Knowledge networks in innovation-driven collaborations

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Notice 1

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Adel Moslehi

Abstract

Knowledge intensive or high-tech industries are widely regarded as important for overall national economic growth and competitiveness, while survival of these industries relies on their ability to create new knowledge and transform that knowledge into new technologies. In these industries, one increasing mode of knowledge creation is through collaboration with peers and other partners. Such collaborations often happen within inter-organisational knowledge networks (k-networks). The increasing attention on k-networks stems from several reasons like turbulent and dynamic markets, cost reduction, fast response to market demands or limited core competencies. The high pace and radical innovation projects in knowledge-based industries emphasise the need for research in the area of k-networks, particularly in the biotechnology industry.

In this context, understanding the way that k-networks can contribute to knowledge creation, seems critical for the survival of knowledge-based industries and accordingly also has a significant influence on society as a whole. While the literature focuses on the contribution of network structure, it also shows that the prior research has produced seemingly contradictory results. A growing body of research highlights the need for going beyond the network structure to address other constructs of k-networks and understand the way that interactions among these constructs may influence knowledge creation. My research first reviewed the k-network literature thoroughly and identified content and process together with network structure as inter-related constructs of k-networks. More particularly knowledge diversity as a characteristic of content, collaboration with partners as the characteristics of process and centrality and density as the characteristics of structure are identified as the constructs interacting with each other in the context of knowledge creation. These constructs are conceptualised into a theoretical model that is examined by employing a quantitative-qualitative mixed method inquiry.

Focusing on the biotechnology industry of Victoria, Australia as a knowledge intensive industry in which knowledge creation is normally tied with patenting, my research used patent co-authorship network as a k-network that involves innovation-driven collaborations.

To map the network and study the structural constructs, first social network analysis, was used. Then my research studied the interaction between constructs of the k-networks by using moderated multiple regressions followed by interaction analysis.

As a result, three significant interactions were found which provided a basis to introduce a novel typology of k-network configurations. To seek confirmation and explanation for these quantitative findings, four cases were selected purposefully to study all the possible k-network configurations in more detail. Using this sequential quantitative-qualitative mixed method inquiry, my research shows how the interactions of the content-process-structure of k-networks may support knowledge creation for actors in the knowledge intensive industries.

My research extends the knowledge network research particularly in the domain of inter-organisational innovation-driven collaborations. The thesis explores the implications of findings and the potential to contribute to explaining previous contradictory results in k-network research, as well as practical contributions for private companies and for policy makers.

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Abbreviations and Acronyms

ABS	Australian Bureau of Statistics
ANOVA	analysis of variance
ANZSIC	Australian and New Zealand Standard Industrial Classification
ASX	Australian Stock Exchange
Ausbiotech	Australia's Biotechnology Organisation
Bio Melbourne	Biotechnology Melbourne Network Organisation
CDA	confidentiality disclosure agreement
CEO	chief executive officer
CMB	common-method bias
CRC	Cooperative Research Centres
CRO	clinical research organisation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ID	industrial district
IP	intellectual property
IPC	International Patent Classification
IT	information technology
KBV	knowledge-based view
KM	knowledge management
K-network	knowledge network
MISQ	Management Information Systems Quarterly
MMR	moderated multiple regression
MUHREC	Monash University Human Research Ethics Committee
OECD	Organisation for Economic Co-operation and Development
PCT	Patent Cooperation Treaty
PRO	public research organisations
R&D	research and development
SCM	supply chain management
SFN	small firm network

SMEs	Small and medium sized enterprises
SNA	social network analysis
SPSS	Statistical Package for the Social Sciences
TCT	transaction cost theory
WIPO	World Intellectual Property Organization

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Chapter 1
Introduction

Outline of Chapter 1

This first chapter introduces the thesis by presenting the nature of the study, including the motivation for doing new research in this growing area. It discusses the goals, the research questions and the research approach and explains the significance of my research. The structure of the thesis is also described. Finally, the dissemination of this research is reported to show how the results have been published and presented in the top academic communities in the knowledge management field.

1.1 Introduction

Creating knowledge has been considered vital for the knowledge economy, particularly for firms in knowledge-based industries. In these industries, creating knowledge often happens within the network of relationships with peers – sometimes called knowledge networks (k-networks). It is critical for these industries and the whole global economy to understand how inter-organisational networks of relationships are used as k-networks to help participants to create knowledge.

To answer this question, the k-network literature has produced contradictory results. While the k-network literature has focused mainly on the structural characteristics of k-networks like the position of actors and their relations in the network, a growing body of research highlights other aspects like content of the knowledge and the collaborative process in the network; though they are not integrated in a single research inquiry. In other words, the content, collaborative process and structure of a k-network have been identified in the literature. The bilateral interactions of those characteristics have also been addressed in the literature. However, to my knowledge there is no research to address the integration of all constructs together.

My research highlights that considering these interactions is important in order to understand the existing seemingly contradictory literature. The research also seeks to provide guidelines to help network participants in practice. More precisely, focusing on the patent co-authorship networks of biotechnology firms in Victoria, Australia, as a k-network involved in an innovation-driven collaboration. My aim was to understand how interactions among the k-network constructs contribute to knowledge creation projects.

1.2 Background and motivation of the research

This section reflects on the importance of the k-network particularly for knowledge-based or high-tech industries. The significance of the topic and the main argument in this research, are then discussed.

1.2.1 Role of knowledge networks within the knowledge economy

Since Drucker (1969) introduced the term "knowledge economy", the attention to knowledge has increased both in industry and academic research (Phelps, Heidl and Wadhwa 2012). In industry the importance of the production, diffusion and use of knowledge has been studied at different levels of the economy including: national and international levels (Furman, Porter and Stern 2002; Powell and Snellman 2004); the industry level (Thornhill 2006); and the organisational performance level (Roberts 1999; Blundell, Dearden, Meghir and Sianesi 2005). In academic research, several concepts have emerged such as the knowledge-based view of firms (KBV), which considers knowledge as a source of competitive advantage (Grant 1996a; Kogut and Zander 1996; Eisenhardt and Santos 2002), and the field of knowledge management (KM) and its information technology (IT) counterpart, "knowledge management system" (KMS), (Alavi and Leidner 2001; Maier 2004). Among all the emergent concepts in knowledge management, "knowledge network" (k-network) is one of the fast growing themes (Phelps et al. 2012), particularly in the context of the knowledge intensive or high-tech industries.

Knowledge intensive industries are widely regarded as important for overall national economic growth and competitiveness (National Science Foundation 2012). The need for innovation among knowledge intensive industries has been widely recognised (Kraaijenbrink and Wijnhoven 2008). For actors in these industries, one of the most widely cited motives for collaboration in such networks is the acquisition of knowledge and capabilities from partner firms (Mowery, Oxley and Silverman 1996). These industries need to be innovative (OECD 2007) and any innovation, such as a new product development, needs to integrate existing and new knowledge (Levina 1999). Although new knowledge may be created internally through conducting research and development or via individual learning, knowledge is continuously changing and depreciating, particularly in knowledge intensive industries. Moreover many companies in these industries are small and medium sized enterprises (SMEs) (e.g. Owen-Smith and Powell 2004) for which external knowledge may be even more critical (Wong and Aspinwall 2004). In this regard, every organisation needs external knowledge (Kraaijenbrink, Wijnhoven and Groen 2007)

and the way that firms acquire such knowledge plays a key role in achieving innovation (Edwards 2005).

In knowledge-based industries, one mode of knowledge creation is through collaboration with peers and other partners. Such collaborations are termed knowledge networks (k-networks). The increasing attention on k-networks stems from turbulent and dynamic markets (Jespersen and Skjott-Larsen 2005), cost reduction, fast response to market demands, limited core competencies (Lin and Zhang 2005), increasingly sophisticated customer demands for differentiated and better quality products, and increasing complexity of products and technologies (Lim, Baines, Tjahjono and Chandraprakaikul 2006). The high pace and radical innovation projects in knowledge-based industries emphasise the need for research in the area of k-networks, particularly in the biotechnology industry (Plum and Hassink 2011).

1.2.2 Motivation for new research on k-networks

A k-network is one kind of network that organisations engage in, so the concept of a k-network is a subset of organisational networks. Networking is an interesting and growing domain in research, yet the focus of my research is to understand k-networks in the organisational context of knowledge creation.

So far it has been mentioned that creating knowledge has been considered vital for the knowledge economy, and k-networks are primary sources of acquiring such vital knowledge (Kraaijenbrink, Faran and Hauptman 2005). Because of the characteristics of high-tech industries, creating knowledge often happens within the k-networks with peers.

Besides the general interest in k-networks, there are two factors that highlight the need for new research on k-networks of high-tech companies particularly SMEs. First, previous research has produced contradictory results in k-network research and called for more contingency-based research to address inter-related constructs in a single research inquiry. Second, the existing literature has focused primarily on large companies or does not appreciate the unique characteristics of the SME sector. There is, therefore, a need to

examine the integrative framework in the SME sector which plays a key part in knowledge intensive industries.

The k-network phenomenon, as a source to acquire and access knowledge, has been studied through the lens of social capital theory (e.g. Granovetter 1973; Granovetter 1985; Cross, Parker and Borgatti 2002; Kane and Alavi 2008). While the literature has focused on social capital theory, existing reviews show the current literature has produced seemingly contradictory results. A growing body of research highlights the need for a contingency approach (Phelps et al. 2012).

By analysing the existing literature on k-networks, it seems that there are three main constructs that could contribute to innovation-driven collaborations among network participants, particularly SMEs, as elaborated in Chapter 2 (Sections 2.2.2, 2.2.3). The first one is about the knowledge itself, i.e. the importance of acquiring new and diverse knowledge for an innovation project (e.g. Inkpen and Tsang 2005). The second construct refers to the importance of collaborative processes for knowledge creation and innovation among network participants; for instance, processes are typically presented as catalysts for knowledge creation and innovation (e.g. Scarbrough 2003). The third one, taking a social network theory perspective, focuses on the role of the network structure – the way in which firms are embedded in the network – on firms' knowledge creation and performance (e.g. Uzzi and Gillespie 2002).

In this research I argue that these three areas of research do not seem to be independent but are inter-related. While the k-network literature has focused on the network characteristics, a growing body of research highlights other aspects like content of the knowledge and the collaborative process as contingent constructs as elaborated in Chapter 2 (Sections 2.2.2, 2.2.3). Hence, the contribution of this research is to develop an integrative framework of k-networks by studying the interaction of the relevant constructs of these networks.

Compared to traditional industries, the k-network research is even more significant in the setting of high-tech or knowledge-based industries. In this type of industry, typically the majority of the participants of the k-networks are SMEs (e.g. Powell, Koput and Smith-

Doerr 1996; Owen-Smith and Powell 2004). Hence, with the focus on high-tech industry, my research deals with SMEs as the major participants of the k-networks.

SME researchers also believe that SMEs are not scaled-down versions of larger firms (Szarka 1990; Levy and Powell 2005) and they need their own targeted research (Wong and Aspinwall 2006). For this reason, it is important to consider the characteristics of SMEs as the major actors in k-networks.

In the literature on SMEs, there are different reasons for SMEs to develop inter-organisational relationships (Carbonara, Giannoccaro and Pontrandolfo 2002; Wincent 2006; Balestrin, Vargas and Fayard 2008; Thakkar, Kanda and Deshmukh 2008), including acquiring knowledge. There is increasing realisation and acceptance that external knowledge is crucial for SMEs (Thorpe, Holt, Macpherson and Pittaway 2006; Pillania 2008b). To achieve this, SMEs rely on their inter-organisational relationships through k-networks.

These networks of relationships that SMEs rely on to acquire external knowledge can be considered k-networks (Mohannak 2007; Morrison and Rabellotti 2009). These networks may be used to solve different business problems, including new product development (Bandiera and Rasul 2006). However, regardless of the variety of their purposes, SMEs' k-networks consist of informal and social relationships of the owner/manager and SMEs' staff with their friends and families as well as formal or informal relationships with other organisations, such as business partners, customers, suppliers, universities and consultants (Parker and Castleman 2009). My research highlights only the formal relationships, but my focus on the integration of the constructs of k-networks in the context of SMEs can bridge some existing gaps in the theory of k-networks among SMEs.

1.2.3 My motivation

On a personal level, my prior work focused on knowledge management (KM) within the organisational context (e.g. Moslehi 2004; Moslehi, Mohaghar, Badie and Lucas 2005; 2006a; 2006b; Moslehi, Mohaghar, Tamizi and Bayati 2006; Moslehi, Mohaghar, Badie

and Lucas 2008; 2009). This research is a step forward to address KM in a new domain: the domain of inter-organisational relationships.

1.3 Statement of the research problem

One of the main factors influencing the survival and growth of high-tech companies, particularly SMEs, is knowledge creation and innovation (Edwards 2005; Levy and Powell 2005). By reflecting Schumpeter's claim that innovation makes new combinations of knowledge, Kraaijenbrink et al. (2005) argued that any organisation needs external knowledge to be innovative, since occurrence of any innovation, like a new product development, needs integration of existing and new knowledge. Moreover, because knowledge is continuously changing and depreciating, every organisation needs external knowledge (Kraaijenbrink et al. 2007). In this regard, high-tech companies collaborate with each other through collaboration networks or strategic alliances (Ding and Peters 2000) to acquire or access external knowledge (Kraaijenbrink et al. 2005; Wong and Aspinwall 2005; Giannakis 2008) and the way that these companies do so plays a very important role in achieving innovation (Edwards 2005).

Networking, as a channel through which high-tech companies access or acquire external knowledge, is a significant factor in the development of the companies. Indeed, participating in a network is one of the most important challenges faced by high-tech companies, particularly SMEs (Szarka 1990). The networking phenomenon for SMEs seems primarily as a competitive response, since their potentially fragile position can be offset by a set of alliances that provide a supporting environment though a resilient network (Szarka 1990; Shaw 2006). Moreover, the intensive competition in SMEs' markets and their need to be flexible, innovative and competitive (Levy, Powell and Yetton 2001) can be the other reasons that SMEs seek networking. In this regard, the concepts of supply chain (network) of SME and small firm networks (SFNs) are not new, however there is ambiguity in this area in terms of content, processes and contribution of such networks (Zeleny 2001; Shaw 2006).

Seeking a more comprehensive perspective, my research focuses on constructs of k-networks in the context of inter-organisational relationships among the network participants

(actors) in the high-tech industry, which are mainly considered as SMEs. The nature of the knowledge (the content), the way that actors process such knowledge with partners (the process) and the network that actors are enrolled in or form (the structure) are the major themes of this research. Although these constructs have been identified in the literature, only selected bilateral interactions between them have been addressed. To my knowledge there is no research addressing the integration of all these constructs together. However, a more comprehensive approach seems necessary to understand how k-networks can contribute to knowledge creation. The Victorian biotechnology industry, as a representative of a type of high-tech industry with many SME participants, is chosen as the setting for this research (Chapter 3). My research studied the patent co-authorship networks of actors in this industry to focus on k-networks that are involved in knowledge creation.

1.4 Research questions

Most of the research on inter-organisational innovation has focused on understanding the reasons for networking, rather than the dynamics of inter-organisational collaboration (Gardet and Fraiha 2012). In my research, the main question is: ***How do knowledge networks contribute to knowledge creation?***

Based on the literature review, it is expected that constructs of k-networks affect knowledge creation performance. First, there is a relationship between network configurations of actors and their knowledge creating performance. For example, Kane and Alavi (2008) studied three constructs of network configurations including tie strength, centrality and density. They found that a similar base of people can have different performance outcomes because of the particular way in which they configure their k-network topology. Most of the time a network with strong relations (ties) was related to a better performance. However there are several benefits of weak ties (infrequent relations) that have been mentioned in the literature, including access to a variety of knowledge (Granovetter 1973), better knowledge searching and low cost to maintain (Hansen 1999), and less dependency and vulnerability (Uzzi 1997). Second, it is argued that the structure of the k-network needs to match the specific characteristics of the knowledge that is going to flow over the network (e.g. Bustamante 2007). Hansen (1999) studied the impact of k-network structure on the search

or transfer of knowledge in the intra-firm k-network. Uzzi (1997) also found that strong ties between groups are better for non-codified and complex knowledge and Granovetter (1973) posited that weak ties are better for knowledge searching.

Overall, to answer the question *How knowledge networks contribute to knowledge creation*, the existing literature implies that: 1) the structure of k-networks is important for knowledge creation but it is not the only construct so is not able to explain knowledge creation properly, and 2) the structure has an interaction with other constructs like the knowledge itself (content) and the way knowledge is processed (process) in the k-network. Hence, it is important to understand the constructs i.e. content, process and structure of k-network:

1. ***What are the characteristics of the knowledge network constructs of content, process and structure?***

From the literature review, content, process and structure of k-network were identified as three inter-related constructs that influence knowledge creation as reported in Chapter 2. Indeed, structure of k-network, itself was studied through two constructs of network centrality and density of the network as discussed in Chapter 2 (Section 2.2.3). The second question is, therefore:

2. ***How do the interactions of these constructs support knowledge creation?***

By answering these questions, my research aimed to extend k-network research particularly in the domain of inter-organisational collaborations. In this research SMEs as major participants of the whole k-network of the selected high-tech industry were studied, whereas the majority of the extant research focuses on large sized companies. In terms of the practical implications, my study can provide guidelines for practitioners in this area. These practitioners may include: actors in the selected network, SMEs owners/managers and policy-making agencies like government.

1.5 Research approach

To study the k-network in the context of innovation-driven collaboration, my research focused on the Victorian biotechnology industry. This is an appropriate setting for my research because biotechnology is a knowledge intensive industry which is highly focused on introducing new innovative products (Plum and Hassink 2011). Australia has a relatively strong position in pharmaceuticals and biotechnology in the Asia-Pacific region (ARC 2000; Ernst and Young 2011). Victoria is among the leading states within Australia, since it is characterised by a large human health subsector, which involves more than 75 per cent of biotechnology companies located in the country (Allen Consulting Group 2010).

To create new knowledge in knowledge intensive industries like biotechnology, collaboration also plays a very important role. Because a single firm rarely has all the required range of knowledge needed for competing effectively in the marketplace, firms look for cooperative links with other actors in the industry (Lam 1997; Grotenhuis and Weggeman 2002). For instance, in the Victorian biotechnology industry, there are different types of actors including public research organisations (PROs) like universities, and pharmaceutical-biotechnology companies, most of which can be considered SMEs as defined in Chapter 2 (Section 2.4).

To answer the research questions within the Victorian biotechnology industry, my research employed a three-phase research approach. In the preliminary work, to understand the prior knowledge to guide the research inquiry (Sekaran 2006), I went through several iterations between the literature review and research question development. As a result, three constructs of content, process and structure were identified. Moreover, the bilateral interactions between them in the literature have been discussed (Outcome 1 in Figure 1-1). Also, I discussed the research problem with two informants in the Victorian biotechnology industry, to get insights from the real world and to make sure about the significance of the research for the biotechnology industry (Gray 2009). Through this phase, the structure of the Victorian biotechnology industry, the importance of patents to the industry and also useful and reliable websites for collecting data, were identified. From this basis, the initial framework and also the research method were designed (Outcome 2 in Figure 1-1).

