attention it deserves, the document had over-estimated goals and it was not updated all through the time framework. I remember the Vision was projected based on average oil price of 16 \$ and a tremendous fluctuation took place after

that. I think more emphasis was needed at the level of the development of economic sectors and the PPP [Public-Private-Partnership]. As you said, this document is used as a main reference document for research and innovation national strategies, but there was no mention of research and innovation. During this long-term Vision (1996-2020) four short time five-year plans were released and I cannot see the coherence between them. The fact is that this document has 'travelled' between different organisations and remained as a significant document (*Director of Development Planning, Government department, 2014*).

In the process of strategy formulation, the chair for the committee was a Minister; however, the Chair for the innovation strategy is the Advisor for His Majesty the Sultan. This change reflects the view of involving politically prominent figures to add more weight to the project and to minimise any sort of tension or conflict between key stakeholders. The processes of science and innovation policy-making are complicated within the local institutional setting, as these types of policies are considered new and policy-making actors did not develop enough to pursue this area.

The NIS is currently in progress and when the document is publically released it will be nearly one decade after the closing of the NRS project. This time interval would have its impact on the strategy and its expected role. According to the interviewees' views, interaction of the actors with these significant policy documents is limited. Regardless of the awareness plans that were carried out by TRC during the implementation of the strategy, awareness seems to be insufficient. The strategy included a central theme of 'Commercialisation and knowledge transfer'; however, the interviewees thought that it is 'very ambitious'. These views have implications with regard to the efficiency of national strategies and their ability to be used by a target audience. It also raises concerns about the status of awareness and the readiness to use these documents and benefit from them.

### 7.3.3. The National Intellectual Property (IP) system

The national Intellectual Property (IP) protection system in Oman is still at the infancy stage. At the governance level, two regulating bodies are handling the IP issues: the Ministry of Agriculture and Fisheries Wealth; and the Ministry of Commerce and Industry. In the bio-sector, two main categories of IP rights were considered, which were: individual rights for new creation; and collective rights for traditional heritage. Whereas the former includes

industrial property, author's right and breeders rights, the latter deals with traditional knowledge and genetics resources (Ministry of Agriculture and Fisheries Wealth).

There was a consensus among the interviewees about the role of the existing national IP system on the performance of knowledge entrepreneurship. The key issues were found to be the split of IP governing authorities and that SQU has their own internal system for IP protection, suggesting institution-owned model of handling patents. The main discussion was about the need to have clear policies or a central system to manage IP issues. As indicated by one participant:

I tend to agree with the idea of having clear model for handling patents; the ownership of IP.. I don't think all researchers aware of the IP system in Oman. For example, the expat academics who worked in more organised IP system find it difficult here. There is no central body that we can refer to... the management is divided between different departments... and there are some initiatives that are going now here... Last year, in [...] workshop, most academics pointed that the IP system is a big obstacle that face applied research here. It becomes more complicated with research that is linked to traditional knowledge, for example the healthy low-carb Halwa [Traditional Omani sweet]. It was difficult to process the patenting because of the conflict between different stakeholders (*Assistant Dean, Public University, 2014*).

This is similar to the trends of research in the literature, which suggest that inventor-ownership can be an alternative to the current university IP regime (Kenney & Patton 2011), so governments seeking to encourage invention commercialisation and academic entrepreneurship need to experiment with this system. One of the issues that emerge from these views is the need to study a suitable model for the bio-sector. Different models of handling IPR are studied in the literature; for example, Japan and many European universities currently emphasise a patent-centred model of technology transfer. Despite the trend towards institutional ownership, universities' IPR regulations in Europe continue to be differentiated and there is no one-to-one mapping to the US system (Geuna and Rossi, 2011). According to Grimaldi et al. (2011), most European countries have been interested in legislative changes that even when not in line with the Bayh-Dole Act (e.g., not granting universities the legal ownership of inventions), share with it the objective to spur the commercialisation of public research results.

As with the discussion of the previous policy document, the dimensions of interaction and awareness are related in the IP system. It seems that actors' interactions with the IP-related documents are very low, as well as the awareness of the researchers and their co-workers and students. The general impression was that the process of raising awareness should be expanded to include other actors, in addition to researchers. Awareness should be started from earlier stages, as with the issue of building entrepreneurial culture. Students of biosciences and biotechnology need to be exposed to IPR issues starting from undergraduate level.

#### 7.3.4. Policy instrumentation in the bio-sector

Drawing on the analysis of secondary data, the government approach seems to incorporate both direct and indirect interventions with regard to the support of commercialisation and academic entrepreneurship. However, it is obvious that more focus is directed towards longer-term investment. Such policies can be associated with 'both top-bottom' and 'bottom-top activities' and are thought to have weight in the long-term commitment (Huggins and Williams, 2011).

For example, TRC is currently establishing the second science and technology park in the country after the Knowledge Oasis Oman (KOM), namely 'the Innovation Park Muscat (IPM)'. It is established in a dynamic location which hosts active actors including PAIE, SQU, KOM and three private universities (GU Tech, Waljat College for Applied Science, and the Middle East College). The Innovation Park comprises of business incubation facilities, a fabrication workshop for prototyping and a social centre to enhance interactions among technologists and entrepreneurs, in addition to space for multinational corporations. Concurrently, the Institute of Advanced Technology Integration (IATI) is being built with the support of TRC. The IATI is expected to be the first research institute with highly advanced facilities for research in cutting edge technologies.

Another two research centres are to be established, which are The Food and Biotechnology Institute, and the Centre for Environmental Innovation and Research. These examples represent massive investment in the development of research infrastructure. For



example, Oman Centre for Plant and Animal Genetic Resources, alone, receives financial support which is more than 80 M OR allocated over a period of 12 years. As the key objective for establishing science parks is to attract advanced companies and increase UI collaborations through industrial funding programmes (Rasmussen *et al.*, 2006), the returns of such investment are in the longer term, and therefore they exhibit an ultimate impact on the transition to entrepreneurial culture and practice.

On the other hand, direct interventions are less developed and most of the challenges that were identified in Chapter 5 were found to be related to this category. One of the most repeated topics among participants from knowledge production was the bureaucracy in funding procedures and the fragmentation of IP protection system. These issues are directly related to knowledge commercialisation processes and government intervention, in this regard, is thought to accelerate the transition to the third mission.

Although both instruments are needed, it seems that several challenges can be resolved by the direct instruments. This implies the need to adopt a balanced approach that can address the emerging issues at different levels. For example, an increase in good research proposals can be achieved through the modification of current funding procedures or public procurement process of lab equipment. At another level, the support of autonomous systems for knowledge-generating organisations can remove the current hurdles and improve the quality of research proposals.

This stance can go well with the nature of the bio-sector and the nature of its actors. The components that are specific for the bio-sector can be identified and addressed by direct policy measures. One of the most important topics in the commercialisation policy is the need for policies that aim to effectively foster the interactions and linkages between actors, especially the UI links. Such policies require the inclusion of all actors, not only academics; for example, local industry needs to be able to initiate and maintain useful collaborations (Perkmann *et al.*, 2013; Park *et al.*, 2014). As well, it is significant to consider the different motives for collaborations to design policy measures that target the larger institutional setting (Giest, 2016), taking into account the importance of Bayh–Dole-type legislation in supporting commercialisation (Wong and Salmin, 2015).

### 7.3.5. Implementation of 'imported' commercialisation policies

It is well accepted that less developed regions need to learn from success examples. However, it is important to consider the local environment and the long-term impact of implementing best practice policies. Innovation policy, in general, is a relatively new topic in public policy in Oman. The term 'imported' policies was selected over 'best practice' to enhance the interviewees to think in the direction of viewing the policies as non-local and designed for different institutional settings. The term best practice might give the participants a direct impression that they are best for all settings. Interviewees with long organisational memory were asked to comment on the suitability of implementing such policies in order to accelerate the transition towards a fully-functioning institutional and policy framework for knowledge entrepreneurship. One interviewee indicated the importance of adding 'the international flavour' to the locally produced policies.

Academic entrepreneurship is part of innovation policies, innovation strategies, innovation systems, then here let me comment generally... it's very difficult to see what is happening in other countries in the world and stay in solo. I think that Oman can mimic and 'copy and paste' various strategies, because there is no point and no time to reinvent the wheel. We just need to encourage certain talents in Oman to capture the proper understandings of best innovation systems and to develop our national innovation strategy and system based on the national needs... and national concepts, taking into consideration the current status of Oman now in terms of weaknesses, threats, opportunities. Then we need to add the international flavour. So, all those things have to be considered for us to develop our national innovation system based on international experience (*Director of Innovation, Public Funding Agency, 2014*).

The majority of interviewees thought that it is more practical to adopt best policy practice, but in a cautious manner. Local circumstances need to be addressed to ensure their suitability to function along with other locally developed policies, e.g. higher education policies. This is similar to a current study about the intensity and diversity of knowledge exchange activities by academics, which indicated the need to reconsider the differences in context of the higher education sector (Zhang *et al.*, 2016). Another participant from the government sphere who stressed the importance of integration while implementing the policies derived from the best policy practice also supports this cautious view about imported policies.

I don't really agree with the term 'imported policies' and I think we... I mean developing countries in general; need to learn from successful stories or standard policies... for example, if you look at various countries that we came across in our discussion, the countries that decided to focus on SMEs. Now the SMEs will not function in isolation, without a proper IP policy for example. If you talk about FDIs in isolation of IP, you cannot make it. So looking at the various components of research & innovation eco-systems and trying to develop specific policies for each of them individually, like the commercialisation policy in its own, and indiscretion, the need for integration will not resolve the problem, and this is what most developing countries are not learning from what is happening in some European countries. If you look at the very good examples of Switzerland, Finland, Sweden, and the UK - you know the top countries in innovation performance. They are looking at national approach, or ecology as a system rather than simple policies that are addressing specific challenges (*Director of Research & Programs, Public Funding Agency, 2014*).