In Phase 2, to define the k-network in the context of the biotechnology industry, I examined patent co-authorship networks as a formal resource sharing network representing innovation-driven collaboration (e.g. Cantner and Graf 2006). These co-authorship networks are characterised by legally binding contracts and licensing to protect the intellectual property (IP) of exclusive partners, and are very common in the biotechnology industry (Walker, Kogut and Shan 1997). Patenting can be used to represent knowledge creation (Almeida and Phene 2004; Wadhwa and Kotha 2006; Markatou 2011). However, there are some concerns with counting patents to understand knowledge creation, which are addressed in Chapter 5 (Section 5.2.4). To collect data on patents, publicly available sources were used as defined in detail in Chapter 4 (Section 4.4). To analyse these data several procedures were used including social network analysis (SNA) and moderated multiple regressions (MMR) (West and Aiken 1991; Dalal and Zickar 2012).

These analyses respond to the research questions (Outcome 3 in Figure 1-1), and also provided a basis for selecting cases purposefully (as discussed in Chapter 4 – Section 4.4.3). Four cases were studied to explain the quantitative results from Phase 2. Finally by synthesising quantitative and qualitative data, the final results of the research are outlined (Chapter 10). Having both quantitative and qualitative perspectives, the initial model was finalised (Outcome 4 in Figure 1-1) as reported in Chapter 11. The reason for having a mixed method and the inference quality of the research are also reported in Chapter 4.

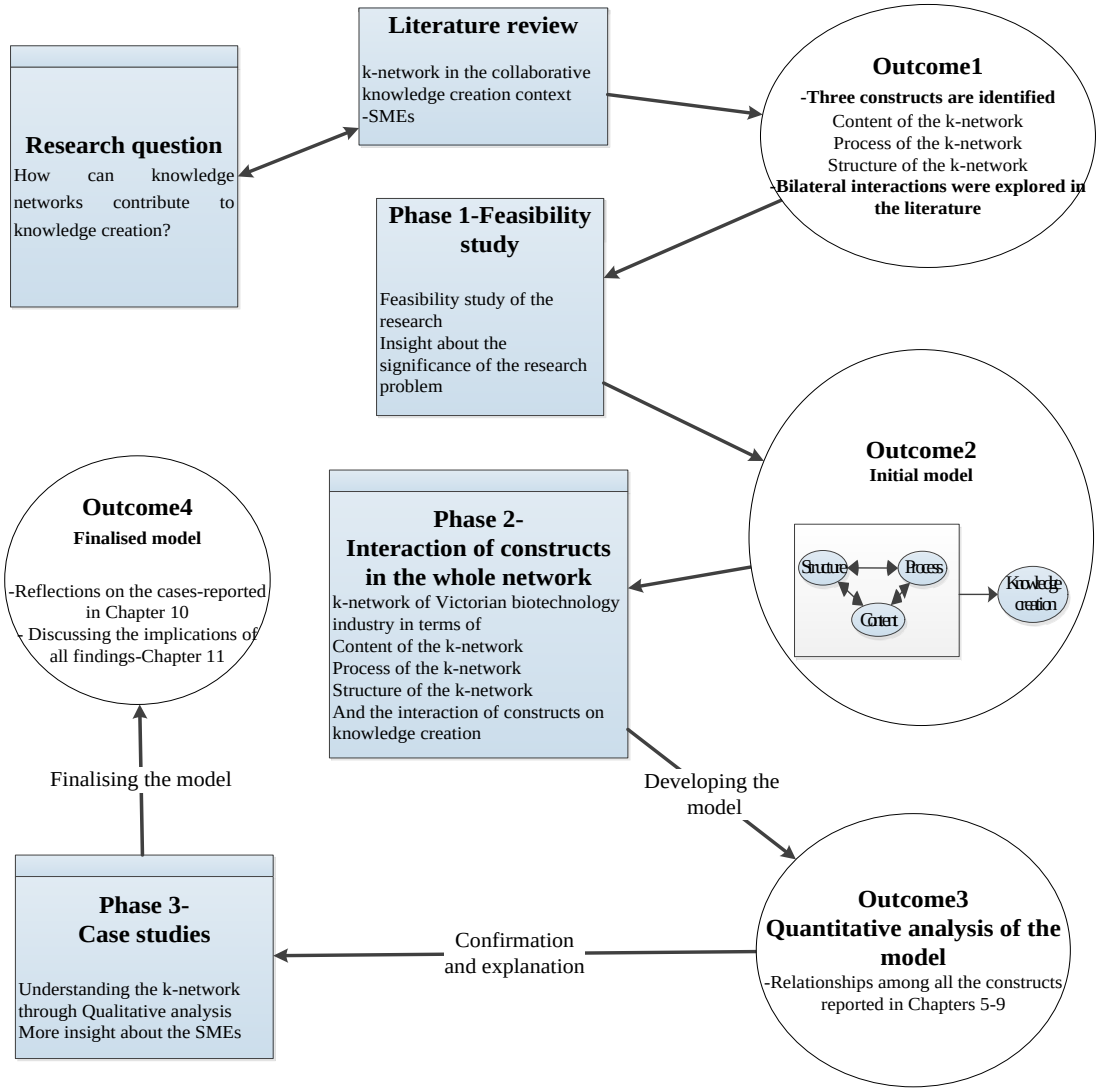


Figure 1-1 Overview of the research process

1.6 Dimensions and delimitation of the research

Targeting the under-explored area of k-network as a means of knowledge creation, this research is positioned in the knowledge management (KM) field, as explained in Chapter 2 (Section 2.1). To define the dimensions of the research, Table 1-1 is presented.

Table 1-1 Research dimensions

Dimensions in this research		Corresponding chapter(s)
Theoretical background	Given the knowledge-based view, survival of the organisations in the knowledge economy relies on knowledge creation and access to knowledge.	Chapter 2
Object	Understanding k-networks that have been considered as a means organisations use to access and create their required knowledge.	Chapter 4
Subject	Constructs of k-networks form the subject of the research. Given the network perspective, the constructs of the k-network like the position of actors and their relations in the network are important aspects that influence knowledge creating. However other constructs of the k-network like its content and the way that knowledge is processed influences knowledge creating as well.	Chapter 3
Major argument	Using actors' k-networks to create knowledge requires understanding the content, process and structure of these networks and the nature of their interactions.	Chapter 5–10, and 11
Constructs	Network: Density and Centrality Content: Diversity of knowledge Process: Collaboration with partners Patent also used to measure the knowledge creation of the k-network	Chapters 2–3 and 10
Setting	Biotechnology, SME sector, Victoria, Australia	Chapters 3–4
Contribution	Providing insight about the way that k-networks may support knowledge creation by considering the interaction among constructs and proposing a novel topology of k-networks.	Chapters 11–12

In summary, this research sought to understand how actors in the Victorian biotechnology industry use their k-networks in order to produce more knowledge. There is no single or unified theory of k-networks e.g. Monge and Contractor (2003) and Galaskiewicz (2007). This study contributes to k-network research by highlighting the interactions of the three main constructs: content, process, and structure of k-networks in a knowledge intensive industry. This research introduces the integrative framework in the k-network research that contributes to resolving contradictions reported in k-network research (Phelps et al. 2012) about the network position and structural hole theory, and also provides implications for exploration/exploitation literature (Li, Vanhaverbeke and Schoenmakers 2008). Also this research sheds new light on the complexities of collaborative knowledge creating as a vital task for all firms, particularly for SMEs in the knowledge intensive industries.

1.7 Dissemination of the research results

Parts of the results of the research have been communicated and published in high-ranking blind peer-review academic publications and presented to the academic and professional

communities in the field of KM as shown in Table 1-2. First I focused on developing a framework to conceptualise the k-network constructs. This paper was published and presented in the 17th Americas Conference on Information Systems (AMCIS 2011), which was held in Detroit, Michigan, USA in August 2011.

By analysing partial results of the second phase, a second paper was published in the 21st International Conference on Information Systems Development (ISD2012), and introduced a framework to highlight four possible configurations of k-networks. Given the feedback from this conference paper, and more data analysis the third publication of this research targeted the Hawaii International Conference on System Sciences (HICCS 2013). This paper was a first attempt at modelling the whole result of the second phase. Given the feedback from the HICCS 2013 conference, two other papers were published in 24th Australasian Conference on Information Systems (ACIS 2013). One of the papers received a best KM paper award from Emerald and an extended version, is being considered for publication in future issues in 2014.

Table 1-2 Dissemination of the research to the information system community

Title of the paper/article	Year	Publication
Towards a KM framework for e-business projects within SMEs.	2011	AMCIS 2011 Proceedings
Knowledge networks and innovation-driven collaborations: a study in Victoria's biotechnology industry	2012	ISD 2012 Proceedings
Role of inter-organisational knowledge networks in innovation-driven collaborations of biotechnology industry	2013	HICSS 2013 Proceedings
The role of diverse knowledge in creating knowledge within industry networks –A study in the Victorian biotechnology industry	2013	ACIS 2013 Proceedings
The role of partner diversity in collaborative knowledge creation–A study in the Victorian biotechnology industry	2013	ACIS 2013 Proceedings
Content of knowledge in co-authorship patent networks – Case studies in the Victorian biotechnology industry	2014	Vine: The Journal of Information and Knowledge Management Systems

1.8 Structure of the thesis

There are 12 chapters in this thesis categorised into four parts as illustrated in Figure 1-2. In the first part, there are four chapters that report on the theoretical understandings of the research, reviewing relevant literature, formulating research questions, introducing the theoretical framework and developing the research design. Along with these activities an introductory study has been conducted as reported in Chapter 4 (Section 4.4.1).

Parts II and III then report sequentially the quantitative network analysis followed by the qualitative study which focused on SMEs as purposefully selected cases. Chapters 5–9 report the quantitative findings and analysis, while Chapter 10 reports the detailed studies of the SME case studies. Final part (i.e. part IV) discusses theoretical and practical contributions, answers the research questions, and provides conclusions and suggestions for further research.

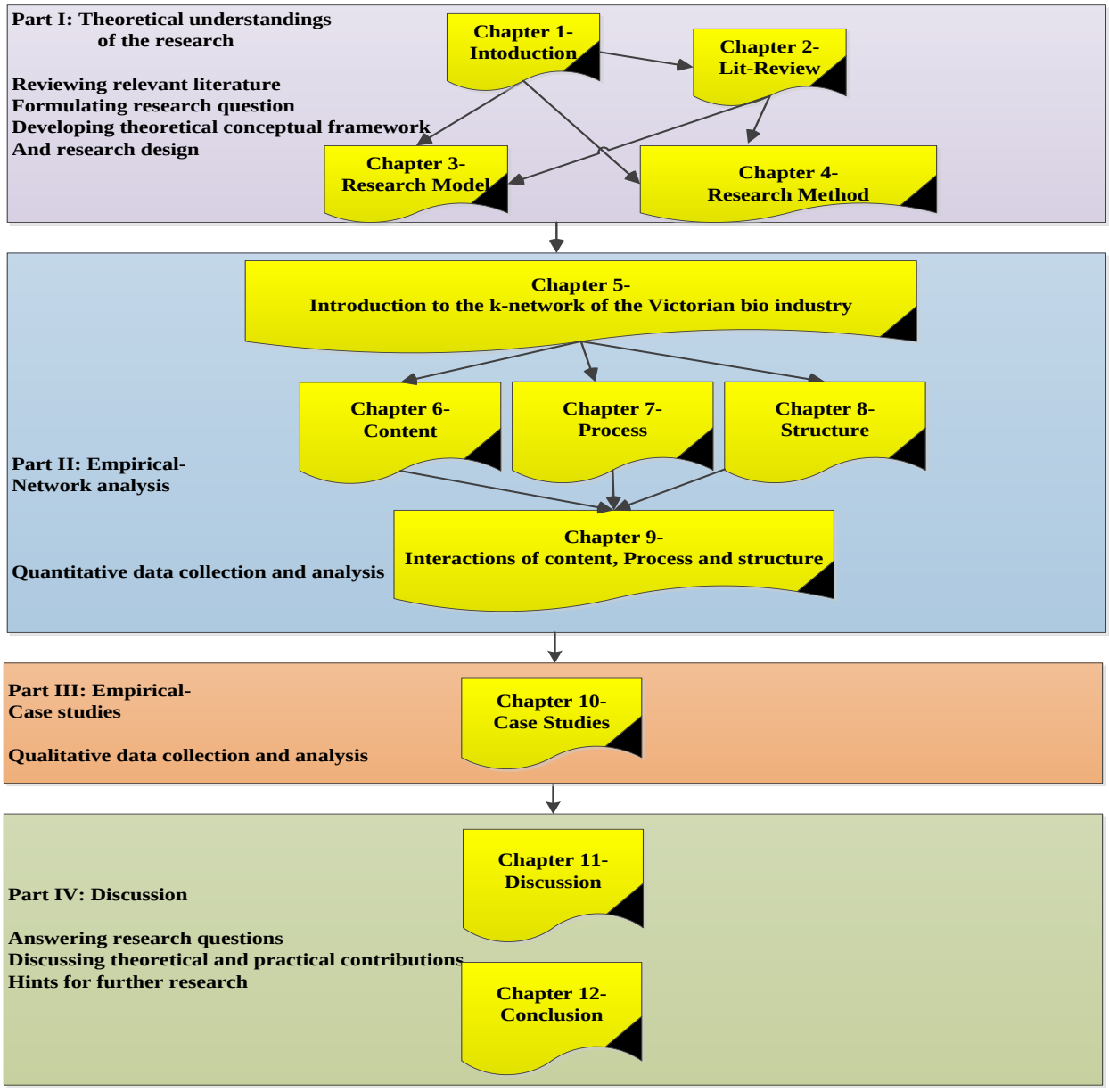


Figure 1-2 The structure of the thesis

Chapter 2
Literature Review

Outline of Chapter 2

As conveyed by the title of the thesis (i.e. *Knowledge networks in innovation-driven collaboration*), this study is multidisciplinary and needs a variety of knowledge areas to address the research problem discussed in Chapter 1. To review what has already been addressed in the relevant literature, this chapter identifies different lines of research starting with introducing the context of k-networks (Section 2.1) where, according to the knowledge-based view (KBV), survival of firms in the knowledge intensive industries depends on knowledge creation and management. This leads to an examination of the role of k-networks as a means of knowledge creation (Section 2.2).

As some of the knowledge creation in knowledge intensive industries is represented in patenting, the patent co-authorship network is defined. In this section I argue why there is a need for new research and then outline and discuss the theoretical boundary of the study in terms of k-network theories, level of analysis, themes and areas of research. Those discussions highlight the specific k-network theories to study the research question. A detailed literature review of these theories is then provided. This leads to proposing the content-process-structure framework as an integrative framework, as a means of filling a gap in k-network research (Section 2.3). In that section, the broader and more general theories are reviewed to understand the theoretical background of the proposed framework, however due to the fact that small and medium sized enterprises (SMEs) have the high majority of actors in the knowledge intensive industries, the k-networks of SMEs in the knowledge intensive industries is discussed (Section 2.4). Hence the importance of understanding the interactions of content-process-structure framework is addressed, which leads to a framework formed the basis of the conceptual model and hypotheses, as reported in Chapter 3.

2.1 The context of knowledge networks

In this section, the knowledge-based view (KBV) as a theoretical background is discussed in the setting of knowledge intensive and high-tech industries. Given that organisational knowledge is mainly communicated and created through collaboration with peers outside the boundary of the organisation, the need to consider KBV in the inter-organisational context is also explained. Then patenting as a form of knowledge creation in the knowledge intensive industries is outlined. Finally, given that the majority of the companies in the knowledge intensive industries are small and medium enterprises (SMEs), the characteristics of SMEs, their networks and knowledge practices among them are presented.

2.1.1 The knowledge-based view as the theoretical context

The KBV as a theoretical background has been considered in the setting of the knowledge intensive and high-tech industries (Drucker 2012). In recent decades, several studies have used a knowledge perspective to research a variety of topics, including new product development. The underlying perspective for this research is the KBV (Eisenhardt and Santos 2002). As described by Grant (1996b), to survive in a rapidly changing environment, this theory considers knowledge as the most strategic resource of the firm and explains the growing attention to knowledge management in academia and industries (Phelps et al. 2012). Knowledge management (KM) has been defined as the generation, capture, and dissemination of knowledge (e.g. (Reagans and McEvily 2003; Hussi 2004). In order to be the source of sustainable competitive advantage and superior corporate performance, such knowledge should be heterogeneous (Deeds and Decarolis 1999; Winter and Szulanski 2001) particularly in the rapidly changing environment like high-tech industries (Davenport and Prusak 2000; Collins and Smith 2006). Therefore, the KBV as a theoretical background and the need for knowledge in high-tech industries are discussed first.

Aligned with the resource-based view of the firm (RBVF), the KBV considers knowledge as the most strategically significant resource of the firm. According to RBVF (Barney

1991), in order for a resource to be considered strategic it should have characteristics like value, rareness and inimitability. KBV scholars argue that the socially complex nature of knowledge-based resources embedded in organisational culture and identity, policies, routines, documents, systems, and employees, make it difficult for competitors to imitate. Therefore heterogeneous knowledge bases and capabilities among firms are the major determinants of sustained competitive advantage (Kogut and Zander 1992; Winter and Szulanski 2001).

Given the fact that the organisational knowledge is mainly communicating and creating through collaboration with peers outside the boundary of the organisation, the need to consider the KBV in the inter-organisational context also needs to be discussed. There are multiple theoretical lenses that have been used to study inter-organisational and supply chain relationships. For instance Johansson (2008) reviewed five theoretical perspectives on inter-organisational collaboration and showed how these different theoretical lenses may contribute to a better understanding of inter-organisational collaboration. These theories were: transaction cost theory (TCT), social exchange theory, resource dependencies theory, network theory, and institutional theory. In his work, Johansson also discussed the extended form of the resource-based view, which reaches outside organisational boundaries. This theory is sometimes called the "relational view of the firm" (the review of the literature on this concept can be found in Levina (1999). This theory is considered as a complementary theory to the resource-based view of the firm and claims that, beyond the internal resources, organisations should look at inter-organisational networks as a source of sustainable competitive advantage (Levina 1999).

Aligned with the relational view of the firm, the KBV has emerged as a particularly appealing theoretical framework for examining issues related to inter-organisational relationships (Desouza, Chattaraj and Kraft 2003; Hult, Ketchen and Slater 2004). While the importance of taking the KBV into inter-organisational relationships is acknowledged (Hult et al. 2004); it is not clear how organisations transfer their knowledge across organisational boundaries (e.g. Simonin 2004), how such processes contribute to firm performance and survival and what factors influence such knowledge transfer (e.g. Gupta

2006). Understanding these aspects of knowledge is vital particularly for the knowledge intensive or high-tech industries.

2.1.2 The KBV in knowledge intensive industries

Knowledge intensive or high-tech industries are widely regarded as important for overall national economic growth and competitiveness. Likewise, global economic growth increasingly depends on these industries. According to the National Science Foundation (NSF 2012), policymakers in developed and developing countries are striving to attract, cultivate, and retain knowledge-based companies and workers to foster national prosperity and to increase national access to the global economy.

According to the Organisation for Economic Co-operation and Development (OECD 2007), these knowledge-based or high-tech industries, which have particularly strong links to science and technology, include five knowledge intensive services and five high-tech industries. The five knowledge intensive services are financial, business, communications services (which are generally commercially traded), education and health services (which are publicly regulated or provided). Also the five high-tech manufacturing industries are aircraft and spacecraft, pharmaceuticals, computers and office machinery, semiconductors and communications equipment and scientific (medical, precision, and optical) instruments (OECD 2007). These industries spend a large proportion of their revenues on research and development (R&D) and make products that contain technologies developed from R&D (NSF 2012).