These views reflect the common perception of interviewees from the government sphere. The central issue here is that the responses considered this type of policy implementation as a policy learning curve. There was no solid view about the drawback of adopting the imported policies. Taking into account that the interviewees realise the lack of specific details of the bio-sector, implementation of such policies can fill the gap and accelerate the transition.

#### 7.4. The entrepreneurial culture in the bio-sector: the missing 'gene'

Historically, entrepreneurship in Oman is not a new paradigm; the country has a long tradition and deep history of trade (NRS, 2008). However, within the current institutional setting of the bio-sector, risk-aversion is the predominant attitude of researchers, academics, and students. The national indicators of biosciences research outputs (patents, licensing, spinouts) is very low, whereas publication and conferences are the main ways for dissemination (STI indicators, TRC database, 2014). The dominant culture among Omani youth is risk aversion and is biased towards career ladders in the public sector. The preference is for routine government jobs, which provide job security and less work commitment. The culture of self-employment and entrepreneurship in general is limited. Hence, most interviewees indicated that building the entrepreneurial culture is the key challenge for the government. As indicated by one interviewee:

We can claim that there is a 'cultural gap'. Yes.. There is a big gap between the government support for SMEs and the dominant culture... our culture does not encourage risk-taking and innovation. Our youth wait for government jobs; they do not see opportunities and believe in their capabilities to start a business. Our culture place more value on permanent jobs, it has a different view about success and job security. So the entrepreneurial activities cannot be performed easily.. a lot of skills are needed to overcome the obstacles, for example networking and communication with external market, acknowledgment of change, and problem solving techniques. So we need to work on all these aspects (Director, Government Department, 2014).

At the individual, organisational, and institutional levels, the topic of entrepreneurial culture is interwoven in the whole thesis. It has been mentioned repeatedly in the discussions of the actors and transformation, the networks as well as the hard and soft entrepreneurial capabilities (Chapters 5, 6 and 7). The interviewees were asked to comment whether the leadership in their organisation 'acts entrepreneurially'. This includes different indicators, such as how the leadership communicate and whether they value the entrepreneurial approach, and whether individuals feel empowered to take the lead and create positive change. Specifically with the interviewees with long organisational memory who witnessed the transformation process. The discussions reflects that the entrepreneurial culture is linked to two factors: the public perception of entrepreneurs and the 'environment of empowerment', which differs from one organisation to another.

Most of the interviewees considered the need to tackle the topic of entrepreneurial culture together with other topics with the same attention; for example, the support of the hard infrastructure and the organisational support mechanisms. The cultural dimension has a big influence as it inhibits the young graduate from pursuing entrepreneurship. Cultural views on entrepreneurial activities have shaped the preference for jobs and the avoidance of taking the risk of new changes. As indicated by one interviewee:

The entrepreneurial culture was part of the Omani culture and history... It was the main way of making a living; people took the risk and travelled to different parts of the world... in Asia and Africa. But this culture has changed with the oil age, the society has changed, our social norms also changed. It is all about the way people define 'success'. People prefer to be around 'successful people', who are in their opinion government employees in middle or senior management positions, or top military careers. But we don't hear about self-made entrepreneurs stories so often. Even the entrepreneurs themselves... they don't talk about their attempts, they don't share their stories whether ended by success or failure. They don't include their previous attempts in their CVs. This can best tell you about the cultural factors and how important to change these social views about entrepreneurship. There is a need to 'rejuvenate'

the culture by using big interventions, like awareness, or by providing incentives for change to speed-up the process (*Assistant Dean for Training, Private University, 2014*).

Regarding the element of empowerment, the interviewees indicated that most of the organisational cultures in the three institutional spheres lack the environment of empowerment for entrepreneurship. They assumed that the bottom-up proposals are not very common and most of the changes that resulted from such initiatives were due to existing political commitment (Chapter 5). This empowerment varies not only from one organisation to another, but also from time to time within one organisation. Small organisations or those that are newly formed seem to act more entrepreneurially compared to big and well-established organisations. For example, one interviewee said:

When I was working in the [...], it was much easier to come up with ideas and propose new ways of implementation... this culture is not here... it is no longer there also, by time more bureaucracy replace the proactive culture. The environment does not acknowledge the values of entrepreneurship, so even the leadership does not support the bottom-up proposals. They [The top management vision] prefer the planned change, may be it has less risks or low uncertainty level... whether it is planned or unplanned; change has to happen (*Biochemistry Researcher, Private University, 2014*).

It can be assumed, therefore, that the current national policies and government initiatives are missing the cultural dimension of knowledge entrepreneurship. However, the government has moved recently towards enhancing the NIS and the innovation culture, particularly in science and technology fields. The following section considers the perception of the actors regarding formal policy reforms and measures in the bio-sector, as well as government initiatives for entrepreneurial support.

#### 7.4.1. The role of formal regulatory, institutional and policy reforms

The bio-sector has witnessed many changes at institutional and functional levels. The interviewees were asked to comment on the existing policy framework and to identify the reforms that are required to enhance commercialisation. Different responses were given and most of them were found to focus on enhancing the bottom-up approach and the mobilisation of strategic organisational resources. The bottom-up method was considered effective to allow the suggestion of reforms that well-matched the sector's need. As indicated by one interviewee:

..Look at the big picture, the Omani culture, investment ecosystem and our business environment... not only the policy for commercialisation... what applies to biotech can be replicated in other sectors. And what about the social dimension, the society-based innovation? What about the young graduates who prefer government jobs? The investment law and the IP system are incomplete. Rafad fund [a government fund to support youth pursue small business and entrepreneurship as a job opportunity] is still new, although similar initiatives were in place for long time. So I don't think a change in some policies will really help, a more holistic approach is what is really missing here. When you talk about fisheries and tourism as priority area, what about sustainability of water resources? You know that Oman is an arid country and more than 90% of our fresh water is wasted in agriculture, yet food sovereignty cannot be achieved by local agriculture only. We need to have innovation across all sectors (*Environmental Engineer, Individual Entrepreneur, 2014*).

However, it is not easy to differentiate between the two approaches (top-bottom and bottom-up) in the institutional setting of the bio-sector. The process of policy formation includes several stakeholders from different institutional helixes. The diversity of the members adds an additional level of complexity to the process, as it can mask the top-bottom approach with false bottom-up initiatives. The complexity is thought to be due to the dependency of knowledge production on huge physical infrastructure, e.g. research labs, as well the tacit knowledge. On the other hand, the limited availability of risk capital for biotechnology-based businesses increases the complexity of setting policies for the bio-sector. Therefore, there is no simple separation between top-bottom and bottom-up approaches in the process of policymaking.

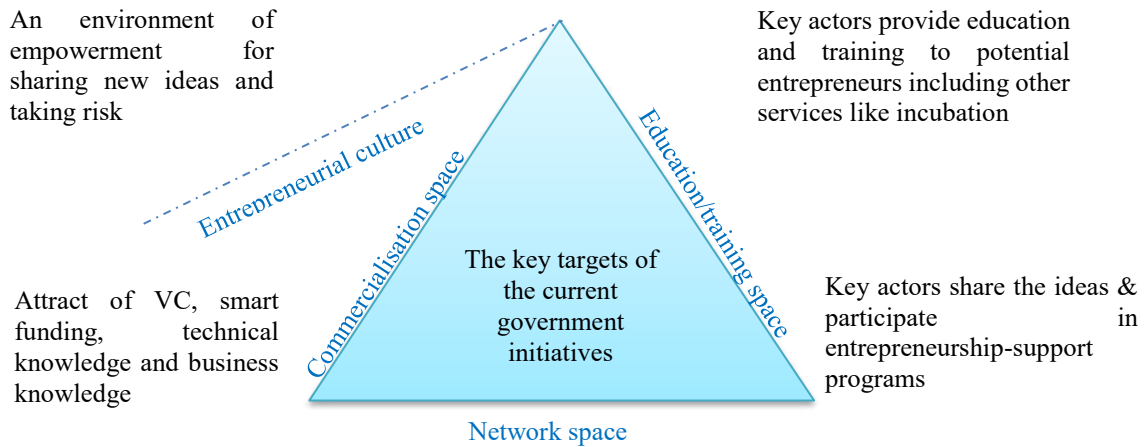
Similarly, regarding the topic of mobilising organisational resources, the interviewees pointed to the importance of utilising all of the available 'strategic resources' to improve entrepreneurial capabilities. The main issue here was the need to get reforms that allow flexibility for using these resources at the organisational and cross-institutional levels. This type of proposal can also be achieved through the bottom-up method. This view is consistent with previous studies in the literature which examined a bottom-up approach (Kitagawa, 2009; Rasmussen, 2008). As presented by Lehrer and Asakawa (2004), the success of the commercialisation of biotechnology research outputs depends solely on the overall economic framework, rather than on the reform of R&D policy alone. This is in line with one interviewee who talked about the overall 'enhancing factors' in attracting FDI, which come from the economic advantages of location, political stability and cultural issues like 'the hospitality of the people'. As indicated by one interviewee:

... And if you talk about Oman, having a country like Oman, which has a lot of advantageous characteristics and factors especially when it comes to stability and security, the hospitality of the people, geographical location, and the big wealth of our associated natural resources... Those are all enhancing factors to attract FDIs. We have to introduce the necessary reforms so that we can compete regionally and internationally, it should be an overall reform to the whole system, not only research activities. And I think to me this is a far more complicated issue to be resolved by individual opinions and individual philosophy (*Section Head of Business Creation, Government Department, 2014*).

When the interviewees were asked to give examples of the needed reforms, two main types of improvement were mentioned: de-regulation of some existing policies, e.g. long administrative procedures in research management; and institutional re-structure to minimise fragmentation of processes. These responses, which were from government and public sector employees, were similar to the views of academics when the challenges of academic entrepreneurship were discussed. Especially, with regard to institutional restructure issues, there was a consensus about the need to unify the function within and among institutional spheres; thereby the transition can be reduced.

#### 7.4.2. Government initiatives for entrepreneurial support

It is interesting to note that most of the significant initiatives started to emerge in the same time interval, which was after the establishment of TRC in 2005 as the majority of these initiatives were proposed by TRC. Specifically, four initiatives for the support of entrepreneurial activities were discussed with the interviewees, as follows: the Commercialisation Company, the entrepreneurial vocational education, the innovation fair, and the LinkingOman programme. These initiatives reflect three different targets such that the company reflects the level of research acquisition and the commercialisation process (Figure 7. 1). The second level aims at entrepreneurial education and training through vocational education and the innovation fair. The LinkingOman programme represents the third level that aims at networks and interactions. However, the entrepreneurial culture is absent in the current government initiatives.



**Figure 7.1:** The targets of the current government initiatives for the development of academic entrepreneurship in Oman (Source: Adapted from the Triple Helix spaces for regional knowledge-based development, Etzkowitz, 2008).

#### 7.4.2.1. *The commercialisation space*

The Innovation Development Oman Holding SAOC (IBTIKAR) Company that was first proposed by TRC to enhance commercialisation of university research. This initiative targets the role of the industry and international investors. The Company has an authorised share capital of R.O. 200,000,000 with an initial issued share capital of R.O. 50,000,000 (The Director of Innovation, TRC, 2014). The key function of the company is owning and holding patents, trademarks, concessions and other incorporeal rights, as well as utilising and leasing/licensing them to the Company’s subsidiaries and other companies. The Company also invest the funds in shares, bonds and securities of other companies, and can provide loans.

Moreover, the Company offers management instruction and advice in accordance with investee companies' needs. It supports the development of business strategies (product, marketing, technology) and the facilitation of necessary linkages, alliances and partnerships between the key actors throughout the innovation cycle. The establishment of this company is considered a landmark in the path to academic entrepreneurship. For a long time, government organisations, including TRC, were not allowed to participate in setting up companies and other business-related activities. The approval for the establishment of this



company was as a result of a significant effort from TRC and its strategic stakeholders. As indicated by one interviewee:

I am not fully aware with the numbers of Oman in the global rankings for innovation, but it is obvious that the start-up and Small-Medium Enterprises (SME) market in the MENA [Middle East and North Africa] region is the least developed. The development of this company supports innovation and addresses Oman's strategic goals for economic diversification, value added and employment. In the absence of VC [Venture Capital] or a business angel system, this initiative is very important to meet the financial and managerial needs of potential entrepreneurs and enterprises. The key issue is the limited access to mainstream finance, currently. This government-owned company, together with other shareholders, is the suitable start until it reaches self-sustaining status. Initially, TRC and Oman Oil provide the seed fund, and as the company grows, more funds will be secured from other government and private entities (Director of Innovation, TRC, 2014).

Despite the significance of this initiative, two issues emerge that are the role of the oil sector in the funding of innovation and the readiness of the actors for commercialisation. The main shareholder in the company is the Oman Oil Company, which indicates the weight of the oil and gas sector in the national economy. Therefore, more initiatives were expected from the sector besides the government. This indicates the absent role of the oil company as a strategic actor that can buffer the dominant role of the government. It can be assumed that if more presence and influence of oil companies was reached, the usual expectations from the government might be reduced.

On the other hand, it is critical to assess the readiness of the knowledge-producing actors for pursuing the academic entrepreneurship cycle. This company was established to raise the accessibility to risk smart capital for early-stage and high-growth companies, which target potential sectors. Therefore, it is essential to include the issue of readiness as well as the awareness of the actors. In most government initiatives, the awareness dimension plays a major role in the progress of these initiatives.

#### *7.4.2.2. The education and training space*

Two examples are significant in the education and training space, which are the entrepreneurial vocational education, and the 'Innovation Fair Oman' initiatives. The Technical and Vocational Education and Training (TVET) of the Ministry proposed this initiative for Manpower. It aims to educate 40,000 students from the six Higher Colleges of

Technology (HCT) regarding opportunities for the creation of business. Based on this initiative, the Ministry has developed plans to establish centres for entrepreneurship and innovation in each technical college. As it provides students with early exposure to entrepreneurship, this initiative is very important and unique in the public sector, as indicated by one interviewee:

This initiative is significant, look at the total number of students. Historically, the Ministry introduced the entrepreneurial culture in the HCT by setting the first business incubator in Al Khuwair branch. The entrepreneurship idea by itself is not new but maybe the entrepreneurship in the field of biosciences is new. We used to encourage students of business schools to come up with ideas that can result in real start-ups. So it is the same with biology or chemistry students, the core concepts are the same, the vocational training serves all fields. The key skill they need to master is how to identify opportunities and assess risks... and, of course, other general entrepreneur's skills like communication, branding and finance. I think other academic organisations need to do similar initiatives; actually, SQU should have done something... I mean in addition to the formal taught courses or modules in entrepreneurship (HoD, Applied Sciences, HCT, 2014).

As mentioned earlier, the key issue with government initiatives is the low awareness, which reduces the impact of these initiatives, as the intended people might not be involved. With regard to the culture dimension, this initiative by its current objectives does foster the entrepreneurial culture within the HTC. Nevertheless, it has a positive impact, in the long term, on the entrepreneurial culture. This initiative has well-defined objectives and it can be utilised as a good example for other academic organisations. Taking into account the previous experience of the Ministry with such activities, the centralisation of training activities can be assumed practical to allow students from other organisations to join the programme. This reflects one of the main characteristics of the actors, which is fragmentation of activities and replication (Chapter 5).

The Innovation Fair Oman is an initiative of the Innovation Department of TRC. It was proposed with the key aim of providing information about the state of innovation in Oman. The fair invites the submission of applications through a formal gathering of innovators and the concerned organisations to share ideas and experiences.

In 2011, we [the Innovation Department] received 81 applications, of which 44 prototypes were selected to show case at INFOM exhibition. Participants with winning applications were then invited to attend workshops in finance and marketing. It was a huge event and we had

very positive feedback. Not only because of the program, but because it was the first initiative that targeted innovators as individuals. It provided a platform to network with other young entrepreneurs and to learn (Director of Innovation, Public Funding Agency, 2014).

However, most of the interviewees were not fully aware of this initiative, despite the media coverage. This indicates the lack of proper awareness between different actors in the sector. It also highlights the need for adequate communication between the actors to allow healthy interactions. With such initiatives, more awareness is important, as the idea is still new to the young entrepreneurs or innovators.

#### *7.4.2.3. The network space*

The 'Linking Oman' programme represents a significant initiative in network space. It is a programme that was also proposed by the Innovation Department of TRC. It aimed to support innovators by providing necessary data about other researchers, organisations and facilities in the sector. As one participant explained:

'Linking Oman' is a programme which we developed in the innovation department and it has been intended to create linkages between various stakeholders who are entrusted in innovation. So we are hoping to develop a database of all innovators' numbers, and including all the important data fields that will help people to filter information and filter clusters on innovators based on their speciality, the region, and their interest, so, it will have an open platform for interactions and linking in the same fashion as Twitter or Facebook. They would also be able to link with scientists around the world who are interested to help young innovators to transform their ideas into prototypes and into business. Linking Oman is to have a comprehensive library which will help innovators to access a lot of useful information without going to buy books and to search in unreliable sources of information related to innovation (Director of Innovation, TRC, 2014).

Furthermore, some interviewees thought that there are several areas that are overlooked. The most important area that needs more political commitment is the initiative to enhance collaborations and linkages between the three institutional helixes. They thought that the most effective method to enhance trilateral relations is through government incentives, and this presented the first area of focus, as indicated by one participant:

The government has been always watching the relationship between industry and academia but they have not even intervened or tried to develop policies or trigger the need for that linkage, and maybe the government cannot see tangible outcomes from the linkages between industry and academia. So I think they are all working independently,

and yet... until a national system for collaborative or joint work is established, maybe that will trigger the collaboration between these three components. The government can issue incentives and support funds to enhance these linkages, the other stakeholders cannot do it (Director of Public Research Centre, 2014).

The initiative of network space is significant, as it addresses an essential element in the academic entrepreneurship. It was a common view among the interviewees that the current commercialisation-related policies overlook the network issue. Interestingly, the government initiatives are well perceived by the actors and are accepted much easier than the policies and strategies. A possible explanation for this might be that one or more actors probably propose an initiative, so it has focused objectives and involves the concerned actors. It is, therefore, less formal than the process of policy formulation, which requires a lot of legalisation. Consequently, the interviewees called for more initiatives, not policies, to support the knowledge networks between actors.

As this chapter examines the role of policy framework and government initiatives for the development of academic entrepreneurship, the most obvious finding to emerge from the analysis is that the cultural aspects can be one of the key factors that reflect the nature of the national system for innovation. In similar line, the study of Huggins and Thompson (2012), about community cultural characteristics, concluded that entrepreneurship policies have to be compatible with the underlying culture. As government initiatives can be viewed as a useful tool in introducing changes and raising awareness, more initiatives are needed to address the topic of entrepreneurial culture. Furthermore, more attention is needed to include aspects of society culture and social norms in the policy making process, in order to accelerate entrepreneurial spirit and practice.

Hence, there is a need to restore this culture and raise awareness for the support of the creation of technology-based small firms. It would reduce the 'cultural gap' between the actors. Moreover, the awareness has to target science and engineering students, as well as the pre-university stage and different school levels. These findings are in line with the literature, as the support mechanisms at the organisational level play a main role in shaping the performance of commercialisation. Hewitt-Dundas (2012) and Chang et al. (2009)

suggested that the organisational supports for knowledge transfer activity might significantly affect the performance of this activity.