The knowledge-based industries have been classified into two types: analytical (science-based like biotechnology) and synthetic (engineering-based like the automotive industry) knowledge-based industries (e.g. Asheim and Coenen 2005; Moodysson, Coenen and Asheim 2008; Plum and Hassink 2011).

Given the higher pace, and radical innovation projects in analytical knowledge-based industries, the need for managing knowledge in knowledge intensive industries is more substantial, particularly in analytical knowledge bases.

Given the characteristics of the high-technology industries in analytical knowledge bases, a single firm rarely has all the required range of knowledge needed for competing effectively in the marketplace, therefore these firms look for cooperative links with external partners. These partnerships may aim at reducing cost and risk and more importantly increasing access to knowledge and capabilities unavailable internally (Lam 1997; Grotenhuis and Weggeman 2002). In this regard, the need for studying knowledge creation in the inter-organisational context has been highlighted in the analytical knowledge bases.

As shown in Table 2-1, analytical knowledge bases like the biotechnology industry are more keen on creating and codifying knowledge to be able to protect it legally in terms of patents.

Table 2-1 Synthetic vs. analytical knowledge-based industries.

Source: Plum and Hassink (2011, p.357)

	Analytical knowledge base like the biotechnology industry	Synthetic knowledge base like the automotive industry
Knowledge creation	Deductive process, sharing formal models	Inductive process, applied, problem related
Innovation process	High pace of innovation; radical innovation by creation of new knowledge	Incremental, innovation by application/combination of existing knowledge
Partners	Research collaboration between firms (R&D departments) and research organisation.	Interactive learning with customers and suppliers
Knowledge content	Codified (documentation in patents and publications)	Tacit (concrete know-how, craft and practical skill)
Proximity	Lower sensitivity, higher percentage of global networking	Higher sensitivity, lower percentage of global networking

2.1.3 Patenting as a form of knowledge creation in knowledge intensive industries

Patent data are often use to measure technological knowledge because patents are valid and robust indicators of knowledge creation (Jaffe and Trajtenberg 2005). In some knowledge-based industries, like biotechnology, the use of patents to protect the knowledge is an effective and widely used approach (Arundel and Kabla 1998). Prior research used patents to measure innovation and shows that the number of patents is closely related to new products, innovation and invention counts and sales and growth (Ahuja 2000). Hence the number of patents a firm has published is considered a meaningful measure of new knowledge creation (Almeida and Phene 2004; Wadhwa and Kotha 2006; Markatou 2011).

The patent can be used to represent knowledge creation since a patent by definition is evaluated under three criteria of novelty to the world – technical reproduction, industrial exploitation and non-obviousness. Hence a successful patent application can represent creation of new knowledge.

However, there are some limitations with counting patents to understand knowledge creation. Firstly, the industry type influences product patent propensity (Arundel and Kabla 1998). To avoid this issue, it is recommended to collect data from a single industry like biotechnology which actively files for patents (Ahuja 2000). Secondly, the full range of each firm's knowledge creation will not be captured by patents. Some knowledge may not be patentable but still have economic value (Arundel and Kabla 1998). However patents have been shown to be an important mechanism in the analytical knowledge bases like the biotechnology industry. Moreover, my research uses the same measure for all firms to understand the role of their k-networks to create knowledge in terms of published patents. Thirdly, the concept of quality of created knowledge is not captured by counting the number of patents. This research does not address the quality of the patents and focuses on whether certain characteristics of k-networks can increase the number of the patents as a measure of knowledge creation.

2.2 The constructs of knowledge network as means of knowledge creation

In this chapter the concepts of knowledge creation through k-networks have been introduced so far. More discussion on this matter and how my research defines knowledge creation and k-network are addressed later in Chapter 3 (Section 3.1.1.2). To understand the knowledge gaps in the literature, the whole concept of k-network and relevant literature on organisational networks are reviewed in this chapter. In the rest of this chapter, the theoretical concepts and boundaries of my research are defined. Then the review of relevant existing works is presented and the need for research on an integrative theory of k-networks is discussed in detail.

2.2.1 Theoretical landscape of the k-network research

In a rapidly changing era, organisations need to create knowledge to be innovative in order to survive. Some scholars (like Salk and Simonin 2003, p. 253 cited in (, p.1Gupta 2006),

have considered management of knowledge to be the very *raison d'être* of inter-organisational relationships.

Given the significance of k-networks in the organisational context, there is increasing research (Figure 2-1) published in academic journals[1] (Phelps et al. 2012). In a more general context, the volume of network research has increased radically in a variety of disciplines like sociology, economics, and management, as shown by Borgatti and Foster (2003).

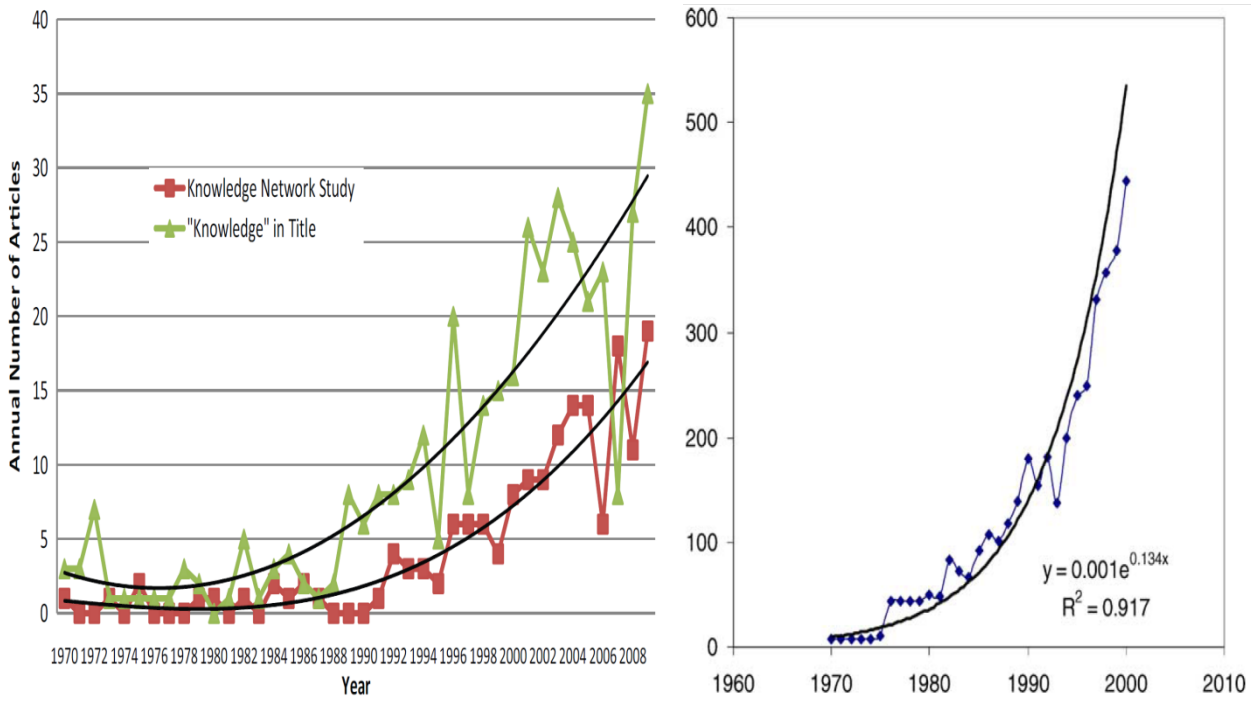


Figure 2-1 Rate of studies in knowledge, k-networks and social networks
Note: On the left side: the growth in studies in knowledge and k-networks from 1970–2009 – adapted from Phelps et al. (2012, p. 1116). On the right side: exponential growth of publications in "social network" from 1970–2002 – adapted from Borgatti and Foster (2003, p.992)

The multiple perspectives on network research issuing from multiple disciplines, is one major source of the complexity inherent in network research (Carpenter, Li and Jiang

[1] Phelps et al. (2012) analysed the following journals from 1970–2009: Management journals included Academy of Management Journal, Administrative Science Quarterly, Journal of Management, Management Science, Organization Science, and Strategic Management Journal; Economics journals include Quarterly Journal of Economics and Journal of Political Economy; Sociology journals included American Journal of Sociology and American Sociological Review; and Psychology journals included Journal of Applied Psychology and Psychological Bulletin.

2012). For example, in some studies, the network has been considered as a dependent variable while in others the network is considered as a contextual factor which influences actors' behaviour (e.g. Borgatti and Foster 2003; Carpenter et al. 2012). Moreover as discussed by Borgatti and Foster (2003) other factors can increase the complexity of the research, for example level of analysis, explanatory goals (how the consequence of the network is defined) and explanatory mechanisms (how the researchers treat ties and their functions).

In order to avoid such complexity and make my research clear for the reader, here I define the dimensions of my research in terms of theoretical focus, organisational level of analysis, organisational size and industry domain, and theme of analysis (Figure 2-2).

2.2.1.1 *Theoretical focus*

There is no single or unified theory of k-networks as mentioned by network scholars like Monge and Contractor (2003) and Galaskiewicz (2007); however, theorising about networks (including k-networks) can generally be considered from two perspectives: the view from the individual organisation that is participating in or located in the network, or the view from the whole network level of analysis. This distinction is also known as a *micro-level* versus a *macro-level* network focus (Wasserman and Galaskiewicz 1994; Provan, Fish and Sydow 2007).

Table 2-2 Schema of network theories adopted from Galaskiewicz (2007, p. 3)

	Micro-level analysis	*Macro-level analysis*
Networks as independent variable	Structural Hole Theory (Burt) Brokerage network position → Getting ahead	Small World Theory (Watts) Local clustering + Short paths + Few ties overall → Network survival/Performance
Networks as dependent variable	Balance Theory (Heider) Positive/Negative Ties → Reciprocity and Transitivity	Neo-Institutional Theory (Hamilton & Biggart) Cultural, political, and historical context → Network structures/Forms
Networks as both dependent and independent variables	Social Comparison Theory (Festinger) Similarity of traits → Dyadic ties → Similar behaviours	Network Evolutionary Theory (Aldrich) Population density → Network association → Cognitive, Moral, and Regulatory legitimacy

Given this distinction, Galaskiewicz (2007) defined six types of network theories as shown in Table 2-2. Building on this classification of theories, my research was intended to expand theories at the micro-level of analysis with network considered as an independent

variable. Therefore most of the following reviewed literature is based on this class of theory.

Which types of network theories? Discussed in Table 2-2

	Micro-level analysis	Macro-level analysis
Networks as independent variable	Structural Hole Theory (Burt) Brokerage network position → Getting ahead	Small World Theory (Watts) Local clustering + Short paths + Few ties overall → Network survival/Performance
Networks as dependent variable	Balance Theory (Heider) Positive/Negative Ties → Reciprocity and Transitivity	Neo-Institutional Theory (Hamilton & Biggart) Cultural, political, and historical context → Network structures/Forms
Networks as both dependent and independent variables	Social Comparison Theory (Festinger) Similarity of traits → Dyadic ties → Similar behaviours	Network Evolutionary Theory (Aldrich) Population density → Network association → Cognitive, moral, and regulatory legitimacy

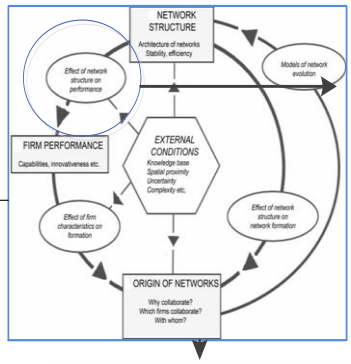
Given this kind of theory

Which level of analysis? Discussed in Table 2-3

Focusing on inter-organizational level

Which themes of research? Discussed in Figure 2-3

	Inter-personal	Intra-organizational	Inter-organizational
Dyad	e.g. What is the effect of relationship on finding jobs? (Granovetter, 1973)	e.g. What is the effect of relationship of unit with other units on access to knowledge? (Hansen et al., 2005)	e.g. What is the effect of prior mutual alliances of a firm with other firms on forming new alliances?Gulati and Gargiulo (1999)
Actor	e.g. How position of an individual in a k-network of an organization relates to her ability to innovate? (Perry-Smith and Shalley, 2003)	e.g. Is team size positively related to innovation? (Hülsheger et al., 2009)	e.g. greater a firm's (a) centrality in a network of relationships and (b) experience at managing ties at a given time, the more rapid its subsequent growth, controlling for prior growth. (Powell et al., 1996)
Network	e.g. how network characteristics (density) of managers in a firm influence the firm performance. Athanassiou et al. (2000)	e.g. how intra-organizational networks characteristics (centrality) effect on knowledge sharing? (Tsai, 2002)	e.g. What factors influence on formation of inter-organizational network? (Ebers and Ebes, 2001)



1.Formation
2. **Effect of Network**
3.Evolution

Which area of the research in theme of the effect of network? Discussed in Table 2-4

		Explanatory goals	
		Social capital (performance variation)	Diffusion (social homogeneity)
Explanatory mechanisms	Structuralist (topology)	***Structural capital***	***Environmental shaping or Convergence.***
	Connectionist (flows)	***Social access to resources***	***Contagion***

Social capital Theories from the k-network perspective

Towards the gap in the literature

Figure 2-2 The theoretical scope where my research was targeted to make a contribute
Note: Defining the types of network theories, levels of analysis, themes and areas of research

2.2.1.2 *Level of analysis*

In traditional research, the level of analysis typically is defined in terms of the scope and complexity of the entities being studied. For instance, organisations represent a higher level than individuals, however, in network research, the situation is different (Borgatti and Foster 2003). This is because, on the one hand, there are dyad, actor or network levels (e.g. Marsden 2005) and on the other hand, there are different types of actors, i.e. inter-personal, intra-organisational and inter-organisational (e.g. Phelps et al. 2012).

Taking social network theory, network research mainly focuses on the relationships between each pair of nodes, not the attributes of each node (Scott 2000), therefore the network data are fundamentally dyadic. For instance, whether actor A and actor B share their knowledge with each other or not, is of interest, not the characteristics of each node (like age or gender of each actor). But since the data can be aggregated to higher levels, it is possible to test hypotheses or answer questions not only at the dyadic level but also at the actor and entire network levels as well. Moreover if gender is used to explain who talks to whom then mixed-level hypotheses are able to be tested (Borgatti and Foster 2003).

From another perspective, the level of analysis in organisational k-network research is also understood in terms of inter-personal, intra-organisational and inter-organisational, as for example discussed in Phelps et al. (2012). This mainly refers to the type of actors in the study, for instance whether one is interested to study the knowledge sharing among organisational units i.e. intra-organisation (e.g. Hansen 2002) or among independent organisations in an alliance i.e. inter-organisational (e.g. Owen-Smith and Powell 2004).

Given these two different perspectives, it is possible to formulate an analytical framework with nine categories (Table 2-3) to define a typology of levels of analysis in k-network research. In each category, one example of the research questions or hypothesis of network studies is provided. However given the cross-level nature of the network research, it is barely possible to define a clear distinction of level of analysis, and as discussed by Borgatti and Foster (2003), the situation is subtle and deceptive[2], particularly for network

[2] To make this more clear here I used the examples provided by Borgatti, S. P. and P. C. Foster (2003). "The network paradigm in organizational research: A review and typology." Journal of Management **29**(6): 991-1013. For

researchers whose research questions usually lie at the intersection between different levels (Capaldo 2007).

Table 2-3 Level of analysis in k-network research
Note: The highlighted areas are the main focus of this research

	Inter-personal	Intra-organisational	Inter-organisational
Dyad	e.g. What is the effect of relationship on finding jobs? (Granovetter 1973)	e.g. What is the effect of relationship of unit with other units on access to knowledge? (Hansen, Mors and Løvås 2005)	e.g. What is the effect of prior mutual alliances of a firm with other firms on forming new alliances? (Gulati and Gargiulo 1999)
Actor	e.g. How does the position of an individual in a k-network of an organisation relate to his/her ability to innovate? (Perry-Smith and Shalley 2003)	e.g. Is team size positively related to innovation? (Hülsheger, Anderson and Salgado 2009)	e.g. How does a firm's (a) centrality in a network of relationships and (b) experience at managing ties at a given time, help the firm to have a higher growth? (Powell et al. 1996)
Network	e.g. How do network characteristics (density) of managers in a firm influence the firm performance? (Athanassiou and Nigh 2000)	e.g. How do intra-organisational network characteristics (centrality) affect knowledge sharing? (Tsai 2002)	e.g. What factors influence formation of inter-organisational networks? (Ebers 2001)

In my research, the level of analysis is mainly inter-organisational, given the nature of the network under consideration. However like most other network research, I may need to use theories and methodologies that were initiated in other levels. For instance the results of inter-personal studies are frequently applied to the analysis of inter-organisational interactions (Capaldo 2007).

Moreover, it is quite common among network researchers to use dyadic constructs and data to explore hypotheses or research questions focused on other levels like actor level, network level, or mixed-levels (Borgatti and Foster 2003). Nevertheless this does not mean that it is acceptable to apply every theory from networks of persons to networks of

instance, suppose the research question of a study is how the position of an individual in a k-network of an organization relates to his/her ability to innovate. This is an actor-level analysis (which is more aggregate from the dyadic level) in an inter-personal level. Now suppose one looks at k-networks of the top management team in 50 separate firms and correlate some characteristics of each network with the firm performance. In that analysis the level of analysis is a network level, a step up from the actor level in an interpersonal level. But now if someone studies alliances among biotechnology firms, hypothesising that firms with more alliance partners will be more successful. Surprisingly, the level of analysis gets back at the actor level of analysis.

organisations, since the nature of actors, their capabilities and the meaning of the relations are totally different (Barabasi, (2002) cited by Borgatti and Foster (2003)). Hence, generalising results from other studies to inter-organisational research should be made carefully.