## 7.5. Conclusion

This chapter addresses the fifth research question, by discussing the role of national support system for the development of knowledge entrepreneurship in the bio-sector. It draws on both secondary data and interviews, and focuses on three perspectives: the hard and soft infrastructure for commercialisation, the national policy framework, and the entrepreneurial culture. Within the NIS perspective, three components emerged as key determinants of the commercialisation process, which are innovation finance, HR skills and tacit knowledge, and local business environment to uptake biosciences knowledge.

The current policies and strategies are incomplete and are mainly directed to the initial stages of academic entrepreneurship, which is the knowledge production stage (e.g. funding strategies). The current commercialisation and academic entrepreneurship activities are taken on a case-by-case basis. The most important policy is the national IP system. Moreover, knowledge-generating processes halt at certain stages, because of the lack of sector-specific policies that address the unique features of knowledge generation and acquisition in the bio-sector. On the other hand, the implementation of imported policies requires 'cautious' adoption of the 'trial-and-error' approach.

The process of policy formulation is characterised by the tendency of gaining consensus among different stakeholders, but with less representation of the academic sector. The formulation of national policies and strategies is thought to be influenced mainly by stakeholders' relationships. This suggests the role of 'strategic policy-making actors' in the process, as these actors dominate the actual actors in the sector.

Since the mid-1990s, the government has followed a mix of direct and short-term policy instruments, as well as indirect and long-term policies. Currently, the focus seems to be on long-term intervention (e.g. the establishment of the Innovation Park). However, most of the key challenges in knowledge production and acquisition in the bio-sector need to be addressed through short-term intervention (e.g. the national IP system). Government

initiatives play a significant role, whereas most of the examples target different support mechanisms for innovators and less focus is observed regarding the awareness of the actors, entrepreneurial education, and cultural issues.

The transition to entrepreneurial practice and culture is still in the infancy stage. The findings implies the need to focus on three areas: policies to enhance connectivity between the three institutional spheres and particularly university-industry links; de-regulation of some existing policies, e.g. long administrative procedures in research management; and institutional re-structure to minimise fragmentation of processes.

## **8. Conclusions**

### **8.1. Introduction**

Commercialisation and knowledge entrepreneurship have gained a considerable attention by researchers and policy makers because of their role in promoting technological innovation as well as social and economic development (Abreu and Grinevich, 2013; Rajaeian et al., 2018; Shan et al., 2018). Within its national systems for innovation, Oman has made concerted efforts to support research and innovation and embed their role in different economic sectors, including the bio-sector, for the overall national development. The literature on biotechnology, which is an important subset of the bio-economy, emphasises 'the importance of biotechnology research, its application and commercialisation of biological research and innovation in different sectors of the economy' (Bugge et al., 2016, p 691). Drawing on the notion of diversification of national economy that has emerged as a central issue in policymaking in Oman over the last two decades, the transition to the knowledge-driven economy is often argued to play a key role in targeting the bio-sectors' challenges such as water and food security, as well as at offering opportunities for regional development, competitiveness and employment through innovation (NRS, TRC, 2008).

This thesis has sought to contribute to the broad academic and policy debate in commercialisation topics by conceptualising the Omani bio-sector. It embraced both the NIS actors and processes and it addressed questions pertaining to the transformation to commercialisation; knowledge networks and interactions; and national support mechanisms. Not only has the thesis shed light on the entrepreneurial activities in the bio-sector, but also contributed to the understanding of the influence of geography and intermediaries. It analysed the less explored angle of the cultural and social characteristics of the actors and their perspective concerning knowledge production, sharing, and commercialisation.

This is the final chapter of the thesis that aims to set down concisely the main contributions to knowledge made by this thesis. Given that the empirical chapters were finished with the conclusions, this chapter focuses exclusively on a succinct review of the

answers to the five research questions. It consists of three sections, and is organised as follows. The first part concisely synthesises the answers to the research questions 1-4 that are reiterated below. The second part tackles the broader context of the commercialisation addressing issues pertaining to national support system and government initiatives to enhance commercialisation, as articulated in research question 5. The last part outlines the fields for future research.

## 8.2. Knowledge commercialisation in Oman's bio-sector: Actors, transformation, and networks

*Research question 1: Who are the key actors for commercialisation of the bio-sector within the Omani national innovation system's institutions?*

Given the collaborative nature of innovation in the bio-sector, combined with the large investments in research laboratories and high risks of commercialisation (Bugge et al., 2016), this thesis gives considerable attention to the actors present in the commercialisation process and policy debate. The analysis indicates that actors of the bio-sector are grouped into three categories: knowledge producers, policymakers and intermediaries, and the bio-based industry. By referring to the NIS perspective, the most prominent actors for innovation are the knowledge producers, which include academia and public research centres. Unlike the well-developed systems of innovations where firms are the key knowledge produces (Gibbons et al., 1994; Jacob et al., 2000; Edquist, 2008; Yoon and Hyun, 2009), universities and public research centres are the key locus of innovation in the bio-sector.

The typology of these actors is characterised by four distinctive features: hierarchy of actors, high dynamics, replication of organisational culture, and lack of conformity between a formal organisational structure and its core activities. The government continues to have an influential role. One of the underlying rationales is that government funds remain the main source of finance for research and innovation, as well as the main employer for biosciences graduates. On the other hand, there is no big role for academia and industry in formulating national policies and strategies for research and commercialisation.



As Chapter 5 explained, the hierarchy status of actors has shaped the type of interactions between the actors in terms of knowledge flow and the adoption of organisational practice. With high dynamism, more actors emerge and the tendency to dilute hierarchy status increases and shifts the 'centre of gravity' to other new actors. However, the actual rise in the numbers of actors does not occur in the three institutional spheres (academia, industry, and government) and most of the emerged actors are in the interfaces between the key spheres. These intermediary organisations include funding agencies, SMEs facilitators, technology incubators, and other public sector bodies. These intermediaries help to fill the gap left by underdeveloped spheres and the absence of active boundary spanners in the three interfaces. Yet, the new actors in most cases mimic the existing actors, which lead to the replication of organisational culture. Consequently, the organisational culture of dominant actors is replicated in the newly formed actors. This reduces the degree of diversity between actors, whereas the formal view and the title of the organisation is not compatible with the core practice.

During the study period, biosciences research has been performed in universities and public research centres with the internal funding and was mainly directed to the basic research. Nevertheless, the concept of commercialisation of research outcomes existed from the idiosyncratic phase, indicating the existence of knowledge gap within and between the three institutional spheres of the actors. This gap was further enhanced by actors' typology and their social and functional patterns. Therefore, these characteristics have twofold effect; on the one hand it shaped the learning of the actors within the innovation system. On the other hand, the university represents a prominent actor for bioscience innovation and the key producer for biosciences' knowledge (discursive knowledge, i.e. publications, and tacit knowledge in the graduates). In this manner, the thesis has addressed the key research gap by shedding light on the bio-sector in a fledging NIS. It also advanced research on actors of NIS by presenting how knowledge is produced in multiple loci for innovation (Lundvall and Borrás, 1998; Liu and White, 2001; Vertova, 2014), as well as the understanding of the cultural and social characteristics of actors in less developed economies.

*Research question 2: How are the commercialisation actors in the key institutional spheres transformed towards knowledge commercialisation and entrepreneurship?*

The analysis of the internal key drivers for the transformation towards academic entrepreneurship indicates that the bio-sector experience in Oman is unique and its evolution is an interesting subject for study. The external pressure on knowledge producing actors has shaped the transformation process, which exhibited three phases. The dominant phase is the attempt to 'emulate' successful ideas based on models of USA firms and most actors went through it, especially during the idiosyncratic phase. The second common phase is the attempt to 'localise' the successful ideas based on the Omani context. The third phase is the attempt to 'explore' real opportunities for commercialisation and academic entrepreneurship. In this way, the thesis has advanced research on the changes in knowledge producing actors (Etzkowitz, 2003; Hewitt-Dundas, 2011; Abreu and Grinevich, 2013) by showing how different systems for knowledge generation adapt to accommodate new trends. Consequently, it has further developed the understanding of the phases of change as an adaptation to external drivers (Rasmussen et al. 2006).

Although the majority of literature tends to emphasise the transformations of the higher education institutions towards the third mission of knowledge entrepreneurship, this thesis indicated that transformation took place in all the three institutional spheres. During the study period, the institutional transformations of the key spheres took place at different paces. With the strong political commitment to diversify the national economy, the organisational pathway to transformation was derived initially by bottom-up proposals. Within each sphere, the role of individual initiatives was profound during the idiosyncratic phase, suggesting the complexity of human component in the process of transformation, taking the role of knowledge carriers who proposed the changes and guided decision-making process. This role was reduced as more actors evolved in the NIS and the centralisation of processes reduced. In this way, the thesis has offered new insights into research on transition to the third mission by showing how individual efforts and bottom-up initiatives has shaped the transition in the bio-sector (Soete, 1999; Jurado et al. 2008; Jonkers, 2011). This is now

evidenced for example by the ICT sector in Oman which is derived mainly by the top-down approach that takes 'centrally planned' type.

Taking into account the small size of the bio-sector, the analysis demonstrates a significant role of the trans-institutional impact, as the three spheres are not equal. The academic sector exerted a compelling effect to consider biotechnology as a new and promising field, especially with employment issues. Thereby, it shortened the idiosyncratic phase within the academic sphere and increased the awareness of external stakeholders. Whereas the bio-based industry remained the silent figure, the government sphere absorbed the experience of the university and a common 'School of thought' emerged with regard to lab management and funding strategies. Consequently, the findings have developed further the understanding of impact of one sphere on other within the transition process (Etzkowitz, 2008; Changa et al., 2009).