2.2.1.3 *Themes of research within inter-organisational network studies*

There are several themes that have been studied within the inter-organisational network research – the level of analysis selected in the previous section (2.2.3.2). From a very broad perspective, one may able to distinguish between the research which has been done on general inter-organisational networks and the inter-organisational k-network research. For example, Ozman (2009), reviewed the vast general theoretical and empirical literature of inter-organisational networks, and defined three major themes of analysis and showed the relationships between these themes as observed in network research. These themes and relations, which are shown in Figure 2-3, include:

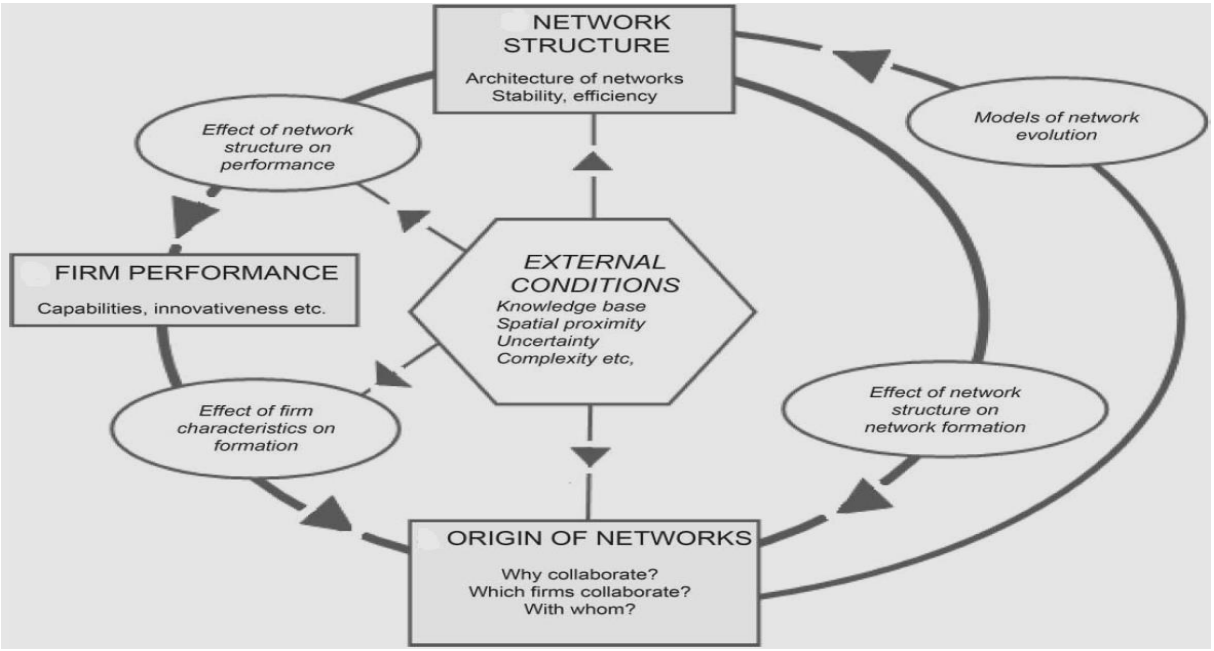


Figure 2-3 Themes of research within inter-organisational network
Source: Ozman (2009, p.41)

Theme 1: Origins and formation of networks. This theme included two parts: motivation for partnership and external effects, and characteristics of partners.

Firm-specific motivation for partnership and external effects are parts of factors discussed in this theme. For example, by studying new entrants into the Ontario wine industry, Roberts and Sterling (2012) showed that friendship ties of the founders of one especially prominent entrepreneurial firm led to significantly higher ice-wine prices. The second part of this theme deals with the basic question of with whom firms collaborate? Baum, Cowan and Jonard (2010), for instance, have studied the role of complementary knowledge stocks and knowledge dynamics, which they believed have received surprisingly limited attention relative to social capital as forces behind the formation and dynamics of innovation networks.

Theme 2: Network structure. This also may relate to three areas of external factors, evolution models of structure and small world and scale-free network (Ozman 2009).

In the k-network research, the role of external conditions on knowledge transfer for example was studied recently in terms of cost of search, environmental turbulence and organisational memory (Levine and Prietula 2011). Network evolution models were also addressed in recent research. For instance, by studying a professional network of lawyers' co-employment in Nashville, Tennessee, USA McEvily, Jaffee and Tortoriello (2012) illustrated the role of two alternative network dynamics including "accumulating" and "imprinting" effects on firm's growth rate. The "small-world" argument in social network theory also emphasises that people are, on average, only a few connections away from the information they seek, however Singh, Hansen and Podolny (2010) argued that some employees may have longer search paths in locating knowledge in an organisation depending on factors like their tenure, or gender.

Theme 3: The effect of networks on firm performance. This theme has also been associated with areas like: effect of embeddedness (or involvement of a focal firm in the network) on performance of the firm; social capital and structural holes; and networks and firm performance in a geographical districts.

Taking this literature review on inter-organisational network studies, my research has focused on the effects of networks in the context of knowledge sharing (theme 3). Therefore the literature review of my research is targeted at understanding the multiple aspects of research on effects of network structure.

2.2.1.4 *Streams of research: studies on effects of inter-organisational networks*

Like the research on inter-organisational networks, there is a seminal literature review article by Borgatti and Foster (2003) that summarises the works on effects of inter-organisational networks. They developed a framework that classified the research on consequences of networks into four areas.

This framework was developed based on two criteria of "explanatory goals" and "explanatory mechanisms". By explanatory goals they mean whether the focus of study is on performance, like Ahuja (2000) who studied the role of certain network characteristics on innovativeness of chemical companies; or on homogeneity, like Harrison and Carroll (2002) who researched how individuals acquire organisational culture through socialisation in a network. While the former perspective focuses on opportunities or the possible benefits and drawbacks of social position for an actor, in contrast the latter concentrates on how practices spread through a system or how the network changes the actors in order to explain homogeneity in actor attitudes (Borgatti and Foster 2003). Given this typology, it is possible to define the main focus of my research which is on the performance stream. Such variation in an actor level of an inter-organisational network may refer to performance and other value-laden outcomes for the actor, like knowledge creation.

The second criterion, however, distinguishes between two types of mechanisms: structuralist vs. connectionist. The structuralist believes that same network position of actors provides similar results for those actors even if these actors are not connected to each other. In other words, network actors with similar positions tend to imitate each other even if they are not aware of each other (Burt 1995). However, connectionists consider quality and quantity of network resources as the main factor that explains the effect of the network. These resources are controlled by the actors' connections (sometimes called alters). In a similar way, structuralist vs. connectionist has been compared with structural vs. relational

embeddedness (Granovetter 1985; Nahapiet and Ghoshal 1998 cited byBorgatti and Foster 2003). Also, Lin (2002 p. 243) addressed two concepts of accessibility (network locations and resources) and mobilisation (use of contacts and contact resources) which to some extent represent structuralist and connectionist perspectives.

Using the two criteria discussed above, Borgatti and Foster (2003) developed a two-by-two framework represented in Table 2-4.

Table 2-4 Typology of research on effect of network
Source: Borgatti and Foster (2003 p.1004)

		Explanatory goals	
		Social capital (performance variation)	Diffusion (social homogeneity)
Explanatory mechanisms	Structuralist (topology)	Structural capital	Environmental shaping or convergence.
	Connectionist (flows)	Social access to resources	Contagion

As the focus of this study is on consequences of k-networks, the review of the other so-called diffusion stream is not provided here. Also as the focus of analysis is on actor-level (see Section 2.2.3.2), the summary of the reviews on structural capital studies and resource access studies at the actor level is provided here. Given this review I discuss the need for the new studies to go beyond these categories.

- ***Structural capital studies***

In these studies, actors are seen mainly as rational, active agents who exploit their positions in the network in order to maximise gain (Borgatti and Foster 2003). Possessing a particular network configuration has been considered as a major factor that explains the outcome. These configurations may be defined either through occupying central positions in the network (e.g. Powell et al. 1996) or by having an ego-network (the immediate network of an actor, which is detailed further in Section 2.2.4.2) with a certain structure or having or missing a tie (link or relation) (e.g. Coleman 1994; Burt 2004). These effects in a k-network may refer to knowledge adoption, transfer and knowledge creation as shown in the literature review by Phelps et al. (2012). As my research focuses on knowledge creation within k-networks such studies are addressed further.

- ***Resource access studies***

Like the structural capital studies, here there is an assumption of rational behaviour of actors as "active agents who instrumentally form and exploit ties to reach objectives" (Borgatti and Foster 2003, p.1004). In this stream of research, while the main focus is on role of social capital on performance, the main factor is quality and quantity of resources controlled by the actor's alters (e.g. Anand and Khanna 2000; Stuart 2000; Oliver 2001; Koka and Prescott 2002; Borgatti and Cross 2003). The relationships between an actor and his/her connections have been considered as conduits through which the actor can access the required resources.

2.2.2 Selected network theories from the k-network perspective

Given the two main streams of social capital research (i.e. structural capital and resource access), in the next section the main theories on social capital are discussed, though from the k-network perspective.

2.2.2.1 Network position research

In an inter-organisational network, [inter-organisational] partnerships of an actor define the position of the actor within the network. The greater the number of partnerships will push the actor to a central position. The partnership and accordingly the centrality may increase by the concept of spatial proximity or propinquity (e.g. Still and Strang 2009) and this is why in some studies the concept of proximity is also included in network position research. However, beyond the factors that impact on centrality, here I focus on possible effects of network position on knowledge creation.

The research on effects of network position on knowledge creation mainly considers central position as a favouring factor for knowledge creation. For instance, Ahuja (2000) showed in his seminal research in large chemical companies that having more inter-organisational partners of a firm leads to a higher number of patents for the firm. By highlighting the concept of uncertainty in R&D projects in the computer and telecommunications industry, Soh, Mahmood and Mitchell (2004) explained the role of central position in providing more partners and accordingly timely access to diverse knowledge. They argue that central

firms, who have many partners to assist them, can reach higher integrative knowledge with lower uncertainty, thereby leading to a faster response to market (Soh et al. 2004). In a similar way, Gibbons (2004), by using the simulation technique, found that central organisations, in comparison with other network members, are associated with higher network connectivity and faster collection of knowledge.

However, there are other studies that show central position may have a weak positive influence (Whittington, Owen-Smith and Powell 2009) or even no influence on patenting as a form of knowledge creation (Owen-Smith and Powell 2004) among biotechnology firms. The firms in both studies were located within close geographical proximity. The types of actors with which these biotechnology firms had relationships have also been considered as important factors. For instance, the knowledge from public entities, such as universities or government institutes is more accessible for a firm mainly because of public organisations' rules for the dissemination and use of scientific findings (Dasgupta and David 1987, 1994; Owen-Smith 2003) and also because of sharply divergent selection environments of these organisations, as mentioned by Owen-Smith and Powell (2004). Likewise Whittington et al. (2009) examined the contingent effects of network position and geographic propinquity in a knowledge intensive industry (human therapeutic and diagnostic biotechnology firms). They found that the network position of a firm contributes to knowledge creation both independently and interdependently with geographic variables, and regional characteristics like proximity to other companies. In a similar way, some scholars found that depth and diversity of knowledge could be one contingent factor to explain the role of network position. For instance, Baum, Calabrese and Silverman (2000) analysed Canadian biotechnology start-ups and highlighted the fact that an efficient network that provides access to diverse information and capabilities with minimum costs of redundancy, conflict and complexity can enhance the performance of the start-up company. Although the efficiency of an alliance network is defined as diversity of information and capabilities per alliance, Baum et al. (2000) measured the diversity of the partners in terms of organisational types. In other words they assumed that if a start-up company has partnerships with various types of organisations like pharmaceutical companies,

universities, government laboratories and research institutes, then the company can access diverse knowledge. This is a point that I elaborate on later in this chapter (Section 2.3.1).

Stuart (2000) by studying semiconductor producers as a high-tech and knowledge intensive industry, posited that the greater the knowledge (measured by patents) of a high-tech firm's alliance partners, the higher the rate of sales growth of that firm, particularly if it is young or small. In his conclusion, he called for research on Burt's (1992) structural holes argument. This theory suggests that the addition of a new (non-redundant) partner with different sets of knowledge is likely be more valuable than the addition of a new partner that is similar in kind to an existing one (Stuart 2000). A summary of the research on network position is presented in Table 2-5.

Table 2-5 Summary of selected research on network position

Role of centrality	Contingencies	Outcomes	References
Centrality is associated with higher social status and higher status organisations are perceived as being of higher quality and more informed and diligent in their decisions.	None identified	Decision making	Podolny (1993)
	None identified		Davis and Greve (1997)
A start-up's number of cooperative relationships has a positive effect on its innovative output.	None identified	Innovative output in terms of patents	Shan, Walker and Kogut (1994)
Centrality – that incorporates indirect ties. While indirect ties can benefit a recipient organisation's knowledge production by providing it with access to more diverse information, direct contacts collect and process this indirect information and can share it with greater richness and fidelity, thereby diminishing the influence of indirect ties on innovation.	Direct ties can reduce the effects of indirect ties.	Positive on knowledge production and innovation__ in terms of patents	Ahuja (2000)
The number of ties per se has weak or no influence on innovation.	Depth and diversity of knowledge, rather than the number of ties per se are influencing innovation	Innovation	Stuart (2000)
A start-up's performance should increase with the efficiency of its alliance network,	Diversity of partner	Innovation performance	Baum et al. (2000)
The more inter-organisational partners a firm has, the greater its innovation.	Network of geographically close firms	Innovation in terms of patents	Owen-Smith and Powell (2004)

Role of centrality	Contingencies	Outcomes	References
Increasing centrality among initial adopters' contacts positively influences diffusion only to the point at which communication occurs with non-adopters.	Volume of information from non-adopting partners – however not tested explicitly	Innovation adoption	Gibbons (2004)
Central firms have many partners to assist them and have timely access to diverse information of high integrity leads to higher new products.	Timely access to diverse information of high integrity with less uncertainty and ability to commercialise	New products	Soh et al. (2004)
The rate of knowledge creation in investor firms has a curvilinear (inverted U-shaped) relationship with the number of corporate venture capital investments.	Corporate investors' technological knowledge diversity will positively moderate the relationship between the number of corporate venture capital investments and knowledge creation.	Knowledge creation	Wadhwa and Kotha (2006)
Increasing reliance on partners for knowledge can have a diminishing and ultimately negative effect on knowledge creation since the costs of maintaining an increasing number of inter-organisational relationships can exceed their knowledge creating benefits.	Negative role of reliance on partners' knowledge	Firm performance in terms of firm innovativeness and firm financial performance	Rothaermel and Alexandre (2009)
In knowledge intensive industries, firm-level innovation increases with centrality in the global inter-organisational network.	Alliance network of geographically dispersed firms	Knowledge creation in terms of patents	Whittington et al. (2009)
Centrality in network of geographically close firms has no effect or a small positive effect on knowledge creation.	Geographically close firms	Knowledge creation in terms of patent	Whittington et al. (2009)
The effect of centrality on the firm's innovation performance is positively moderated by the number of partners with repeated ties in the firm's ego-network.	Repeated ties – achieve better standardisation efforts	Firm's innovation performance	Soh (2010)
The effect of centrality on the firm's innovation performance is positively moderated by the density level of the firm's ego-network.	Density level of the firm's ego-network	Firm's innovation performance	Soh (2010)

2.2.2.2 Closed network vs. sparse network research

As described earlier in this chapter (Section 2.2.1), my research is conducted at the nodal level. Focusing on the nodal level of analysis, research studies have discussed the role of the ego-network on the ego's performance. In network theories, the concept of ego in ego-networks refers to a focal node or ego, and the ego-network includes the focal firm and its

partners – the nodes to whom the ego is directly connected. These partners of the ego sometimes are called alters (Wasserman and Faust 1994). A hypothetical whole network and two of its ego-networks are illustrated in Figure 2-4 (Ego-networks of A and B).

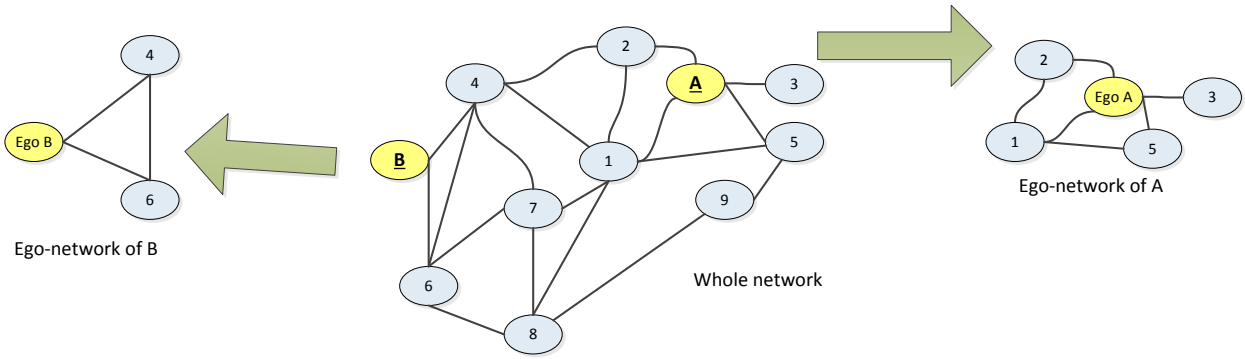


Figure 2-4 Ego-network vs. whole network
The ego-network of two nodes of A, and B are illustrated

Moreover, as discussed earlier (Section 2.2.3.4.), my research is focused on the effect of social capital within inter-organisational networks. From this stream of research, there are two competing views about the role of the ego-network, namely closed vs. sparse networks or as sometimes called closed network theory vs. structural hole theory which are perceived as polar approaches. To define these two approaches and their different perspectives, here I use the widely cited example of Burt (2001) shown in Figure 2-5.

In a hypothetical friendship network of Burt (2001), Robert and James have the same number of relations, six strong ties and a weak tie. However to understand which position has “more social capital” or “better connection” (Burt 2001), these two theories have two interpretations. Closure network theory (Coleman 1988; 1994) argues that James has a “better” connection since all his connections belong to group B and he is tightly connected to people in group B. However, Robert’s friends are fragmented within different groups so he is not well involved or connected to either of these groups as much as James belongs to group B.

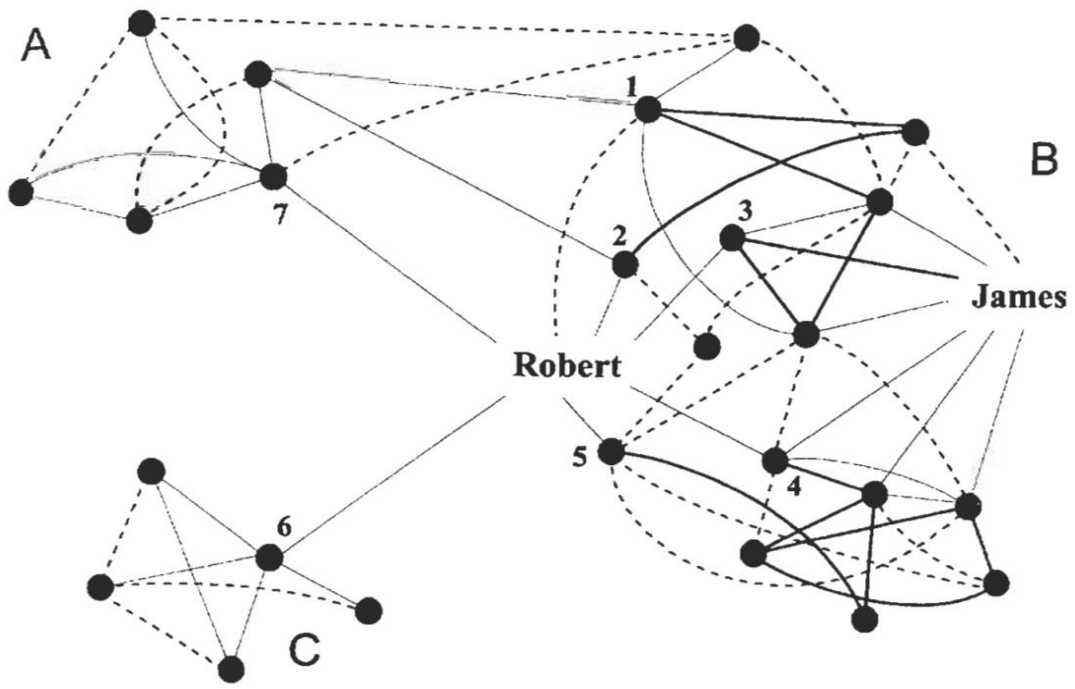


Figure 2-5 Closed vs. sparse network and the concept of structural hole.
Source: Burt (2001, p. 33)

As shown in Figure 2-5, the connections between groups A, B and C are not very tight or strong since there are many gaps among them. These gaps are called structural holes (Burt 1995). This theory explains the merit position of Robert and argues that he has more social capital than James (see Figure 2-5) by using the concept of structural holes. It argues that his "weaker" connections provide non-redundant sources of information from group A, B and C. In other words while James is well connected to group B and informed about this group, Robert has the opportunity to broker the flow of information between various groups (Rangachari 2009).

To have a better understanding of these two theories, I review the two inter-related network concepts of ego density and tie strength. Then building on these two concepts, the application of these two perceived polar theories (i.e. structural hole vs. closed network theories) within inter-organisational k-network research is discussed.

Tie strength

Most of the network literature has emphasised positive aspects of relations for creating social capital (e.g. Inkpen and Tsang 2005, cited by Barzilai-Nahon 2008), however Labianca and Brass (2006) focused on the meaning of negative relationships. To understand the role of relationship, strength of tie or relation is a key concept (Scott 2000).

In a network relationship the tie strength refers to features of relationship, or tie between receiver and sender. These features, based on the nature of the network, may be defined by a variety of criteria like the time that the sender and receiver spend with each other, the frequency of their relationships, the emotional intensity between them, the reciprocal services and also the intimacy (e.g. (Brass, Butterfield and Skaggs 1998; Kane 2006)).

Given these features of network relationship, the literature has considered the role of strong tie networks compared to weak tie networks. Granovetter (1973) was the first to discuss and compare these two. His research at the inter-personal level concluded that job seekers with higher weak ties acquire better knowledge about the opportunities. However at the inter-organisational level, much of this research highlights the positive role of strong ties on innovation adoption, knowledge transfer, and organisational knowledge creation (Table 2-6).

Table 2-6 Role of tie strength in inter-organisational k-network

Role of tie strength	Contingencies	Outcomes	References
The strength of structural links suggests that creating collective governance structures stimulates innovation.	None identified	Hospital innovation	Goes and Park (1997)
Strong ties might be particularly valuable in promoting adaptation.	None identified	Professional program adoption	Kraatz (1998)
Experience is negatively related to ambiguity and ambiguity is negatively related to knowledge transfer.	None identified	Knowledge transfer	Simonin (1999)
The more extended the design scope of the relationship, the greater the learning opportunities of the relationship.	Content in terms of design scope and task interdependency	Efficiency vs. learning	Sobrero and Roberts (2001)
Collaborations that have high levels of involvement among partners and that are highly embedded in their institutional field will be positively associated with the creation of novel practices.	None identified	Adoption of novel practices	Lawrence, Hardy and Phillips (2002)

Role of tie strength	Contingencies	Outcomes	References
Strong connection if associated with partner diversity improves a firm's learning.	Partner diversity	Learning	Beckman and Haunschild (2002)
Greater joint problem solving (e.g. through intense communication) facilitates the transfer of complex and tacit knowledge between job shop manufacturers.	Content in terms of knowledge type	Transfer of tacit knowledge	McEvily and Marcus (2005)
Increasing relationship duration can increase a recipient firm's understanding, adaption and finally transfer of a source's knowledge	None identified	Knowledge transfer	Williams (2007)
The ability to integrate a large periphery of heterogeneous weak ties and a core of strong ties is a distinctive lead firm's relational capability.	None identified	Innovation	Capaldo (2007)
In technology-driven industries, the greater a partner's internal involvement in a multi-partner alliance, the greater its benefits from membership in that alliance.	None identified	Organisational knowledge creation-like number of certified products	Lavie, Lechner and Singh (2007)
Strong ties are positively related to knowledge integration in innovation-seeking project alliances.	None identified	Knowledge integration	Tiwana (2008)
The effect of centrality on the firm's innovation performance is positively moderated by the number of partners with repeated ties in the firm's ego-network.	Centrality on the firm	Firm's innovation performance	Soh (2010)
Repeated ties have no influence on telecommunications equipment manufacturers' innovation.	None identified	Exploratory innovation	Phelps et al. (2012)
The relational strength of a firm's ego-network partners is positively associated with the innovative performance of the focal firm.	None identified	Innovative performance	Demirkan and Demirkan (2012)

In this literature, strength of ties is characterised by long relationship duration, frequent and intense collaboration, and repeated partnering over time. To solve the seemingly contradictory effects, Rowley, Behrens and Krackhardt (2001) believe that resolution of the debate regarding the benefit of strong versus weak ties may ultimately require a contingency approach. By reviewing network-based research in entrepreneurship, Hoang and Antoncic (2003) mentioned that strong ties may be more relevant during the founding stage and early growth stage of a new venture as they are likely to be ready, low-cost links to critical resources. However, in an intra-organisational context, Hansen (2002) highlighted the role of tacit/explicit knowledge and showed that strong ties between groups are better for tacit knowledge transfer, while weak ties are better for explicit knowledge.

Ego density

In a network relationship there are several concepts referring to density. One of them is edge density which is calculated by the ratio of actual ties to the number of possible ties in the network (e.g. Reagans and McEvily 2003). This is a measure for the whole network. The other concept is ego density or network efficiency (Burt 1995), which is calculated by the number of triangles or closure triads ÷ n(n-1)/2, where n is number of the ego's partners (or alters) and closure triads refers to closed relationships between any three actors. For instance, if actor A has a relationship with actor B, and actor C, then there is triad closure between actors A, B, and C if actor B and C are also linked to each other (Borgatti, Everett and Freeman 2002; Rodan and Galunic 2004). Given the level of analysis and the themes discussed in Section 2.2.1, in my research the concept of ego density is of interest, however in some parts of the existing research it may be referred to simply as density. Having a dense or sparse ego-network has its own merits and flaws. A summary of the contributions of high or low density networks is provided in Table 2-7.

Table 2-7 Role of ego density in inter-organisational k-network

Role of Density	Contingencies	Outcomes	References
Structural holes (non-redundant contacts ratio) in the firm's advice network will positively influence its acquisition of competitive capabilities.	Participation in regional institutions	Acquisition of knowledge/capabilities	Zaheer and McEvily (1999)
A start-up's initial performance increases with the efficiency of its alliance network at founding.	Partner diversity	Knowledge creation	Baum et al. (2000)
Increasing structural holes (non-redundant contacts to total contacts) decreases innovation.	Type of tie	Firm innovation in terms of patents (knowledge creation)	Ahuja (2000)
The amount of inter-organisational learning which takes place within a production network increases when the network creates nested networks to facilitate the sharing of different types of knowledge.	None identified	Inter-organisational learning	Dyer and Nobeoka (2002)
Collaborations that have high levels of involvement among partners and that are highly embedded in their institutional field will be positively associated with the creation of novel practices.	None identified	Enhances the diffusion of novel practices	Lawrence et al. (2002)

Role of Density	Contingencies	Outcomes	References
Dense ego-networks (repeated partner) are associated with new product performance.	None identified	New product performance	Soh (2003)
The presence of structural holes in a firm's ego-network of alliance relationships has a deleterious effect on its inventive output.	None identified	Firm innovation in terms of number of patent	Schilling and Phelps (2007)
Bridging ties are positively related to knowledge integration in innovation seeking project alliances.	None identified	Knowledge integration	Tiwana (2008)
Brokered access has a stronger positive effect on the acquisition of explicit than tacit local knowledge.	Explicit vs. tacit knowledge	Knowledge acquisition	Li, Poppo and Zhou (2010)
The effect of centrality on the firm's innovation performance is positively moderated by the density level of the firm's ego-network.	Centrality – better organisational support from partners and knowledge sharing	Firm's innovation performance	Soh (2010)
Network density has a positive and significant effect on exploratory innovation.	The effect of network technological diversity	Exploratory innovation	Phelps (2010)
A dense network increases the positive effect of marketing knowledge from foreign partners on the likelihood of venture initiation of foreign sales.	None identified	Venture initiation of foreign sales	Yu, Gilbert and Oviatt (2011)
Firms whose spillover network is rich in structural holes tend to be more innovative.	None identified	Firms' innovative performance—patent based	Operti and Carnabuci (2011)
The effect of the focal firm's structural holes on its innovativeness will be more positive when the focal firm's and its partners' countries are both highly corporatist than when the focal firm's country is low on corporatism and its partners' countries are highly corporatist.	Partner and broker corporatism	Innovativeness in terms of patent citations	Vasudeva, Zaheer and Hernandez (2012)
The effect of the focal firm's structural holes on its innovativeness will be more positive when the focal firm's country is highly corporatist and its partners' countries are low on corporatism than when the focal firm and its partners' countries are both low on corporatism.	Partner and broker corporatism	Innovativeness in terms of patent citations	Vasudeva et al. (2012)

Role of Density	Contingencies	Outcomes	References
The greater the extent to which partners' contemporaneous professional ties are bridging, the greater a law firm's growth rate	None identified	Firm's growth rate formation and evolution of the professional network of lawyers' co-employment	McEvily et al. (2012)

For a firm, there are several benefits of having a sparse ego-network or an ego-network with an abundance of structural holes. For instance, by using structural holes of its network a firm can have access to a knowledge rich network (Operti and Carnabuci 2011) through non-redundant (Zaheer and McEvily 1999) and indirect relationships with mutually unconnected partners. As a consequence they have access to many varied knowledge flows (Baum et al. 2000; Tiwana 2008), although the indirect nature or weakness of its relations may increase the difficulty of knowledge transfer to the firm (Tiwana 2008). According to structural holes theory, firms can gain from bridging ties to access new and novel knowledge (Burt 1995). In an inter-organisational context, this type of tie which serves as a bridge to new opportunities, connects firms separated by a structural hole, which otherwise would not be accessible to each other (McEvily et al. 2012).

On the other side, more studies highlighted the role of dense ego-networks of a firm on its knowledge creation, knowledge integration, and adoption of new ideas (see Table 2-7). They have focused mainly on the existence of significant trust between the partners in order to reap the resource-sharing benefits of collaboration, including combining their skills, sharing their knowledge, and conducting joint projects to obtain scale economies (e.g. Simonin 1997; Lavie et al. 2007; Tiwana 2008). Dense ego-networks enhance trust and are mainly needed when dealing with alliances among competitors. These alliances are subject to substantial risks of partner opportunism, which can discourage knowledge sharing and hence creating of knowledge among these partners (Ahuja 2000). Dyer and Nobeoka (2002) also showed that effective k-networks require nested and dense relations with a low number of structural holes to transfer different types of knowledge.

2.2.2.3 Knowledge content and collaborative process as contingent factors

As reviewed in Tables 2-5, 2-6 and 2-7, the findings in these theories are not accepted universally. There are several contradictions discussed in the social capital research. To

explain these different results, at least in part, scholars, however have proposed contingent factors. A summary of these is represented in Table 2-8. The **bolded** constructs in Table 2-8, which are the common ones among both streams of research, are later used to develop an integrative reseach model (Section 2.3.4).

The inter-organisational k-network literature highlighted the contingent factors which deal with the content of the k-network. From the network position research, this content factor refers to depth and diversity of knowledge (Baum et al. 2000; Stuart 2000; Gibbons 2004). Likewise in the sparse vs. closed network research, the content factor is represented in terms diversity of technological knowledge (Phelps 2010).

In the second row labelled collaborative process, the role of partner diversity in both network position research (Wadhwa and Kotha 2006; Rothaermel and Alexandre 2009) and sparse-closed network research (Beckman and Haunschild 2002) has been highlighted. The reason for having this label is presented in this chapter Section 2.3.2.

Table 2-8 Contingent factors in two main streams of social network research into inter-organisational k-network

	Network position research*	Sparse vs. Closed network research*
Knowledge content	Depth and **diversity of knowledge** (Stuart, 2000); more timely access to more diverse information (Beckman and Haunschild 2002; Wadhwa and Kotha 2006); speed and depth of information transmission (Gibbons 2004)	The effect of network technological diversity (Phelps 2010), **knowledge diversity(**heterogeneity**)** (Demirkan and Demirkan 2012) Knowledge type (McEvily and Marcus 2005); explicit vs. tacit knowledge (Li et al. 2010); design scope and level of task interdependency (Sobrero and Roberts 2001)
Collaborative process	Negative role of reliance on partners' knowledge (Wadhwa and Kotha 2006; Rothaermel and Alexandre 2009) **partner diversity** (Baum et al. 2000)	**Partner diversity** (Beckman and Haunschild 2002); types of partner (Vasudeva et al. 2012); quality of partner (Demirkan and Demirkan 2012)
Structural elements	The effect of **centrality** on the firm's innovation performance is positively moderated by the **density** level of the firm's ego-network (Soh 2010) – geographical distance (Owen-Smith and Powell 2004; Whittington et al. 2009)	The effect of **centrality** on the firm's innovation performance is positively moderated by the **density** level of the firm's ego-network (Soh 2010). Repeated ties achieve better standardisation efforts (Soh 2010). Direct ties can reduce the effects of indirect ties (Ahuja 2000), e.g. by the number of indirect ties (Beckman and Haunschild 2002). Participation in regional institutions (Zaheer and McEvily 1999)

* the bolded constructs which are the same contingent factors identified in the both streams

In their research about the susbtitutability of partners, Bae and Gargiulo (2004) also discussed the possible consequences of inceasing reliance on few partners' knowledge for knowledge creation of telecommunication firms. In other words, to process the required knowledge for an innovative project, firms are either relaint on few partners or they may try to explore new partners. The strategy to choose between few or multiple partners is also reflected in the exploration/exploitation literature introduced by March (1991) and March and Levinthal (1993). Building on this concept, Lavie and Rosenkopf (2006) identified three domains of exploration and exploitation, including function, attribute and structure. The structural exploration has focused on diversity of the partners, i.e. whether a firm is forming an alliance with diverse partners or keeps recurrent alliances with a partner that has prior ties to the firm. Two other dimensions of the exploration/exploitation factor are the function and attributes of the partner. Lavie and Rosenkopf (2006) refer to the attribute domain by which organisational characteristics of partners, like size and industry focus, differ from those of the other partners of the firm. However the function refers to whether alliances are engaged in R&D or commercialisation projects. From this perspective the concept of structural exploration/exploitation represents parts of the whole concept of collaborative process in terms of exploration/exploitation.

And the last factor refers to the interactions of structural factors like centrality and density on each other. Although each of these concepts shows an effect on firm knowledge creation, the results are conflicting, as shown in the previous section. Similarly, in their k-network literature review, Phelps et al. (2012) highlighted these conflicts. To explain part of these results some scholars studied the interaction of structural elements (like centrality and density) on each other. For instance, Soh (2010) showed that the effect of centrality on the firm's innovation performance is positively moderated by the density level of the firm's ego-network.

2.3 Towards an integrative theory in k-network research

As shown in Table 2-8, content, process and structure of k-networks are common concepts that are reported in the existing literature as contingent factors required to understand the

role of the k-network. In this regard, this section seeks to explore the origin of these concepts.

2.3.1 Content of knowledge within the k-network

The idea of content of relationships can be traced back to anthropology as a broad school of thought in social science. Tichy, Tushman and Fombrun (1979) defined the origin of this concept in the exchange theories of (Frazer 1919; Malinowski 1922; Lévi-Strauss 1971), in which the content of the relationships joining individuals was emphasised. In their study, Tichy et al. (1979) distinguished between four different types transactional content including (p. 508): expression of affect, influence attempt, exchange of information, and exchange of goods or services. In a network of relationships content refers to the information, resources, social identity, and authority substance that is conveyed through a relationship (Burt, 1997; Podolny and Baron, 1997, cited by McEvily and Marcus 2005).

In network research overall, there are surprisingly few studies that have focused on the role of content, although the importance of the concept has been emphasised at least since 1970. For instance, to understand the possible effects of CEO–Board relations on the formation of joint ventures, Gulati and Westphal (1999) focused on the content of relationships, as "specification of behavioural processes underlying a connection between two actors" (p.473). They showed that in general, the various network variables do not have independent effects on alliance formation; instead, network effects are contingent on the content of CEO–Director relationships (p. 494).

Likewise, there are very few examples in previous empirical studies in k-network research, particularly at the inter-organisational level that have focused on the content of the network (see Table 2-8). McEvily and Marcus (2005), for instance, studied the relative influence of embedded ties with lead customers vs. lead suppliers on the acquisition of capabilities. Using case studies in job shop manufacturing, they revealed that the content of embedded ties differs in terms of the degree of firm-specific knowledge held by customers vs. suppliers. The distinction here mainly referred to types of knowledge, for instance, lead customers were predominantly focused on evaluating, controlling, and improving the quality levels of the metal coatings applied to customers' parts (p. 1039) which is output-

based, while this was not the case with suppliers who provided knowledge that was technically complex and difficult to articulate. Hence McEvily and Marcus (2005) proposed that joint problem-solving with suppliers will be more strongly related to acquisition of competitive capabilities than joint problem solving with customers. This finding refers to manufacturing firms located in a dense network, however McEvily and Marcus (2005) did not discuss the possible role of firms' networks.

Sobrero and Roberts (2001) also studied two separate variables of design scope and level of task interdependency as measures for content. They were interested in studying the role of such content in network outcomes, either in terms of efficiency or learning. The results showed that both relationships involving design concepts and relationships involving high interdependencies work being performed by outside agents provide more opportunities for learning than relationships involving only a functional parameter definition. However relationships involving high interdependencies are less efficient than relationships involving low interdependent tasks (Sobrero and Roberts 2001). This finding refers to fifty supplier–manufacturer relationships drawn from three new product development projects in Europe. By defining four types of relationship in manufacturers' ego-networks, Sobrero and Roberts (2001) studied the role of social interaction, however other possible roles of their networks like density and centrality were not discussed.

Within the context of k-network research, the other aspect of the content that has been studied, is the tacit vs. explicit dimension of knowledge (Polanyi 1967). Using survey data from foreign subsidiaries operating in China, Li et al. (2010) focused on relational and contractual mechanisms and examined their impact on foreign subsidiaries' acquisition of tacit and explicit knowledge from local suppliers. They showed that brokered access has a stronger positive effect on the acquisition of explicit knowledge than tacit local knowledge. Brokered access can be defined as a partner with weaker structural links in terms of less frequent interaction, less motivated to spend time, and more distant (Uzzi 1997, cited by Li et al. 2010), who can work as a bridge to link firms which otherwise do not have relationships with each other. This is particularly supported when the contracts are formal. Tacit knowledge, however, requires more integrated communications, hence is difficult to transfer by brokered access. Although this research shows the interaction of having

brokered access with property of knowledge, the role of firms in the whole network is undear (for example whether this finding still will be held if the position of the firm itself is central?). Similarly, the role of the network density of the brokered access is not clear as Li et al. (2010) measured the concept by asking two questions about: "1. We have gotten new supplier contacts through this supplier and 2. This supplier has 'opened the doors' to other suppliers for us" (p.370).

Diversity of knowledge is another aspect of the content which, as illustrated in Table 2-8, is reflected in both network position research and sparse vs. closed network research.

In the stream of sparse vs. closed network research, Demirkan and Demirkan (2012) highlighted the role of the qualitative characteristics of the network like heterogeneity of knowledge that is being shared in the network. They showed a positive effect of having heterogeneous knowledge on innovative performance. Phelps (2010) also discussed the role of knowledge heterogeneity and ego-network density on exploratory innovation, which is defined as the creation of technological knowledge by a firm that is novel relative to its existing knowledge stock. He measured exploratory innovation using patent citations, while network technological diversity was evaluated by using Rodan and Galunic's (2004) measure of knowledge distance. Ego-network density was also measured as the percentage of all possible ties among the ego's alters. His research predicted an inverted U-shaped effect of network technological diversity on firm exploratory innovation. However Phelps (2010) found evidence of a positive linear effect but not a curvilinear effect. He also showed that network density strengthens the effect of network technological diversity. In his research, network density had a positive and significant effect on exploratory innovation, independent of diversity. In summary, the research showed that the co-existence of dense ego-network – wherein a firm's partners are also partners with each other –and access to diverse knowledge may result in combined benefits that increase new knowledge creation.