The co-evolution pattern of commercialisation processes and actors occurred in all institutional spheres simultaneously but not equally; the changes were more evident in the academia and the public sector (See chapter 5). Four drivers shaped the change; the internal perception of knowledge-generating process, diversity of public funding, functional and organisational changes of actors, and the changes in the coordination mechanisms between key actors. This research is, therefore, instrumental for understanding the co-evolution of organisations with changes in the institutional framework of the national research system (Lynskey, 2006). However, knowledge networking exhibits decoupled type of development. The bi-lateral and the trilateral linkages are shaped by the intensity of networking activities and the openness of other actors. The transition was a multi-level process that utilised knowledge, organisational practices, and the culture in the three institutional spheres. This implies the need to rethink the process of knowledge entrepreneurship in the light of changing roles of the universities and the emerging roles of other actors (the government and business). The finding has confirmed the theoretical assumptions regarding the confluence of multiple approaches in the development and transition to commercialisation and technology transfer (Colyvas, 2007).

Thereby the analysis of transformation in the bio-sector advances the understanding of the factors that derived the transition of NIS actors to the third mission (Jonkers, 2011; Moeliodihardjo et al. 2012; Silva et al 2012), and in particular the transformation of universities to the entrepreneurial paradigm (Rasmussen et al. 2006; Colyvas, 2007; Bramwell and Wolfe 2008; Etzkowitz, 2008; Youtie and Shapira, 2008). From the theoretical perspective, these findings indicate that the evolutionary perspective of the NIS approach is not sufficient to address the holistic aspects of transformation, particularly in different setting of knowledge production, which is characterised by the absence of strong local business actor. The use of multi-lens theoretical framework allowed to study of internal transformation and the trans-institutional role through the TH model (Etzkowitz *et al.*, 2000; Etzkowitz, 2003; Etzkowitz and Leydesdorff, 2000),

*Research question 3: What are the modes and dynamics of knowledge networks in the bio-sector?*

Given the importance of linkages between the NIS actors in the transfer of innovation-related knowledge (Giuliani 2010), this thesis contextualises these interactions at two levels, the bi-lateral and tri-lateral levels. The analysis indicates that although there are active interactions between actors at the bi-lateral levels, the tri-lateral and multilateral coalitions are mainly determined by the perception of partnership at different stages of knowledge-production and the openness for linkages. Thereby, the typology of knowledge networking is phase-dependent, where informal linkages dominate the interactions, particularly in the initiation stages. For academic knowledge-producing organisations, the inter-organisational networks are active, whereas cross-institutional networks are more effective with non-academic knowledge-producing organisations. Therefore, the evolution of the tripartite interaction in bio-sector confirmed the analogy of the 'dance hall' (Powell et al., 2005), as both the actors and the institutional spheres shift over time.

The interactions between actors take different types of knowledge sharing activities, whereas commercialisation-related types are limited, suggesting the need to widen the current focus of the literature, which is mostly on patent-based activities to include other knowledge-based activities (Abreu and Grinevich, 2013). This thesis contributes to the topic

of formal versus informal interactions and confirms the role of 'systemic interactions with other key players' (Powell *et al.*, 1996; Gilman and Serbanica, 2014). In essence, the extent of the knowledge networking depends on the openness of the key actors for collaboration, which is a cultural element, therefore, confirming the link between enterprise activity and the overall community culture (Huggins and Thompson, 2012).

The analysis of the mechanisms for selecting partners between network actors in the bio-sector suggests the importance of the tacit knowledge throughout the networking cycle (Murray, 2002; Jensen, 2016). For the initiation of the partnership, 'knowledge-based factors' (market-related as well as science-related) (Thursby and Thursby, 2011<sup>b</sup>) plays a key role. Furthermore, hard entrepreneurial capabilities, such as the availability of compatible partners, funds, and organisational logistics, play a secondary role. The maintenance of sequential stages of knowledge networking (the active, the stationary, and either the decline or regenerative phases) is mainly directed by the previous experience and both the role of organisational culture and the individual mind set. Five modes of selection are identified: the pre-determined selection, the intermediary-influenced, common interest-related, previous experience-based selection, and the reversible selection. Thus, the thesis advances the knowledge on research of network formation and the factors that drive choices of partnership for commercialisation (e.g. Belderbos, *et al.*, 2004<sup>a</sup>; Belderbos, *et al.*, 2004<sup>b</sup>; Bercovitz and Feldman, 2007; Bercovitz and Feldman, 2011; Johnston and Huggins 2016).

Therefore, the thesis adds to the work on the role of knowledge networking to enhance commercialisation (Dundas, 2011; Perkmann *et al.*, 2013), by identifying the modes of interactions and the motivations. The thesis also contributes to the understanding of UI linkages, especially within the concept of open innovation (Kautonen *et al.*, 2014). In similar vein with the literature on high-tech clusters (e.g. Huggins, 2008), the phases of knowledge networking are explored according to the actors' inter-dependence (Powell and Brantley, 1992) and available resources, which implies the need for adopting new approaches such as the concept of 'building up territorial knowledge pools' (Benneworth and Charles, 2005). Finally, from the theoretical perspective, the TH model addressed the interactions for the creation and reproduction of knowledge, as well as dynamics of networking, which is similar

to other empirical studies (e.g. Moeliodihardjo et al., 2012; Silva et al, 2012) who applied the TH model to university-industry-government in less developed economies.

Drawing on clusters' literature, the preferred policy solutions to promote collaboration between innovation actors have been to promote the establishment of high technology clusters (Porter, 2008; Huggins and Izushi, 2011; Manning, 2013; Bugge et al., 2016). However, this research has proved the importance of the involvement of industry and other actors through public-private partnerships that blur the boundary between public and private interests of innovation. This means that particularly in the bioscience sector, there is a need to enhance interactions via government-enhanced linkages while encouraging the 'selectivity valuable U-I linkages' (Giuliani and Arza, 2009; Giuliani et al., 2010). This can be achieved by granting incentives for interactions between different spheres through the improvement in the existing evaluation and reward mechanisms of researchers in knowledge producing organisations. The incentives have to match both personal and organisational motives, such as additional funding, access to resources, and recognition. As the culture within the institutional setting of the bio-sector values recognition, the actors can promote recognition of active researchers by peers and socially. Moreover, the government can put in action policies that recognise the outstanding achievers, allowing temporary leave or part-time prestigious positions.

Similarly, government-enhanced linkages require including the employment of biotechnology graduates, as indicated in the finding; 'Biotechnology from Mars, the employers from Venus' (Chapter 5, p 121). Finally, it needs to be underlined, that the influence of language barrier between the key actors at different stages of knowledge production and sharing is still rather an unresolved issue. During the initial stages, most of the challenges are found to be in the communication between the actors within and among the three institutional spheres. This finding suggests that communication gaps and language barriers seems to be a result of the rapid institutionalisation of biosciences and biotechnology research in knowledge-producing actors as most of the evolution milestones were triggered by bottom-up proposals, confirming the wider perspective of the institutionalisation patterns of biotechnology in the academic sector (Colyvas, 2007).

*Research question 4: What is the influence of network resources, spatial proximity, and intermediaries on knowledge networking in the bio-sector?*

The analysis of knowledge networking in the bio-sector indicates that technological, organisational and institutional resources have a significant influence on the emergence of collaborations, and thus advanced the understanding of the role of network resources (Ankrah et al., 2013; Freitas et al., 2013). As the perception of proximity differs among the actors, the Boschma's (2005) fivefold classification of geographical, cognitive, social, institutional and organisational proximity was used to study the topic from different perspectives. The discussion showed a relative importance of each proximity dimension depending on the type of knowledge being produced and the mode of collaboration, whereas actors benefit mainly from social proximity. In this way this research is instrumental for understanding the interdependences between proximity dimensions (Marek, 2017; Davids and Frenken, 2018; Hervas-Oliver, et al., 2018).

As knowledge production and the absorptive capacity of the local bio-based industry are too low, the three spheres prefer international collaboration over domestic partnerships. Thereby, it can be argued that the role of different dimensions of proximity in a fledging system of innovation is further influenced by the entrepreneurial capabilities that shape the selection of distant knowledge compared to the localised knowledge. The findings contribute to the understanding of actors preference of domestic or international collaboration (Qiu, 2017), and advance the theoretical assumption concerning geographical proximity as not the key prerequisite for effective knowledge interaction between the actors (Cooke and Huggins, 2004; Ratinho and Henriques, 2011). Furthermore, it broadens studies at the individual levels of researchers and graduates and the role of geographical and social proximity in science-based businesses (Larsson, et al., 2017).

While responding to the question pertaining to the role of cognitive proximity, the thesis has indicated that the 'concept of knowledge base homogeneity' (Subramanian, et al., 2018) applies to the case of actors of the bio-sector. Linkages draw upon similar sets of knowledge elements play role in enhancing network convergence at both the organisational and inter-organisational levels. Considering the cultural factors in the local institutional

setting, such proximity influenced inter-organisational interactions and learning, especially in the context of young newly-established organisations with limited knowledge stocks, e.g., private universities and public research centres. Thus, the thesis confirms that cognitive and organisational proximity are equally important for enhancing collaboration between various knowledge-producing actors (Oinas and Malecki, 2002).

The discussion about the role of innovation intermediaries in the NIS of the bio-sector (See chapter 6) showed a key 'facilitator' function, with more positive impact during the idiosyncratic phase. Thus it advanced the previously defined roles of innovation intermediaries as network builders, bridgers (Yusuf, S. 2008; Caloffi et al., 2015) and innovation system architects (Klerkx and Leeuwis, 2008). The emergence of intermediaries at the interfaces continued during the study time (1995-2015), whereas intermediary actors between the academic sector and industry are considered more significant, as they are directly related to knowledge production and commercialisation, as well as they maintain their importance from the knowledge and experience of interactions with various actors. However, as more actors emerged in the interfaces, the flow and sharing of knowledge reduces. In this way, the thesis has offered new insights into research on knowledge-based practices adopted by innovation intermediaries (De Silva, et al., 2018).