In network position research, while many studies (Shan et al. 1994; Ahuja 2000; Owen-Smith and Powell 2004; Whittington et al. 2009) considered central position and having more inter-organisational link to others as a factor that positively improves organisational

performance (mainly in terms of innovation), there are other studies (Beckman and Haunschild 2002; Gibbons 2004; Wadhwa and Kotha 2006) that showed the importance of diverse knowledge and mentioned the role of central position is moderated by access to diverse knowledge.

In network position research, like ego-network research, the concept of knowledge diversity is reflected in a few studies, though sometimes implicitly. For instance, Gibbons (2004) did not test knowledge diversity as a construct, but in her discussion she pointed out the role of diversity of a firm's knoweldge and mentioned that increasing centrality among firms' partners positively influences diffusion only to the point at which communication with non-adopters overshadows inputs from initial adopters. In other words, it is highlighted that the central network only can improve the diffussion of innovation if it provides access to diverse knowledge. Similarly, Beckman and Haunschild (2002) by studying 300 of the largest publicly held service and manufacturing firms in the US, mentioned that the importance of having a central position in a k-network depended on providing more timely access to more diverse knowledge. However, Wadhwa and Kotha (2006) showed empirically that technological knowledge diversity (or knowledge breadth) of 36 corporate firms in the telecommunications equipment manufacturing industry positively moderated the relationship between the number of corporate venture capital investments and knowledge creation.

2.3.2 Process within the k-network

In Table 2-8, the second row shows partner diversity as a contingent factor in both streams of k-network research. In this section I will explain why I have dubbed this row as "process", but before that, to understand the theoretical background of this measure, two different perspectives are introduced: partner diversity as a network attribute, and partner diversity as a collaborative process attribute.

2.3.2.1. Partner diversity as a network attribute

Role theory (Gross, Mason and McEachern 1958; Kadushin 1968) as a broad school of thought in social science, is used to theorise different possible roles of actors in social networks (Tichy et al. 1979). Implying network concepts in an organisational context, the

role of firms can be defined by the way they link to their partners. In this regard, Tichy et al. (1979) defined several possible roles in a network including:

- Star—a firm with the highest number of partners
- Liaison—a firm which is not a member of a cluster but links two or more clusters
- Bridge (linking pin) —a firm which is a member of multiple clusters in the network
- Gatekeeper—a star which also links the social unit with external domains
- Isolate—a firm which is uncoupled from the network

The role that a firm plays, however, is highly reliant on with whom the firm is linked. From this perspective the critical role of partner and partnership become important to the extent that all the network has to offer comes through such partnerships.

From the network partner perspective in inter-organisational k-network research, which sometimes is called the nodal perspective (Phelps et al. 2012), there are some studies that have highlighted the role of partners on firms' performance. For instance, the structural position of the partner (Gibbons 2004), the knowledge-related benefits firms derive from their partnerships (e.g. Sampson 2005), the transmission capacity – the capability of partner to transfer the knowledge (Demirkan and Demirkan 2012), the prestige of source organisations (e.g. Still and Strang 2009), the depth of the innovation capabilities of a firm's partners (e.g. Tallman and Phene 2007), and the collaborative capability (e.g Simonin 1999) have been studied in inter-organisational k-network research. By example, providing effective and efficient inter-organisational routines, a collaborative capability can enhance a firm's ability for searching within existing partnerships for new knowledge (Zollo, Reuer and Singh 2002).

However, among all these aspects of partners, the diversity of partner is represented in both streams of network position research and sparse vs. closed network research (Baum et al. 2000; Beckman and Haunschild 2002; Wadhwa and Kotha 2006; Rothaermel and Alexandre 2009; Vasudeva et al. 2012).

In network position research, Baum et al. (2000) studied Canadian biotechnology start-ups and concluded that increasing the number of alliances, which literally means having a

central position in a k-network, can create inefficient configurations. This inefficient network not only may return “less diverse information and capabilities for greater cost than a smaller non-redundant set” (p. 274), but it may also prevent a firm from acquiring new knowledge since the firm is limited to a few identical partners (Uzzi 1997; Rowley et al. 2001). However Baum et al. (2000) did not test their idea empirically.

By testing the firm’s technology sourcing, Rothaermel and Alexandre (2009) concluded that strong reliance on a partner as a source of technology can have negative performance implications. Likewise, Wadhwa and Kotha (2006) by studying knowledge creation among investors in telecommunications equipment manufacturing, argued that managers need to actively manage and augment their investments with other inter-organisational relationships, in order to be able to unlock the learning potential inherent in their affiliations and generate greater value from multiple relationships. These studies highlighted the role of partner diversity, though implicitly.

Within the stream of sparse vs. closed network research, Beckman and Haunschild (2002), tested the effect of diversity of network partners' experience on firms' acquisition decisions. Results showed that strong connection, if associated with partner diversity, improves a firm’s learning, because firms linked to partners with diverse experience tend to pay less for their acquisitions and have better performing acquisitions than those linked to partners with homogeneous experiences. In other words, partner diversity of a firm strengthens the firm’s learning. For example, to learn about industry and environmental trends, Toyota’s suppliers are part of large and diverse networks, as reported by Dyer and Nobeoka (2002). Moreover Beckman and Haunschild (2002) showed that firms whose direct ties connect them to a larger number of indirect ties have more timely access to more diverse information, which increases organisational learning. However, they did not measure density of the networks, so it is not clear to what extent these relations are due to having a sparse network, as shown by Baum et al. (2000). Similarly Vasudeva et al. (2012), to explain the conflicting results on the role of sparse vs. closed networks, tested the role of process of collaboration with partners. They introduced ‘type of partner’ as a contingent factor which affects the behaviour of network partners in the process of knowledge creation. They studied the role of partners in collaboration vs. competition by classifying

countries of actors (including partners) by their level of 'corporatism – a sociopolitical institution that characterises the nature of collaboration' (e.g. Jepperson 2002). Likewise, and with more emphasis on partner diversity, Bae and Gargiulo (2004) tested the concept of partner substitutability within the US telecommunication industry and showed that although firms are expected to benefit from the exclusive resources brought in by resource-rich, non-substitutable alliance partners, the costs of allying with such partners could offset those benefits. Partner substitutability affects the degree of density since the study of Bae and Gargiulo (2004) affirmed that for firms with low-density networks, the organisational profitability from alliances decreases as the proportion of non-substitutable partners increases. Conversely, for high-density networks, the return on alliances increases with the proportion of non-substitutable partners. In summary, reliance on a limited number of partners for a firm may decrease the organisational profitability from its alliances, although if the firm embedded in a closed network structure (i.e. high-density ego-network) it may have a better return from its alliances.

The summary of findings in these two streams showed that having diverse partners may increase access to more diverse knowledge required for knowledge creation. The key point here is that partner diversity helps an organisation to not be too dependent on a limited number of partners with limited knowledge. In other words, having diverse partners gives firms more freedom and opportunity to substitute their partners whenever required, hence firms are able to create more knowledge through their partners.

2.3.2.2. Partner diversity as a collaborative process attribute

As mentioned in Section 2.2.2.3, in inter-organisational k-network research, partner-diversity has been considered as a collaborative process attribute (Lavie and Rosenkopf 2006; Tiwana 2008; Rothaermel and Alexandre 2009).

Within an inter-organisational k-network, actors are represented by participating organisations that collaborate with other network members (i.e. partners) in order to create knowledge in terms of new products or services. These collaborations consist of knowledge sharing and knowledge creation (particularly in knowledge intensive industries), which

happens through organisational collaborative processes to access, to acquire, to integrate and to transfer the required knowledge. These actors in the context of inter-organisational k-networks are involved in collaborative processes, particularly in the knowledge intensive industries, (e.g. Walker et al. 1997). Drucker (1993) mentioned that a firm needs to have the capacity of generating knowledge and applying it in the form of innovation (Chen, Tong and Ngai 2007), hence the collaborative process which is typically presented as a catalyst for innovation happens through inter-organisational relationships. This kind of innovation is sometimes called open innovation (Scarbrough 2003).

The process may aim at either enhancing exploitation by focusing on existing knowledge which is acquired, transferred and used in other similar situations or exploration which is creating new knowledge by sharing and synthesising of knowledge (March and Levinthal 1993). Although exploitation is important for knowledge creation, it is largely exploration through knowledge sharing that allows the development of genuinely new approaches (Swan, Newell, Scarbrough and Hislop 1999). Moreover, as March (1991) mentioned, companies need both exploration and exploitation in order to survive for the long-term, but there is often a trade-off between the two approaches due to constraints on resources and the firm's strategic orientation (Bierly, Damanpour and Santoro 2009). Finding a balance between these two processes has also been discussed as a major challenge of creating new products (Atuahene-Gima 2005; Kim, Song and Nerkar 2011).

Rothaermel and Alexandre (2009) also research concluded that pure exploration or exploitation for a firm does not enhance the firm's performance, but an ambidexterity is required. The concept of balance in exploration or exploitation is introduced in their work; however, it is represented in terms of balance between internal and external technology sourcing of known and new technology. Although they duscuss the importance of balance of exploration and exploitation collaborative processes, they do not address the role of network structure as context of knowledge creation.

Tiwana (2008), however, emphasised the interaction of structural elements like strong ties and bridging ties in improving the knowledge integration process to reach ambidexterity in

inter-organisational e-business projects. By strong ties he referred to the extent of close personal interaction, reciprocity, mutual trust, mutual respect, and personal friendship at multiple levels among the members of the project team, while bridging ties were measured in terms of access to partners with widely varying areas of expertise, different backgrounds and experiences, and of skills and abilities that complement each other. By ambidexterity he meant meeting the alliance objectives and adaptation to new information that emerged over the course of the project, while knowledge integration at the project level was assessed by the extent to which the participants in each project alliance had synthesised their old and new knowledge in a coherent project-level design.

Tiwana (2008) showed that strong ties and the interaction of strong ties with bridging ties also contribute to knowledge integration and ambidexterity. He argued that having simultaneously strong ties and bridging ties will provide access to a diverse array of specialised knowledge, perspectives, and skills on the one hand, and provide ability to convey complex ideas to diverse partners on the other hand.

Partner diversity in terms of the exploration vs. exploitation process was mentioned by Lavie and Rosenkopf (2006). Addressing the exploration/exploitation literature at the inter-organisational level (Beckman, Haunschild and Phillips 2004; Verspagen and Duysters 2004; Baum, Rowley, Shipilov and Chuang 2005), Lavie and Rosenkopf (2006) argued that recurrent alliances between organisations are considered a form of exploitation, and alliances formed with new partners are considered exploration. In this regard, having a diverse range of partners is a sign of an exploration collaborative process while having few partners for a firm shows the firm's tendency towards an exploitation process. Lavie and Rosenkopf (2006) dubbed partner diversity as structural exploration/exploitation.

By keeping the partnerships with existing partners for new projects, firms can rely on existing arrangements and channels to facilitate access and transfer of knowledge already prevailing in its immediate alliance network.

Beckman et al. (2004) argued that the nature of the uncertainty facing the firm will drive network partner selection. The higher the level of firm-specific uncertainty, the more likely

a firm is to focus on knowledge exploration by forming alliance relationships with new partners, while the higher the level of market uncertainty reinforces knowledge exploitation through forming additional alliances with existing alliance partners. Verspagen and Duysters (2004) also affirmed that the collaborative process is affected by network structure. By having multiple relationships with its existing networks, a firm may reduce the risk of knowledge transfer mainly through having in-depth familiarity with the existing partners; hence the firm is more able to reuse the existing knowledge. Lavie and Rosenkopf (2006) explained that such a pattern of alliance corresponds to March's (1991) notion of exploitation. In contrast, a firm with strategic partner seeking should also look into new partnerships through the exploration collaborative process, which broadens its access to knowledge that cannot be reached through its immediate network.

In high-tech industries like biotechnology, alliances of firms are most likely involved in patenting, as discussed in Section 2.1.3. Now considering exploration/exploitation processes, one may think that the networks or alliances that are identified by patents (see Section 2.2.2) is only involved in the exploration collaborative process. However Rothaermel and Deeds (2004), in their research on the biotechnology industry, mentioned that patents are an output of the discovery (exploration) and development stage (exploitation) of the product development process rather than an input to it. Therefore it is acceptable to have both exploration and exploitation within patent networks.

The last point is about the possible issue with having one measure to represent exploration and exploitation processes. For the concept of knowledge exploration/exploitation, March (1991) appeared very clear in his theorisation that exploration and exploitation are fundamentally incompatible, even though having a balance between them is essential for long-run adaptation. However, some scholars distinguish between the two concepts of exploration and exploitation. A more detailed discussion on this issue can be found in Gupta, Smith and Shalley (2006). This research, however, used the concept of partner diversity as an indication of collaborative process.

2.3.3 Structure of the k-network

As summarised in Table 2-8, not only structural elements of inter-organisational k-networks influence knowledge outcomes and performance of firms; interactions of structural elements also have their own impacts as explored in the two main theories of network position and closed vs. sparse networks.

In inter-organisational networks, research shows that there is some evidence to support both theories, meaning that each of them, with different causal mechanisms, links network structure to knowledge outcomes (Phelps et al. 2012). However my literature review also highlighted the interaction terms of these two streams.

At the dyad level of a k-network, links represent the collaboration ties that two organisations share with each other. Through these links, organisations share their knowledge. At a network level, however, these links comprise the whole structure of the network. As has been argued in the k-network literature (Section 2.2.4), the main element of closed vs. sparse network is the construct of density, while centrality is the main construct of network position theories.

Structure of the firm's network is an influencing factor on the firm's performance. Central organisations, for instance, are embedded in social networks that may contribute to beneficial outcomes like power (Brass 1984), decision making (Friedkin 1993), individual innovation (Ibarra 1993, as cited by Salman (2002). Dense networks provide close relations and trust within the network which facilitate better access to valuable strategic knowledge (Cross and Cummings 2004), while they are possibly located in the limited network which is not open to new and unbiased ideas (Ahuja 2000). In other words, it means dense networks may make it difficult for their members to access new knowledge from nodes located outside their closed relations.

The interactions of these two main constructs in inter-organisational k-network research, are reflected in several studies (Zaheer and McEvily 1999; Beckman and Haunschild 2002; Owen-Smith and Powell 2004; Whittington et al. 2009; Soh 2010). Aspects of these interactions include factors like geographical proximity (Owen-Smith and Powell, 2004;

Whittington, Owen-Smith, and Powell, 2009) and participation in regional institutions (Zaheer and McEvily 1999).

However, this literature review also showed that density and centrality as the main constructs of the two theories are inter-related (Ahuja 2000; Beckman and Haunschild 2002; Soh 2010).

Ahuja (2000) argued that having direct relations with partners can reduce the effects of indirect relations. This is also reflected in other studies (Beckman and Haunschild 2002). More specifically, Soh (2010) showed that the effect of centrality on the firm's innovation performance is positively moderated by the density level of the firm's ego-network. Central position is strategically important when firms compete for technology dominance in the market to acquire new knowledge and to shape the expectations of other firms, including their potential partners and rivals. Dense ego-networks help to achieve better standardisation efforts though repeated partnerships.

2.3.4 Interactions among content, process and structure in k-networks

Phelps et al. (2012), who reviewed the empirical k-network literature published in top relevant journals from 1970 to 2009 developed a framework represented in Figure 2-6. The themes that have been defined in their works as k-network elements include structural properties, knowledge properties, relational properties and nodal properties. In a similar way, my literature review on inter-organisational k-networks explored three concepts of content, process, and structure of k-networks.

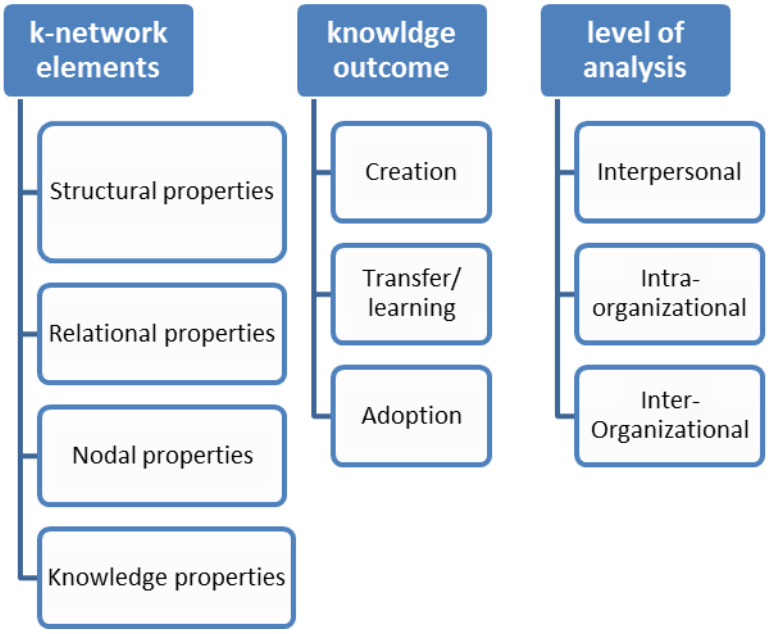


Figure 2-6 Organisational framework for k-network research
Source: Phelps et al. (2012, p. 1120)

Given the inter-organisational k-network literature, the role of the three concepts of content, process and structure of the k-networks of firms on their knowledge creation and innovation are discussed. It seems that there are inter-relationships among these three concepts, as discussed in the previous sections (Sections 2.3.1, 2.3.2, and 2.3.3).

More precisely, these three concepts in the reviewed literature refer to four constructs of knowledge heterogeneity (as a construct of content), partner diversity (as a construct of process), centrality and density (as two constructs of structure). Although these four constructs have their own influences on knowledge creation and innovativeness of firms, only parts of their interrelations have been addressed in the literature and a comprehensive framework of their interactions are yet to be explored (Table 2-9).

My thorough literature review of inter-organisational k-networks showed that these constructs have some sort of interaction with each other. For this reason, to develop a new integrative k-network research framework, my research focused on the interactions of these four constructs. However, there are other important factors like trust (Zaheer, McEvily and Perrone 1998; Molina-Morales and Martínez-Fernández 2009), and power (Ibarra and Andrews 1993; Wong, Ho and Lee 2008) that are outside the scope of this research, mainly

because they have not been addressed in the common constructs among the two main streams of the reviewed literature.