Finally, the TH model and NT frameworks applied in the thesis highlighted the importance of individuals and other non-governmental actors in the process (see: Section 5.3). The notion of 'recombinant actors' (derived from recombinant DNA molecule, quoted in chapter 6 p 190), is thought by the interviewees to be the possible status that can further enhance the role of innovation intermediaries. By this means, instead of forming new actors, the existing ones can be 'engineered' to carry on 'recombinant roles', taking into account the size of the bio-sector and the fact that most of the knowledge intermediation roles are performed by government bodies. Therefore, the key implication of these findings implies that the government needs to review the organisational roles of the intermediary actors in the interfaces in order to enhance hybrid roles. It is equally important to enhance the participation of actors from other spheres, such as the private sector, the NGOs or individuals, in order to increase the diversity among intermediary actors.



### 8.3. The 'entrepreneurial mutation': The national support mechanisms for commercialisation

*Research question 5: What are the implications of commercialisation capabilities and government initiatives on the transition to knowledge entrepreneurship?*

Through the analysis provided in this thesis, it has been established that the commercialisation of biosciences knowledge has become much more than just a national scheme and can serve as a platform that allows examination of the entrepreneurial ecosystem in a fledging system of innovation. By investigating the broader context of the national support mechanisms, the commercialisation process may be strongly affected by four components; the hard and soft entrepreneurial capabilities; the business environment; the policy framework; and intangible elements of entrepreneurial knowledge and culture. As this thesis focuses on one sector that is the Omani bio-sector, it has further developed the studies on antecedents to enhance the evolution of university entrepreneurialism (Lehrer et al., 2009; Changa et al., 2009; Hewitt-Dundas 2011).

Among the entrepreneurial capabilities, the thesis highlighted the role of individual biosciences researchers, as most of commercialisation initiatives driven by personal motivations. However, it is essential to consider other factors beyond the individual academic, such as research niche, funding mechanisms, the presence of active TTO. In this way, the study broadens the knowledge about the drivers for academics to pursue entrepreneurial activities (Lam, 2010; Fini et al., 2011), as well as the role of academic entrepreneurial behaviour (Abreu and Grinevichb, 2013; Holley and Watson, 2017).

Commercialisation of research and academic entrepreneurship is still new in Oman. UI linkages emerged in the mid-1990s and most knowledge-based interactions were based on informal relations at the scholarly level of biosciences sector. The government supported these interactions, but did not pursue an active S&T policy at that time. Commercialisation-related policies, especially the national IP law that is derived from the Bayh Dole Act, evolved alongside other industrial policies and higher education strategies. Knowledge-producing actors continue to deal with commercialisation topic on case-by-case base, as the law is not explicit about the control rights and the sharing of income between the organisation and the

academic inventors. As demonstrated in chapter 7, the IP law is one of the key determinants of researchers' tendency to pursue applied research for commercialisation purpose. This results are in line with recent study of (Halilem, *et al* 2017), which suggests that contrary to most of the literature; academic inventors' behaviour is influenced by other details of the invention ownership regime, such as the internal issues between the researcher and the organisation.

The findings demonstrate also that commercialisation-related policies and strategies are not strictly 'national', from the very beginning. Therefore, the implementation of imported policies remains a controversial topic. Although local knowledge producers adopting the USA model, policy actors maintain a cautious status regarding the implementation of 'imported policies'. Thereby, the thesis sheds light onto the topic of the transformational effect of R&D policies like the Bayh Dole and the international emulsion of this policy regarding university management of IP and licensing (e.g., Aldridge and Audretsch, 2011; Geuna and Rossi, 2011; Girmaldi et al., 2011; Kenney and Patton, 2011; Thursby and Thursby, 2011<sup>a</sup>; Andersson et al., 2012; Huggins and Kitagawa, 2013).

As Chapter 7 explained, skilled HR and lab facilities are the most critical input to the research leading to commercialisation. Considering that the government supports knowledge-producing to establish entrepreneurial infrastructure, the key implication is that the government need to plan a transition towards central research and innovation facilities that can enhance all actors to pursue applied research. In this scenario, the variation in lab sophistication will be minimised, as every actor retain the basic facilities in host organisation and utilise the access to the central facilities. Hence, more interaction and exchange of tacit knowledge will be induced, and the culture of "sharing" can be enhanced. This scenario will also reduce fragmentation and replication of efforts, the two leading causes to low performance in the public sector.

The issue of commercialisation-related policies has been interwoven in the whole thesis. Chapter 7 has explained the specificity of the policy formulation process and the role of policy actors. Basically, the government has followed a mix of direct and short-term, as well indirect and long-term policy instruments, with more focus on the long-term intervention

(e.g. the Innovation Park). However, most of the key challenges in knowledge production and acquisition in the bio-sector need to be addressed through the short-term intervention (e.g. the national IP system) (Hong et al., 2016; Wang, 2018). As the bio-sector evolved, the need to compensate the incomplete policy framework induced the emergence of small-scale government initiatives that operate within the 'innovation spaces' (Etzkowitz, 2008). These initiatives prove to deliver more efficient outcomes compares to the well-established policies. By this way, the thesis offers new insights into research on the role of government as 'market facilitating state' (Mok, 2005; Luukkonena and Nedeva, 2010). It broadens the understanding of the influence of government-led initiatives and the role of 'strategic' actors, which adds to the work on government role that supports research capabilities and organisational productivity (Met, 2006; Liu et al., 2011).

Nevertheless, the role of government remains essential within the Omani NIS, and it is important to consider its dual role as policy actor, funding source and incubator at the same time. This perspective is in line with other systems of innovation, where government R&D subsidy successfully addresses market failure in private R&D investment. Public financing at different stages of knowledge production and commercialisation results in higher formation of science-based enterprises (Hong et al., 2016; Choi and Lee, 2017). For example public funding of biotechnology start-ups in Japan has resulted in higher rate of start-ups, compared to VC, with those originating from universities are more likely to go public earlier than other start-ups (Honjo and Nagaoka, 2018). This thesis contributes to the understanding of how the selection of policy instrument according to long-term or short-term objectives, was adopted during the study period. Therefore, the findings shed light on the role of government as a policy actor and advance knowledge regarding the influence of government intervention on enhancing the technological innovation (Huggins and Williams, 2011; Wang, J. 2018).

These findings imply the need to consider three types of interventions. Firstly, the completion of lacking policies, such as the national IP law is essential. Secondly, some policies require reformation in order to remove the obstacles to knowledge production process, such as the public procurement. Finally, the adoption of short-term direct policies and

government initiatives need to focus on the key bottlenecks in knowledge commercialisation, such as funding for development of embryonic outcomes of biosciences research and entrepreneurship training fund.

The entrepreneurial culture within the NIS in Oman remains less explored. Broadly, one can conclude that for the success of knowledge commercialisation, the social and cultural dimensions of the actors require more attention. The cultural setting in the three institutional spheres plays a role relating to enabling the atmosphere for “entrepreneurial attitude of mind’ (Gibbons et al., 1994; Stokes, 1997). While the literature has focused on the role of entrepreneurial culture in the academic sphere (e.g. Bramwell and Wolfe 2008; Kato and Odagiri, 2012), this research has indicated the importance of the entrepreneurial culture in non-academic setting. Such impact is demonstrated in the mechanisms of selecting partners for networking which are attributed mainly to the entrepreneurial culture and the social characteristics of the network actors (see: Section 6.6). This extra layer further reinforced the theoretical discussion of the role of entrepreneurial culture in the institutional setting of fledging systems of innovation, as suggested in recent study of (Gümüşay, and Bohné, 2018) about structural and cultural-cognitive inhibitors to the development of entrepreneurial competencies in universities.

As shown above, one of the fundamental cultures of the actors that have hugely influenced the processes of knowledge production and networking is the hierarchy structure of the actors, suggesting a comprehensive yet decentralized approach for the development of entrepreneurial competencies. Therefore, the key implication is the importance to “shift the centre of gravity” from one dominant actor by supporting other actors. The potential candidates are the private universities, as there are examples of good performers in teaching and research. There is a need to enhance private universities to overcome the shortage of expansive lab facilities for research purpose. In addition, these universities need to reduce the high load of teaching that prevents academics from doing research.

Finally, the multi-angled theoretical framework of NIS, TH, and NT applied in the thesis highlighted the importance of the social and cultural dimensions of commercialisation actors. Within the fledging system of innovation in the bio-sector, it is essential to consider

what is referred to by the interviewee as the '*entrepreneurial mutation*'. Policy actors are required to restore the entrepreneurial culture through an extensive education and awareness programmes, which mainly target two objectives; on the one hand, the transformation from the culture of collectivism to collaboration, and on the other hand, the embedding of the culture of sharing between actors. The entrepreneurial mutation can be further enhanced through long-term commitment in education, e.g. school curriculum and student competitions.

#### 8.4. Future research

The empirical research conducted for this thesis has signalled several research avenues that merit further investigation, which includes three significant areas: the institutionalisation of knowledge commercialisation, the role of proximity, and woman academic entrepreneurship in the biosciences. This study has focused on the evolution of knowledge production for commercialisation and the overall evidence is that the transformation in knowledge-producing actors is an interesting topic. It included several actors and bidirectional pathways of bottom-up and top-bottom proposals. Therefore, it is important to shed more lights on the topics that contribute to the understanding of the performance of commercialisation.

Given that, the commercialisation process is both long and complicated, and is affected by the environment of the knowledge-producing organisations, specifically the process of institutionalisation of organisational learning in biosciences and biotechnology. Future studies are required to explore the efforts made by these organisations to incorporate technical and tacit knowledge at the organisational level. Such studies could explore the roles of knowledge carriers play in the institutionalisation of commercialisation of biosciences research. Furthermore, the organisational memory of knowledge-producing actors can be analysed to assess the post-institutionalisation process and the role of the embedded knowledge in enhancing or inhibiting the next learning process. These studies can provide more explanation on the performance of knowledge-producing organisations.