Table 2-9 Summary of the literature on four constructs of inter-organisational k-networks and their interactions

Studies	Knowledge heterogeneity (K)	Partner diversity (P)	Centrality (C)	Density (D)	Interactions
Stuart (2000)	*	NA	*	NA	NA
Baum, Calabrese, and Silverman (2000)	NA	*	*	*	NA
Sobrero and Roberts (2001)	*	NA	NA	*	NA
Beckman and Haunschild (2002)	*	*	*	NA	NA
Gibbons (2004)	*	NA	*	NA	NA
Owen-Smith and Powell (2004)	NA	NA	*	*	NA
McEvily and Marcus (2005)	*	NA	NA	*	NA
Wadhwa and Kotha (2006)	*	*	*	NA	K*C
Rothaermel and Alexandre (2009)	NA	*	*	NA	NA
Whittington, Owen-Smith, and Powell (2009)	NA	*	*	NA	C*D
Li, Poppo, and Zhou (2010)	*	NA	NA	*	NA
Phelps (2010)	*	NA	NA	*	K*D
Demirkan and Demirkan (2012)	*	*	NA	*	NA
Vasudeva, Zaheer, and Hernandez (2012)	NA	*	NA	*	P*D

* shows the construct that has been researched in each study

It is worth remembering that these four constructs are the only common constructs that have been discussed in both streams of network position and network structure research as two main streams of social capital theory (Table 2-9). Yet, to have a more comprehensive understanding of these constructs, in this stage I also reviewed all frameworks from k-network research at different levels, i.e. inter-personal and intra-organisational research. The summary of these findings are reported in Appendix 1.

2.3.4.1. Why the interactions are of interest?

The origin of the interaction concept of content-relation-structure within the social network literature may be traced back to social exchange theory where Firth (1967), cited by Emerson (1976):

> *Firth (1967, p. 4) has put it: There is in social anthropology an understandable view that it is the social relation which is primary, which dictates the content and form of the transaction. (p.346)*

Emerson also mentioned that Firth quoted Sahlins (1965, p. 139) on the same point:

> *A material transaction is usually a momentary episode in a continuous social relation. The social relation exerts governance: the flow of goods is constrained by, is part of, astatus etiquette. (p.346)*

Emerson (1976) discussed three concepts, notably: actions or decisions by individuals (i.e. process); transactions between individuals (i.e. content); and exchange relations as series of transactions between the same individuals that construct the network structure (i.e. structure). He continued by explaining the inter-play among these three concepts:

> *On a philosophical plane**, no one of these units can claim to be more real than another**. The fact that persons can be pinched makes them no more substantial than social relations. That exchange relations are composed of actions gives actions no empirical primacy over relations. For example, the act of giving a gift takes place within a social relation, and such an act evolved as part of a social relation. Most acts evolve within such relations. (p.346)*

Within the strategic management discipline, Pettigrew and Whipp's (1993) model, the three elements of content-process-context are discussed as an analytical framework in change management theory. They argued that a successful firm may consider the interactions of what is being changed (content), how it is being changed (process), and why it is being changed (context) (Pettigrew 1990). It is plausible to keep their reasoning and propose its extension to inter-organisational k-network transfer to understand what is being shared (content), how it is being shared (process), and why it is being shared with these particular partner(s) among the network (which partially can be understood by network structure). Moreover this idea, to some extent, is similar to Snowden's (2002) content-narrative-context framework of third generation knowledge management, which says the most appropriate process (narrative) to deliver the knowledge content is highly dependent on nature of that content and of its context.

Within the k-network literature, the interaction of these three concepts on firms' performance refers to the extent to which the role of k-networks of firms within knowledge-based industries is dependent on the knowledge processed in a particular network structure. In other words, the key question is how can the combination of diversity of knowledge and partners within a network structure contribute to knowledge creation within firms in knowledge-based industries?

Beyond this immediate question, three possible interactions among content, process and structure can be considered (Figure 2-7).

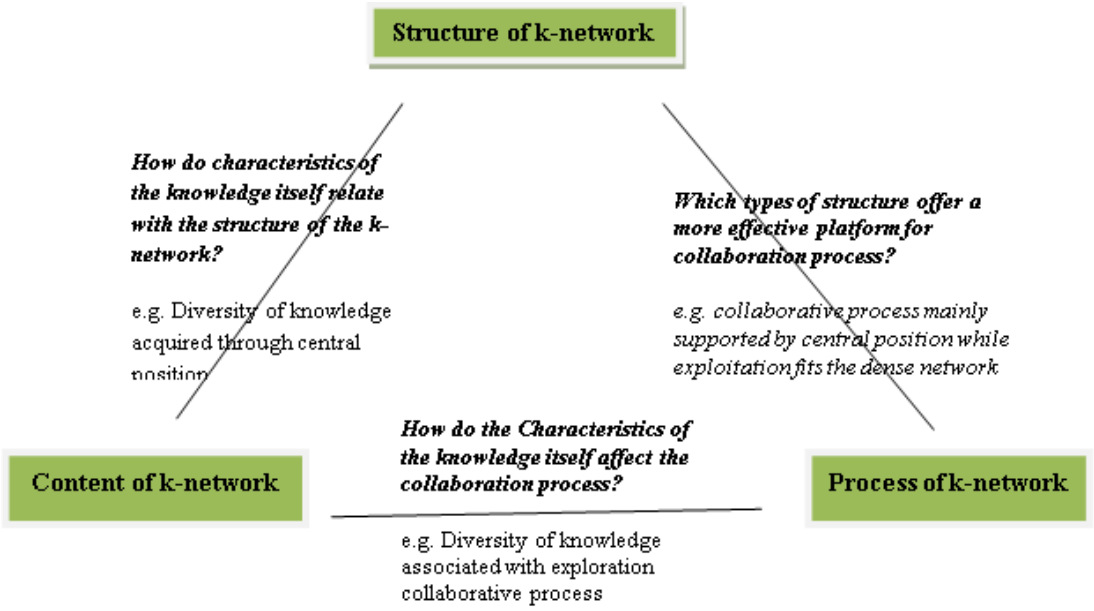


Figure 2-7 Need for considering interactions: three possible interactions among content, process and structure of k-networks

Understanding the interaction between these three elements is the means to focus on how k-networks are used in innovation-driven collaboration. This understanding raises questions such as what are the interactions among content, process and structure of the k-network? And how do such interactions influence knowledge creation?

2.3.4.2. Interactions between content and process of the knowledge network

In the literature of knowledge management it is mentioned that there should be a match between the process of knowledge and content of knowledge being shared. Within the

context of the k-network, there are two characteristics of content that are of interest: 1) types of knowledge in terms of tacit/explicit and 2) diversity of knowledge (Table 2-10).

Table 2-10 Summary of the literature on inter-relations of process and content

Inter-relations	Related concepts	Indicators	References
Content and process How do the characteristics of the knowledge itself affect the knowledge process?	The influence of knowledge on the knowledge transfer process.	Knowledge tacitness-process	Zander and Kogut 1996
	Tacit knowledge is difficult to transfer.	Knowledge tacitness and knowledge sharing	Szulanski 1996
	Diverse group ties provide more value of external knowledge sharing.	Ties heterogeneity and knowledge sharing	Cross and Cummings 2004
	Higher heterogeneous knowledge fosters creativity.	Ties heterogeneity and knowledge exploration	(Amabile, 1996; Fiol, 1995; Kanter, 1988) cited by Sammarra and Biggiero (2008)
	Firms that are willing to take risks are more willing to transfer explicit knowledge to recipient firms.	Degree of tacitness and risk taking	Becerra et al. 2008

The concept of knowledge heterogeneity or diversity has also appeared as the common factor moderating in both streams of social capital theory (Table 2-8). Winter and Szulanski (2001) in defining the concept of a replication and reuse strategy referred to concept of "arrow core" as the knowledge of which attributes are replicable and worth replicating, together with the knowledge of how these attributes are created. They argued that transfer and creation of knowledge either through exploration or exploitation requires dynamic capabilities among the firms. However in the knowledge transfer, adaptation efforts seek to align the target organisation to the characteristics of knowledge from the external environment. Sammarra and Biggiero (2008) argued that in the literature it is claimed that access to diverse knowledge improves firms' creativity required for the exploration collaborative process.

Also Easterby-Smith, Lyles and Tsang (2008) proposed a framework (Figure 2-8) for researching knowledge transfer in the inter-organisational context. Here they recommend that to understand process of knowledge in this context, the nature of knowledge should also be considered.

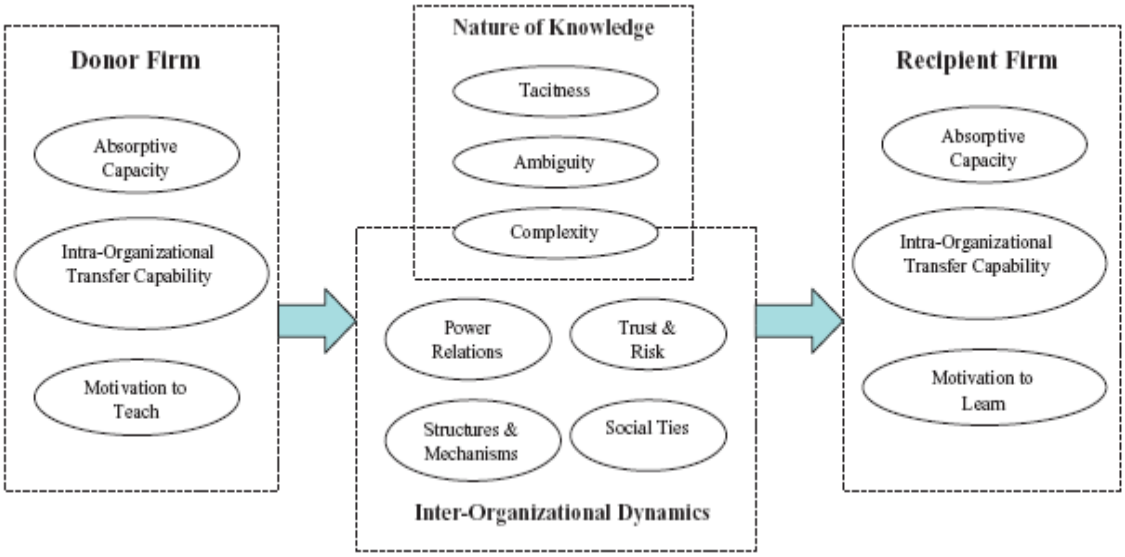


Figure 2-8 A proposed framework to research knowledge transfer at the inter-organisational level.
Source: Easterby-Smith et al.(2008, p. 679)

2.3.4.3. Interactions between process and structure of the knowledge network

Tiwana (2008) has reviewed the literature on interaction among knowledge process and network structure (Figure 2-9). Is his research, he emphasised the interaction of structural elements like strong ties and bridging ties in improving the knowledge integration process to reach ambidexterity in inter-organisational innovation seeking projects.

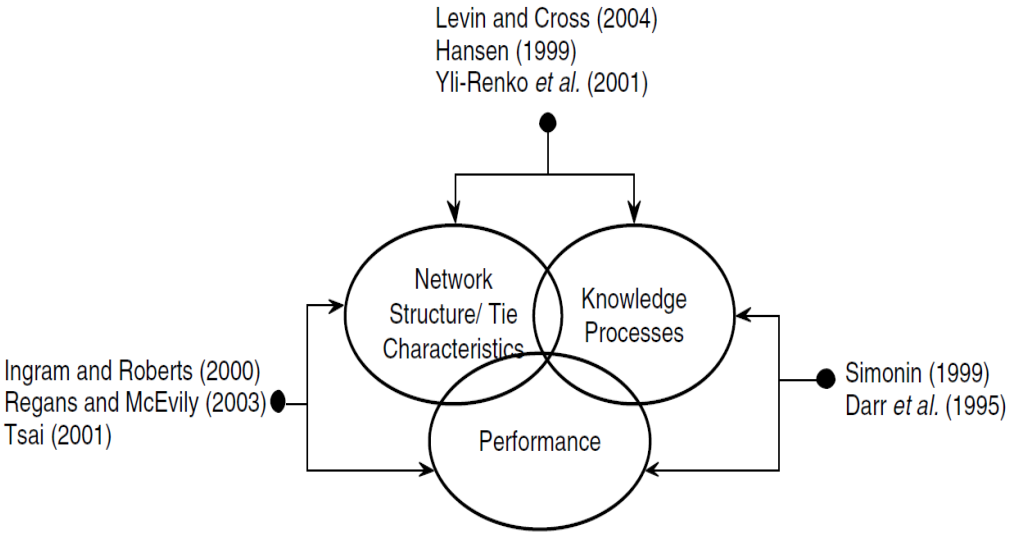


Figure 2-9 Intersections of network structure, process and firms' performance
Source: Tiwana (2008, p. 252)

Hansen (1999, 2002) showed that weak ties are more effective at searching for new knowledge and more efficient for transferring codified knowledge. However strong ties are better at transferring non-codified knowledge and are detrimental to transferring codified knowledge (Hansen 1999; Hansen 2002). Yli-Renko, Autio and Sapienza (2001) also by studying entrepreneurial high-technology firms showed that having social interactions and close relationships with customers had significant effect on knowledge acquisition and exploitation; however the quality of the relationship in terms of trust had no effects.

The summary of findings on the interactions of process and k-network structure is summarised in Table 2-11.

Table 2-11 Summary of the literature on inter-relation of process and structure

Inter-relations	Related concepts	Indicators	References
Process and structure e.g. Which types of structure offer a more effective platform for knowledge transfer?	In dress making firms, managers with strong ties were more likely to engage in a greater degree of deeper level knowledge sharing.	Strength of ties and level of knowledge sharing	Uzzi (1997)
	Within large electronics companies, weak ties are better at searching for new knowledge and are better at transferring codified knowledge in R&D teams. Strong ties are better at transferring non-codified knowledge and are detrimental to transferring codified knowledge.	Strength of ties and different processes of knowledge transfer	Hansen (1999); Hansen (2002)
	Whole network performs better when the central nodes are better able to serve the role of knowledge broker.	Centrality and whole network performance	Rulke and Galaskiewicz (2000)
	Close relationships with customers have significant effect on knowledge acquisition and exploitation.	Strong ties and exploitation	Yli-Renko et al. (2001)
	Strong ties improve knowledge process performance.	Strong ties and knowledge process	Levin and Cross (2004)
	Strong ties and the interaction of strong ties with bridging ties also contribute to knowledge integration and ambidexterity.	Strong ties and bridging ties	Tiwana (2008)

2.3.4.4. Interactions between structure and content of the knowledge network

Levin and Cross (2004) also reviewed the interactions among k-network structure (structural and relational aspects of network) and content of network (Figure 2-10). By considering the role of trust they highlighted the positive role of strong ties in improving knowledge process performance or “perceived receipt of useful knowledge” in their terms.

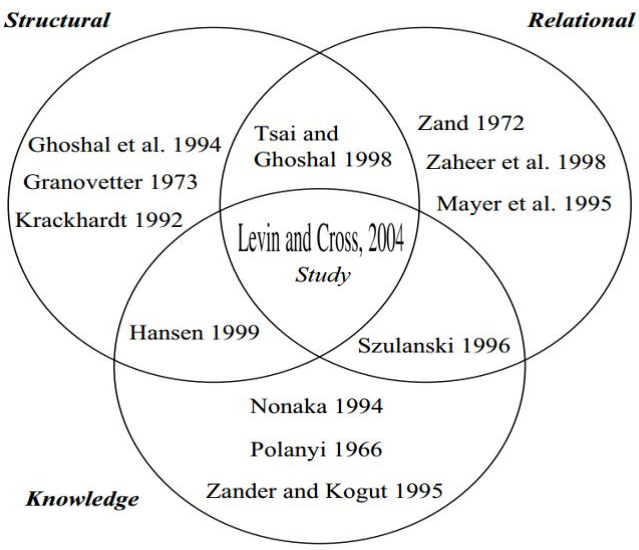


Figure 2-10 Selected studies on the interactions of process and network structure in the inter-personal knowledge level.
Source: Levin and Cross (2004, p. 1479)

In his thesis Bustamante (2007) used simulation to test the links between knowledge properties like tacitness, ambiguity and complexity and network structure in terms of centrality, density and strength of ties. He showed that a firm's k-network topology affects the influence that knowledge has on the organisation's performance. Moreover, the firms' k-network topology which matches the particular properties of the knowledge that is going to be communicated, improves an organisation's performance (Figure 2-11).

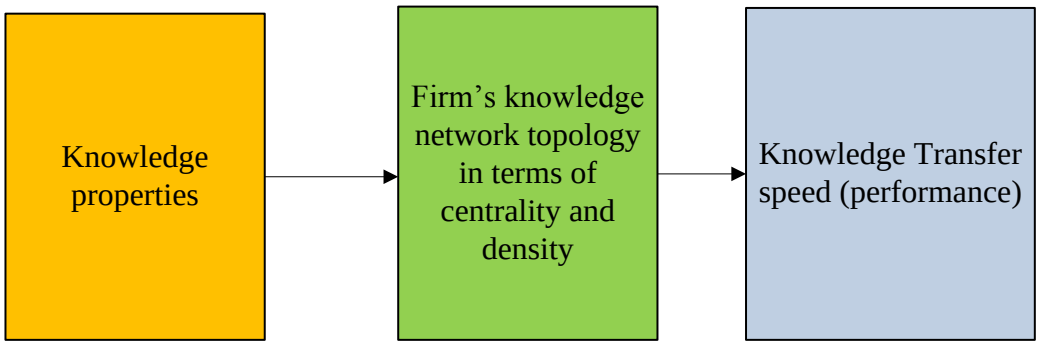


Figure 2-11 Research on Content and structure of k-network
Note: The model used by Bustamante (2007, p. 26)

By studying knowledge transfer and learning within informal inter-organisational relationships, Uzzi and Lancaster (2003) found that the participating banks seemed to implement a specific kind of k-network structure to transfer specific characteristics of

knowledge. For instance, embedded ties were more frequently associated with the transfer of private knowledge, and arm's-length ties were much more frequently associated with inhibiting the transfer of private knowledge. The summary of findings on the interactions of knowledge and k-network structure is given in Table 2-12.

Table 2-12 Summary of the literature on inter-relations of structure and content

Inter-relations	Related concepts	Indicators	References
Content and structure e.g. How do characteristics of the knowledge itself relate with the structure of the k-network?	Sparser networks are superior because of facilitating greater access to more diverse knowledge.	Density and knowledge heterogeneity	Burt (1995)
	Teams with generalist knowledge perform better in centralised networks.	Centrality and area of knowledge	Rulke and Galaskiewicz (2000)
	Firms need to implement a specific kind of k-network structure to optimise their communication depending of the particular characteristics of knowledge.	Public vs. private knowledge	Uzzi and Lancaster (2003)
	A match between knowledge properties and k-network structure will improve the speed of the knowledge transfer process.	Tacitness, complexity, centrality and density	Bustamante (2007)
	The need to have an inter-relation between knowledge areas and network structure has been addressed in the literature.	Density and area of knowledge	Sammarra and Biggiero (2008)

2.4 SMEs as key actors in knowledge intensive industries

Most of the firms in analytical knowledge intensive industries are small and medium sized enterprises (hereafter SMEs). Despite the key importance of SMEs in k-networks among high-tech industries, k-network research has not addressed the content, process and structure of their k-networks and the possible interactions among these aspects among SMEs. The relevant literature on SMES is reviewed here in order to understand the particular needs and perspectives of knowledge intensive industries. Although SMEs can also be considered in the public sector, this thesis, and accordingly the literature review, is focused on private sector SMEs to avoid theoretical discrepancies.