This study discusses the impact of geographical proximity and other dimensions of proximity on knowledge networking between the actors in the bio-sector. The outcomes suggests limited role of geographical proximity indicating both positive and negative impacts. Accordingly, it is important to expand the knowledge of the role of proximity by investigating the problem of actors lock-in, which is one of the key problems that impede active interactions and learning (e.g. Wang and Lin, 2018). More work is required with regard to the role of social networks in knowledge networking between university departments and co-located actors, in the light of the availability of 'world-class science' for big established actors. Such studies can shed more light to whether geographic proximity matters in the transfer of tacit knowledge and the mechanisms of selecting collaborates within actors of the bio-sector.

Further work is also required to study the contribution of female bio-scientists in the formation of entrepreneurial science-based firms as it becomes a significant area of research (e.g. Chatterjee and Ramu, 2017; Whittington, 2018). In literature, most studies focus on female entrepreneurship in scientific fields that were traditionally male-dominated and are now experiencing a significant gender shift toward the predominately female, such as human and veterinary medicine or engineering. However, the academic organisations in the Omani bio-sector witnessed the predominance of female students in the biosciences and biotechnology fields. The study of women academics' commercialisation activity offer new insights for the impact of different academic support environments, career advantages, and reward structures. It is significant to focus on commercial involvement of female bio-scientist in the institutional setting of the bio-sector (i.e. hierarchical organisations, limited social networks) as it add another level of knowledge with regard to decision for involvement and the available opportunities. Such studies can explore whether female bio-entrepreneurship is the overlooked opportunity.

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## 10. Appendices

### Appendix A: List of interviewees

Knowledge producing actors (Academics, researchers and supporting knowledge staff)

Participants	Organisation
Biotechnology Professor	Public University
Former HoD Biology Department	Public University
Dean of College of Science	Public University
Assistant dean for research and post-graduate studies (College of Science)	Public University
Assistant Dean for Research and Post-graduate studies (College of Agricultural and Marine Sciences)	Public University
Head of Microbial Enhanced Oil recovery research Unit	Public University
Microbiologist	Public University
Researcher (industrial biotechnology)	Public University
Genetics Professor	Public University
Biology Professor	Public University
Research technician	Public University
TTO personnel	Public University
Former Dean of applied Sciences	Higher College of Technology
HoD of Applied Sciences	Higher College of Technology
Senior Lecturer (Biology)	Higher College of Technology
Senior Lecturer (Biochemistry)	Higher College of Technology
Director of the Aflaj Research Unit and Assistant Dean For Training	Private University
HoD Biotechnology	Private University
Biochemistry Researcher	Private University
Former Dean of Research	Private University
Veterinary Epidemiologist	Public Research Centre
Crop Sciences Researcher	Public Research Centre
Expert (Plant genetics)	Oman Centre for Animal And Plant Genetic Resources
Expert (Microbial genetics)	Oman Centre for Animal And Plant Genetic Resources
Director General of Arab Organisation for Agricultural Development (founder of tissue culture lab in the public research Centre early 1990s)	Arab Organisation for Agricultural Development (AOAD) - Head Office (Sudan)



## Policymaking actors and intermediaries (Government employees)

<u>Participants</u>	<u>Organisation</u>
Director of Information Management	National Centre for Statistics and Information
Statistician (Office for Oman 2040 Vision)	National Centre for Statistics and Information
Director of Development Planning	Supreme Committee for Planning
Director General for Agricultural & Livestock Research	Public Research Centre
Under Secretary for Agriculture	Ministry of Agriculture and Fisheries Wealth
Head of Agricultural and Fisheries Statistics	Ministry of Agriculture and Fisheries Wealth
Director of Research programs	The Research Council
Director of Innovation	The Research Council
Technical staff - IP department	Ministry of Industry and Commerce
Section Head – Business creation	The Public Establishment for Industrial Estates
Director of SMEs development	The Public Authority for SMEs Development
Section Head - Scholarships & studies	Ministry of Higher Education
Agricultural scientist	Retired government staff
Laboratory analyst	Retired government staff
Food Chemist	Retired government staff

## Bio-based industry and business

<u>Participants</u>	<u>Organisation</u>
Engineer	Oil Company (a)
Engineer	Oil Company (b)
Environmental Engineer	Individual entrepreneur
Biotechnologist	Environmental consultation company (a)
Environmental biologist	Environmental consultation company (b)
Bioremediation specialist	Environmental services company
Production Director	Fisheries company (a)
Quality Control (QC) Specialist	Fisheries company (b)
Food processing specialist	Food Manufacturing company (a)
Marketing, communication & outreach specialist	Food Manufacturing company (b)

## Appendix B: Consents

### Appendix B. 1: Informed Consent Form for questionnaire

**Project:** Commercialisation of biosciences research in Oman: the entrepreneurial challenge

**Context:**

This questionnaire is part of an academic research project that is funded by the Research Council of Oman (TRC) for a PhD degree and is done in Cardiff School of Geography and Planning, UK. It aims to study the performance of knowledge commercialisation and academic entrepreneurship in the sector of biosciences research in Oman. The study attempts to analyse the interactions and networks between the key players (academia – government – industry/business) in order to map the interactions in reference to the triple Helix model of innovation. The study also evaluates the influence of institutional capabilities, as well the role of commercialisation policies. It is expected that the outcomes of this will identify entrepreneurial challenges and provide policy implications. It can also serve as reference material for policymakers, academicians and researchers about university-industry linkages and emergence of technology clusters in Oman. All the information you supply us with will remain confidential, and will only be used for academic purposes.

I, the undersigned, agree to participate in this project and confirm that:

1. I have read and understood the information about the project, as provided in the information sheet. Also, I have been given the opportunity to ask about the scope of this project and my degree of participation.
2. I understand that my participation in this questionnaire and the information it contains will be used solely for the purposes defined by the research project.
3. I voluntarily agree to participate in this project, bearing in mind that I can withdraw at any time without giving reasons.
4. I understand that I can decline to answer certain questions without justification.
5. I understand that the questionnaire data will be handled so as to protect their confidentiality. Therefore, names of participants or their organisations will not be mentioned, and the information will be coded.
6. I understand that I have been selected to participate in this questionnaire as an autonomous research object and my opinion does not represent my current affiliation or any other organisation throughout my career.

**Participant:**

Name:

signature:

Date:

**Researcher:**

Name:

signature:

Date:

## Appendix B. 2: Informed Consent Form for interview

**Project:** Commercialisation of biosciences research in Oman: the entrepreneurial challenge

**Context:**

This interview is part of an academic research project that is funded by the Research Council of Oman (TRC) for a PhD degree and is done in Cardiff School of Geography and Planning, UK. It aims to study the performance of knowledge commercialisation and academic entrepreneurship in the sector of biosciences research in Oman. The study attempts to analyse the interactions and networks between the key players (academia – government – industry/business) in order to map the interactions in reference to the triple Helix model of innovation. The study also evaluates the influence of institutional capabilities, as well the role of commercialisation policies. It is expected that the outcomes of this will identify entrepreneurial challenges and provide policy implications. It can also serve as reference material for policymakers, academicians and researchers about university-industry linkages and emergence of technology clusters in Oman. All the information you supply us with will remain confidential, and will only be used for academic purposes.

I, the undersigned, agree to participate in this project and confirm that:

1. I have read and understood the information about the project, as provided in the information sheet. Also, I have been given the opportunity to ask about the scope of this project, and my degree of participation.
2. I understand that the interview I give, and the information it contains will be used solely for the purposes defined by the research project.
3. I voluntarily agree to participate in this project, bearing in mind that I can withdraw at any time without giving reasons.
4. I understand that I can refuse to answer certain questions, decline to discuss certain topics, or put an end to the interview without justification.
5. I understand that the interview is recorded, and data (audio, video or other forms) will be handled so as to protect their confidentiality. Therefore, names of participants or their organisations will not be mentioned, and the information will be coded.
6. I understand that I have been selected to this interview as an autonomous research object and my opinion does not represent my current affiliation or any other organisation throughout my career.

**Participant:**

Name:

signature:

Date:

**Researcher:**

Name:

signature:

Date:

## Appendix C: Questionnaire and Interview plan

### Appendix C.1: Questionnaire

#### **Commercialisation of biosciences research outcomes in Oman: the entrepreneurial challenge**

**This questionnaire is part of an academic research project that is funded by the Research Council of Oman (TRC) for a PhD degree, and is done in Cardiff School of Geography and Planning, UK.**

The key purpose of this questionnaire is to collect information on how academics in the biosciences and biotechnology sector interact with the public, industry and the private sector. The results of this survey will help to improve understanding of the interactions between key players in the sector (academia – government – industry/business). It will also shed light on the nature and dynamics of university-industry linkages, as well the knowledge networks between the key players. Therefore, the outcomes of this survey will help to identify the entrepreneurial challenges and provide policy implications.

All the information you provide will be treated as strictly confidential and will be kept in anonymised form. The results will only be used for academic research.

The questionnaire should take less than 15 minutes to complete. If you have any questions or queries regarding the questionnaire or the study, please do not hesitate to contact me. Contact details are as follows:

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**Part 1: General information**

1) Please indicate your gender:

Male	<input type="radio"/>	Female	<input type="radio"/>
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2) Please indicate your age group:

Under 30s	<input type="radio"/>	30 -39	<input type="radio"/>
40 – 49	<input type="radio"/>	50 and over	<input type="radio"/>

3) **What is your position in your institution:**

Professor	<input type="radio"/>	Research Associate	<input type="radio"/>
Senior lecturer	<input type="radio"/>	Research Assistant / Teaching Assistant	<input type="radio"/>
Lecturer	<input type="radio"/>	Other ( <i>please specify</i> )	<input type="radio"/>

4) What is your main role in your institution:

<b>Teaching</b>	<input type="radio"/>	<b>Administrative activity</b>	<input type="radio"/>
<b>Research</b>	<input type="radio"/>	Outreach activity	<input type="radio"/>
<b>Management responsibility</b>	<input type="radio"/>	Other ( <i>please specify</i> )	<input type="radio"/>

5) What is your main subject area:

Biology /Environmental Studies	<input type="radio"/>	Veterinary Science	<input type="radio"/>
Biotechnology	<input type="radio"/>	Agricultural Studies	<input type="radio"/>
Marine Sciences	<input type="radio"/>	Other ( <i>please specify</i> )	<input type="radio"/>

**Part 2: Research activities and collaboration with other organisations**

6) Which of the following statements describes your research

Basic research: theoretical, empirical or experimental work driven by the researcher curiosity, with no specific application or intended use.	<input type="radio"/>
Demand-driven research: theoretical, empirical or experimental work that is mainly inspired by consideration of its demand.	<input type="radio"/>
Applied research: is a form of systematic inquiry involving the practical application of science	<input type="radio"/>
None of the above	<input type="radio"/>

7) If you undertake demand-driven or applied research, which of the followings describes the application of the outcomes

The outcomes have been applied in a commercial context	<input checked="" type="radio"/>
The outcomes are useful to business / industry / private sector	<input checked="" type="radio"/>
The outcomes are useful to non-commercial sectors (public sector)	<input type="radio"/>
None of the above	<input type="radio"/>

8) Which organisations do you collaborate with? Please indicate the geographical location of the organisations involved (for the purpose of this question, please refer to the 11 administrative regions of Oman as follows: Muscat, Al Dakhilyah, Musandam, Al Dhahira, Al Buraimi, Al Batinah North, Al Batinah South, Al Sharqiyah North, Al Sharqiyah South, Al Wosta, and Salalah)

Key collaborators or partners	Local area (10 mile)	Within Region	Other regions
Sultan Qaboos University			
Nizwa University			
Sohar University			
German University for Technology			
Higher College of Technology			
Ministry of Agriculture & Fisheries Wealth			
UNESCO Chair for Marine Biotechnology			
Ministry of Industry and Commerce			
Knowledge Oasis Muscat (KOM)			
Oil & gas companies			
Public Establishment for Industrial Estates (PEIE)			
Industrial Innovation Centre			
Other (please specify)			

9) For the past five years, have you or your research team engaged with other organisations with regard to the following activities?

Academic- oriented activities	Commercialisation - oriented activities	Other knowledge - based activities
Co-authorship	Spin - offs	School activities
Contract research	Licensing IP	Public lectures
Use of facilities	Joint venture	Conferences & forums
Consultancy	Partnership	Advisory boards
Training & placements		Brain-storming sessions
Other (please specify)	Other (please specify)	Other (please specify)

10) On a 0 – 4 scale (where 0 is never and 4 is on-going collaboration), how often do you collaborate with partners from other organisations?

Key organisations	0	1	2	3	4
<b>Public sector research centres or laboratories</b>					
<b>Private sector or industry</b>					
<b>Higher Education Institutes and universities</b>					

11) How often do you or your research team use ‘intermediary organisation’ to facilitate interactions with other organisations?

Intermediary	Always	Very likely	Moderately likely	If opportunity permits	Never
<b>Technology Transfer Office (TTO)</b>					
<b>Chamber of Commerce</b>					
<b>The Industrial Estates</b>					
<b>The Innovation Centre</b>					
<b>Business associations</b>					
<b>Other (please specify)</b>					

**Part 3: Institutional capabilities**

12) To what extent have the supporting mechanisms in your institution helped you in collaborating with other organisations in regard to commercialisation activities?

Supporting mechanisms	Extremely helpful	Significantly helpful	Partially helpful	No help
Availability of funds (public sector & industry)				
Physical infrastructures (Research labs, incubators, Technology parks)				
IP process				
TTO logistics (mentoring, networking, and outreach)				
Entrepreneurial culture & commercial mind-set				
Networks and awareness				
Market pull information				
Availability of Venture Capital and Foreign investments				
Other (please specify)				

13) On a 0 – 4 scale (where 0 is not important and 4 is highly important), please rank the motivation to collaborate with partners from other organisations

Motivation for collaboration	Rank
My institution is giving more weight to working with business and industry	
Collaboration with other organisation keeps my research up to date and allow pilot of the results	
Collaboration with other organisation allows using of advanced equipment	
Collaboration with other organisation create external source of funds	
Collaboration with other organisation strengthen my professional networks	

**Part 4: Governance and policy framework for research commercialisation in Oman**

14) To what extent do you agree or disagree with the following statements about the policy framework for knowledge commercialisation

Statements	Strongly agree	Tend to agree	Neutral	Tend to disagree	Strongly disagree
Entrepreneurship related legislations (e.g. IP law, patenting & licensing) are sufficient to support academic entrepreneurship					
The public sector is providing the needed funds to the higher education sector and R&D institutes					
There are reforms and expansions in the higher education system towards entrepreneurial university					
The government recognises biotechnology as a strategic industry and it aims to support it to become a leading economic player					
The overall financial and policy support is sufficient to support commercialisation of research outputs					

15) Do you have any other opinion or is there any other topic regarding knowledge commercialisation that you think it is worthy to be included in this questionnaire?

*Please write your answer here (No more than 250 words):*

- END OF THE SURVEY -

*Thank you for completing this survey.*



Appendix C.2: Interview Plan

**Theme 1: Networks: UI linkages, intermediaries, and proximity**

**Target participants:** All helixes (Academia / government / public sector / Industry)

Main questions	Additional /clarifying questions
<b>Q1:</b> How do you evaluate an effect or successful interaction between your organisation with external organisations regarding knowledge exchange activities?	
<b>Q2:</b> What would make you more likely to collaborate with other institutional spheres in the bio-sector?	<i>Can you expand a little on this?</i> <i>Can you give some examples?</i>
<b>Q3:</b> How effective do you find informal linkages and personal ties?	<i>Can you tell me your own story</i>
<b>Q4:</b> And how do you evaluate the role of intermediary organisations?	<i>or experience?</i>
<b>Q5:</b> How do you evaluate the advantage of co-location in enhancing interactions? And what type of linkages is more linked to proximity?	
Conclusion of theme 1 of the interview:	

1. In your opinion, what are the main 3-5 challenges for your institution to sustain effective linkages with other key actors in the sector?
2. Are there additional elements that are needed in supporting the bio-based actors in the industrial areas?
3. Are there any other networks issues that we have not discussed and that you find them significant?

**Theme 2: Entrepreneurial capabilities**

**Target participants:** Government / public sector / academia

Main questions	Additional /clarifying questions
<p><b>Q1:</b> To what extent do you think sufficient procedures/plans/funding for supporting knowledge commercialisation are in place at Omani higher education/research funding institutions?</p>	
<p><b>Q2:</b> How do you evaluate the supports for business innovation in Oman generally (e.g. entrepreneurial education, workforce training and development, science and engineering education)?</p>	<p><i>Can you expand a little on this?</i></p> <p><i>Can you give some examples?</i></p> <p><i>Can you tell me anything else?</i></p>
<p><b>Q3:</b> In your experience, how do you evaluate the physical infrastructure to support research activities?</p>	
<p><b>Q4:</b> Please identify the 3-5 most important barriers, in your views, that face research commercialisation, academic engagements and /or academic entrepreneurship?</p>	
<p><b>Q5:</b> How do you evaluate the local entrepreneurial culture and mindset of individuals and organisations?</p>	
<p>Conclusion of theme 2 of the interview:</p>	
<ol style="list-style-type: none"> <li>1. In summary, what are the main actions needed from your organisation to enhance entrepreneurial capabilities?</li>   <li>2. Are there any other capacity issues that we have not discussed and that you find them significant?</li> </ol>	

**Theme 3:** Entrepreneurial environment**Target participants:** Business / Private sector

Main questions	Additional /clarifying questions
<b>Q1:</b> In your business, what is the main source of knowledge (e.g. university research, consultation)?	
<b>Q2:</b> Do you think the entrepreneurial environment (business creation cycle, investment & commercial laws) is capable of supporting science-based ventures?	<i>Can you expand a little on this?</i>
<b>Q3:</b> To what extent the current linkages and interactions with other organisations supports your business?	<i>Can you give some examples?</i>
<b>Q4:</b> What changes would most improve the roles for the private/business sector in the commercialisation process (e.g. IP regime)?	<i>Can you tell me your own story?</i>
<b>Q5:</b> In your opinion, do you think the quality of life (political stability, economic factors) is helpful in the attraction of external investments (e.g. FDIs, VC)?	
Conclusion of theme 3 of the interview:	

1. In your opinion, what are the main strengths / weakness of the local entrepreneurial environment that influence knowledge commercialisation activities?
2. Are there any other issues regarding the quality of place that we have not discussed and you find them significant?

**Theme 4: Policy framework and transformation****Target participants:** All helixes (Academia / government / public sector / Industry)

Main questions	Additional /clarifying questions
<b>Q1:</b> In your experience, what do you think was the main long-term outcome of government economic plans for economy diversification (e.g. Oman Vision 2020, the 5-year plans, R&D policies, Human Capital initiatives, etc).?	
<b>Q2:</b> How do you see the government initiatives regarding research and innovation policies (short-term/long-term)?	<i>Can you expand a little on this?</i>
<b>Q3:</b> Briefly, describe the transformation of your institution towards more interactions with other institutional spheres? And which factors are qualified as driving forces for the transformation?	<i>Can you give some examples?</i>  <i>Can you tell me your own story?</i>
<b>Q4:</b> To what extent the individual initiatives and bottom-up proposals had contributed to the organisational transformation?	
<b>Q5:</b> In your opinion, how do you evaluate the advantages or disadvantages of implementing imported policies?	

Conclusion of theme 4 of the interview:

1. In your opinion, what are the main policy issues regarding academic entrepreneurship that is missing from the current innovation policy?
2. What are the key milestones in your organisational transformation process and what are their drivers?
3. Are there any other issues regarding the policy framework and transformation that we have not discussed and you find them significant?