2.4.1 SMEs characteristics

Dominant actors here refers to the fact that the majority of the companies in analytical knowledge intensive industries like the biotechnology industry are SMEs (e.g. Owen-Smith and Powell 2004). These SMEs rely on other larger sized public research organisations

(PROs) – such as universities – to access skilled employee and novel scientific competencies. The definition of SME varies in different countries and different industries. In Australia, SMEs are organisations with less than 200 employees (Australian Bureau of Statistics, 2006). The SME sector plays a very important economic and social role in many countries. For instance, the economic and social contributions to economic growth include employment rates of 60–70%, and private sector turnover rates of 54% (Schlenker and Crocker 2003). Most of the companies in each national economy are SMEs (95–99% of organisations) (OECD 2000) therefore productivity of each society is heavily reliant on them. Moreover SMEs are recognised as a source of innovation in some industries. SMEs are recognised as a vibrant and growing sector in most economies round the world (e.g. Levy and Powell 2005), but they also have significant impacts on supply chain performance (Hong and Jeong 2006). Gulledge (2002) mentioned that many suppliers are SMEs; however they may participate in a supply chain in different roles (Hong and Jeong 2006). By reviewing the SME literature, some of their characteristics can be summarised here:

- Although SMEs are widely recognised as companies with limited resources, they are usually more entrepreneurial and willing to experiment and innovate in terms of business models and operations than are larger organisations (e.g. Jutla, Bodorik and Dhaliwal 2002).

- SMEs are not scaled-down versions of larger firms (e.g. Levy and Powell 2005). SMEs' owner/managers seek a diversity of objectives and have much shorter-term objectives compared to managers in larger organisations. SMEs mainly focus on flexibility to be able to adjust their companies quickly to respond to unexpected changes in the environment.

- SMEs have special needs because of their limited resources in terms of personnel, finance, and knowledge that they need for management, marketing, commercialisation, or information technology (IT) development (e.g. Julta et al., 2002).

- Most SMEs do not own several of the needed processes in their business (e.g. Hopkins 1997, cited by Schlenker and Crocker 2003) and as a result, they are forced

to collaborate with each other and with larger organisations to address their need to survive, to compete, and to produce sustainable revenues over time (Schlenker and Crocker 2003). Moreover high-tech SMEs tend to be clustered in a small number of geographic regions (Audretsch and Stephan 1996, Zucker and Darby 1996, cited by Häussler and Zademach 1996).

- SMEs lives in a more competitive environment because of several reasons, including their reliance on one or two main customers (e.g. Levy & Powell 2005).

2.4.2 SMEs within networks

There are several reasons to explain the increasing attention to organisational networks among organisations and firms. Turbulent and dynamic markets (Jespersen and Skjott-Larsen 2005), cost reduction, fast response to market demands, limited core competencies (Lin and Zhang 2005), increasingly sophisticated customer demands for differentiated and better quality products (Piachaud 2002; Jespersen and Skjott-Larsen 2005 cited by Lim et al. 2006), and increasing complexity of products and technologies (Momme and Hvolby 2002, cited by Lim et al. 2006) are some of these reasons.

These main factors seem even more relevant to knowledge-based SMEs. Participating in a network is one of the most important challenges which an entrepreneur, particularly in an SME, faces from the beginning of their business (Szarka 1990). The networking phenomenon for SMEs seems primarily as a competitive response (Hanna and Walsh 2002), since the delicacy of such firms can be offset by the supporting environment provided by a resilient network (e.g. Szarka 1990; Shaw 2006). The intensive competition in SMEs' markets and their needs to be flexible, innovative and competitive (Levy and Powell 2005) are other reasons that SMEs seek networking. In this regard, the concept of organisational networks has been attracting considerable attention in the management literature since the 1980s (e.g. Szarka 1990). The concepts of supply chain (network) of SMEs and small firm networks (SFN) are not new, and there is considerable research that covers these concepts. However, up to now, there is ambiguity in this area in terms of terminology (Szarka 1990; Shaw 2006), and the content, processes and dynamics of such networks e.g. (Zeleny 2001; Shaw 2006).

Indeed, SMEs can be members of several networks. These networks can be a regional agglomeration, e.g. industrial district or a supply chain of a larger company. Some forms of inter-relationship which have been mentioned in the literature include SFNs (e.g. Shaw 2006)), strategic SMEs network (e.g Wincent 2006)), and the concept of industrial district (ID) that was introduced by Marshall in 1929; and other ID-like concepts such as cluster (Porter 1998, cited by Carbonara et al. 2002). Such relationships have been studied under the concept of supply chain and its management in SMEs as well (e.g. Thakkar et al. 2008).

2.4.3 Knowledge practices within SMEs

Several scholars mention that there is increasing realisation and acceptance that knowledge creation is crucial for SMEs (e.g. Levy and Powell 2005; Thorpe et al. 2006; Pillania 2008a). SMEs, like their larger counterparts – or even more than them, may need to acquire external knowledge and share their knowledge with their partners for different reasons. Although knowledge may be created internally through conducting research and development or via individual learning (Almeida and Phene 2004), based on the SME literature, it is rarely the case for SMEs (e.g. Wong and Aspinwall 2004). Moreover, internal capability and external collaboration are not substitutes for one another, but are complementary (Mowery and Rosenberg, 1989; Arora & Gambardella, 1994 as cited by Powell et al. 1996). Therefore to access such knowledge, inter-organisational relationships seem vital, especially for SMEs.

To address this concept in the SME context as comprehensively as possible, there are different points of view including: features of knowledge creation adopted by SMEs, organisational and supply chain level impact of knowledge practices in the SME context, and management of knowledge through the lens of innovation theory in SMEs and their supply chains. Based on my literature review on SMEs and knowledge management (KM), some of the main conclusions of previous research projects that may impact on my research are provided.

To research the management of knowledge in the SME setting, the features of knowledge practices in this context need to be considered. SMEs have some unique characteristics which are not necessarily similar to those of larger companies. These features are

considered an important factor for developing knowledge practices among SMEs. Several scholars (e.g Sparrow 2001; Wickert and Herschel 2001; Wong and Aspinwall 2004; Sparrow 2005) note that to understand knowledge practices in SMEs, these features need to be understood. This body of research shows the importance of idiosyncratic research on KM in the SME context.

One of the issues is the concept of informal KM. Wong and Aspinwall (2004) pointed out that key concepts of KM are not properly understood by SMEs and consequently there has been slow adoption of formal KM among SMEs (Holm and Poulfelt 2003). Matlay (2000) mentioned that SMEs do not manage their knowledge very well in terms of knowledge acquisition, transfer and use. However, Skyrme (2002) claims that SMEs are practising KM even if they do not recognise it as such. This idea is supported by Hutchinson and Quintas (2008), who showed the importance of informal KM among SMEs and their approach towards creating, communicating, searching/sourcing, synthesising, and applying and reusing their knowledge.

The other point in this literature is the role of the SME owner/manager in managing SMEs' organisational knowledge, which is also mentioned in non-KM studies in the SME context (e.g. Levy and Powell 2005).

Through a case study, Frey (2002) showed the importance of the SME owner/manager in effective KM. He concluded that KM encourages an SME's people to create, share, and benefit from knowledge when it is supported proactively by senior management, i.e. the owner/manager.

By acknowledging the importance of the SME sector to the Australian economy, in 2006, Standards Australia published a handbook (Standards Australia 2006) to provide guidance to SMEs on the interpretation and implementation of the *Australian Standard for Knowledge Management*, which was published in AS5037 (Standards Australia International 2005). The standard describes the key concepts of KM, including characteristics and benefits of KM; provides a universal model for approaching KM to show how different aspects of KM can be addressed in order to help any type of

organisation achieve its strategy; and provides an overview of the most important knowledge enablers.

However, the standard provides no clues for SMEs on how they can deal with inter-organisational knowledge and acquiring knowledge from the external environment through their so called-knowledge networks. This issue, as the literature shows, is both important and problematic for SMEs.

2.5 Summary

This chapter has discussed the concepts introduced in Chapter 1. Firstly, by highlighting the knowledge-based view as the theoretical context, this chapter explained the need for understanding k-networks as a means of knowledge creation, particularly within knowledge-based industries like the biotechnology industry. Then the characteristics of small and medium sized firms as the main actors of such industries was discussed, mainly in terms of creation of knowledge though their networks.

Building on this context, in the second part the concept of k-network was elaborated in terms of definition and types, and then the theoretical boundary was set by explaining the theories, level of analysis, themes, and main streams of research.

After defining the theoretical landscape, the relevant literature was reviewed and the targeted contribution of this research under the concept of an integrative framework of k-network was explained. It has been found that content, process and structure of k-networks have been introduced as inter-related constructs. Hence an integrative framework of k-network, needs to consider these constructs.

Having reviewed the common understanding of the subject and introducing the theoretical background in this chapter, the next chapter introduces my conceptual model.

Chapter 3
Conceptual Model

Outline of Chapter 3

The objectives of this chapter are two-fold: first to introduce the Victorian biotechnology industry as the setting of my research; second, to discuss the conceptual model of the study.

As discussed in Chapter 2, creating knowledge has been considered vital for the knowledge economy, particularly for SMEs in high-tech industries. Creating knowledge often happens within the network of relationships with peers, sometimes called a knowledge network (k-network). This research focuses on k-networks in the context of inter-organisational relationships among actors involved in innovation-driven collaborations. More specifically, taking a knowledge-based view (KBV), interactions of content-process-structure of k-networks are the focus of attention, as the main gap of knowledge in social capital theory and inter-organisational k-network research. In the existing literature, bilateral relations of these constructs are proposed. My research, however, provides an integrative framework of k-network in the knowledge creation context.

3.1 Knowledge networks within the Victorian biotechnology industry

Following the discussions in Chapter 2 (Sections 2.1 and 2.2), using k-networks is a critical mechanism within knowledge-based industries to produce knowledge. In this research the Victorian biotechnology industry was selected as a knowledge-based industry. Hence the nature of this industry as the setting of my research is outlined. Then, given the characteristics of this cohort and the literature reviewed in Chapter 2 (Section 2.3), the conceptual model is developed.

There are two main elements used to to define the cohort of my research. First the Victorian biotechnology industry was selected as a knowledge base with an extensive need for k-networks, following the discussion in Chapter 2 (Section 2.1.2). Then the patent co-authorship network is discussed to represent a type of k-network involved in knowledge creation (Chapter 2; Sections 2.1.3, 2.2.2).

3.1.1 The Victorian biotechnology industry

At its simplest, biotechnology is technology based on biology (BIO 2008) and includes all techniques for manipulating micro-organisms (Walker et al. 1997). Nowadays, as mentioned by Powell et al. (1996), many commercial applications ranging from medical drugs and food-processing to chemical substances heavily rely on scientific advancements in biotechnology. These new scientific discoveries have an enormous benefit in several industries such as food, chemicals, paper, energy, textiles, livestock and environment industries (BIO 2008).

Typically, biotechnology has been considered as a knowledge intensive industry with high rates of innovation and collaboration. Walker et al. (1997), assert that the motivation for inter-organisational collaboration in this industry is strong, due to the need of companies, including both large and small sized firms, to complement their resources from other companies through collaboration.

Although Australia is not strong in most high-tech areas such as computers and peripherals, telecommunications, semiconductors and electronics, it has a relatively strong position in pharmaceuticals and biotechnology (ARC 2000). According to Ernst and Young (2011),

Australia is the largest presence in the Asia-Pacific region, and Victoria is among the leading states within Australia, since it involves more than 75 per cent of biotechnology companies located in the state (Allen Consulting Group 2010). Moreover, in 2009, Victoria had more than 22,000 people employed by biotechnology organisations and 17 public biotechnology companies were capitalised by more than $50 million. In aggregate, these companies were valued at almost $24 billion (Allen Consulting Group 2010). In 2011, the indicative funds over projects in Victoria was over $91.5 million, which is more than 28% of total ARC funding for *Discovery Projects*[3] in 2011.

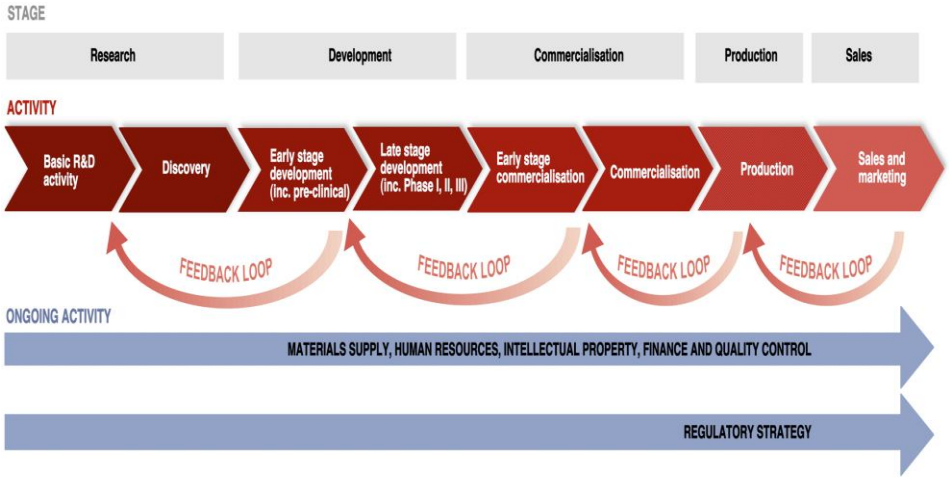


Figure 3-1 The biotechnology industry value chain (supply chain)
Source: Allen Consulting Group (2010, p. 2)

According to Allen Consulting Group (2010), Victorian companies can be involved in a wide range of activities across the industry value chain (Figure 3-1). However, most companies are involved in research and development rather than in the later stages of production, and sales and marketing. The value chain of the Victorian biotechnology industry may include:

- Research: basic research and development activity and discovery

[3] http://www.arc.gov.au/media/mga11/summary_dp.htm

- Development: product development, including early stage 'pre-clinical' development and late stage development (such as phase I-III clinical trials[4] in the case of bio-pharmaceuticals)
- Commercialisation: the process of commercialising a tested product
- Production: development of large-scale product manufacture
- Sales: sales and marketing of the new product.

In this industry, there are different types of organisations including public research organisations (PROs) – for instance universities – pharmaceutical-biotechnology companies[5], government agencies, hospitals, or even individual innovators.

According to the Australian and New Zealand Standard Industrial Classification (ANZSIC), the biotechnology sector is a part of manufacturing (ABS 2006). Data from the Australian Bureau of Statistics (ABS) show that manufacturing SMEs experience higher engagement in innovation compared to the other sectors. According to the ABS, SMEs are organisations with more than five but less than 200 employees (ABS 2009). The following provides a summary of key features of Australian manufacturing, including the biotechnology industry:

- Has the highest number of businesses which are perceived as innovative (i.e. introduced or implemented any new or significantly improved products/services (23.9%) or any other initiatives (48.5%). for both SMEs and large size companies
- However, has an almost average rate of the collaborative arrangements in comparison with other industries (26.6 %)
- Has used patenting more than other industries to protect its innovations (11.5%) for both SMEs and large size companies

[4] These tests show what medical approaches work best for certain illnesses. To support integrity and safe/ethical development of biomedical products, biotech companies are also required to follow certain principles in their clinical trials.

[5] There are differences between biotechnology firms and pharmaceutical firms, however such differences has not been recognized in my research. This decision was made in the first phase of my research through interviews with two domain experts, mainly due to the fact that such differences are too technical and debatable, and for most it is not influential on this research.

- In Australia, the biotechnology sector is a Revealed Technological Advantage (RTA[6]) for patents granted by the USPTO and the EPO (1.48) (OECD 2011)
- The Pharmaceuticals and Cosmetics grants to Australians in Australia have increased since 2002, with an impressive growth rate of 80% between 2005 and 2006.

3.1.2 Knowledge networks of innovation-driven collaborations:

The k-network phenomenon – as a source to acquire and access knowledge – has been studied through the lens of social network theory (Granovetter 1973; Granovetter 1985; Cross et al. 2002; Kane and Alavi 2008). These networks operate in every organisation and are not limited to network-type organisations, matrix organisations, or team-based organisations (Allee 2000; Poell, Chivers, Van der Krogt and Wildemeersch 2000). These networks, also can be classified as internal and external (Birkinshaw and Hagstrom 2000, cited by Škerlavaj, Song and Lee 2010). External or inter-organisational k-networks comprise relationships that a firm has with its customers, suppliers, peers and other external stakeholders (Škerlavaj et al. 2010). A k-network includes individuals and collection of individuals, such as groups, departments, organisations, and agencies.

In fact inter-organisational k-networks have been considered as the context for knowledge creation within innovation projects (Powell et al. 1996; Swan, Newell and Robertson 2000; Scarbrough 2003; Swan and Scarbrough 2005). In this regard, firms collaborate with other companies through collaboration networks or strategic alliances (Ding and Peters 2000) to acquire or access external knowledge (e.g. (Kraaijenbrink et al. 2005; Wong and Aspinwall 2005; Giannakis 2008).

Knowledge creation in innovation projects here is considered in terms of patenting. Innovation-driven collaboration has been considered as open innovation (Chesbrough 2003; 2006), in contrast to closed innovation – in which a company relies primarily on its own internal resources and their R&D in order to introduce new innovations. In this regard,

[6] Revealed Technological Advantage (RTA) compares the fraction of Australian patents in a particular Technology Group as a percentage of total Australian patenting activity, with the fraction of all patenting activity in that Technology Group as a percentage of all patenting activity [AU patents in TG/all AU patents]/All patents in TG/all patents]. A value >1 indicates that Australians have a greater proportion of patenting activity (greater patenting intensity) in that Technology Group relative to total patenting activity.

innovation-driven collaboration or networked innovation is defined as innovation occurring through networking (Radjou 2005; Swan and Scarbrough 2005).

In this section, first a typology of the k-network is introduced, then the patent co-authorship network as a type of k-network engaged in innovation-driven collaborations is discussed.

3.1.1.2.1. Knowledge network typology

According to network theories like social network theory (Granovetter 1973; Burt 2004), a network is usually defined by its nodes (also called actors or vertices) and ties (also known as links or edges) (Scott 2000). Ties are the relationships between nodes, while nodes represent actors within the network like individuals, teams or organisations (Wasserman and Faust 1994).

To define k-networks, this research adopted the definition used by Hoegl, Parboteeah and Munson (2003), and Kane and Alavi (2008). A k-network of an actor refers to a collection of individuals or organisations with whom the focal actor interacts to acquire or access needed information to accomplish tasks in their new product development projects. A more detailed definition is provided in Chapter 4 (Section 4.4.2).

There are several types of k-networks that organisations use to access their required knowledge. For instance, in terms of the boundary of the network, it is possible to have two types of k-networks: internal and external (e.g. Birkinshaw and Hagstrom 2000, cited by Škerlavaj et al. 2010). While an internal k-network refers to nodes located in the same organisation, external k-networks comprise relationships that a firm has with its customers, suppliers, and other external stakeholders (Škerlavaj et al. 2010). The k-networks studied in the current research are external k-networks, which include knowledge interactions among focal actors with their business partners.

The other k-network typology can be defined by the formality of the relationships, since interactions may occur through either formal or informal relationships. The degree of formality in k-networks has been discussed in the literature as an influencing factor on the way that companies process the knowledge that they acquire from or share within their networks (Appleyard 1996; and Liebeskind, Oliver, Zucker and Brewer 1996, cited by

Levina 1999). Similarly, the literature on inter-organisational collaboration has emphasised two types of collaborations (e.g. Owen-Smith and Powell 2004). The first type, which is labelled "*closed conduits*", is characterised by legally binding contracts and licensing to protect intellectual property (IP) for exclusive partners. The second type, representing open channel – also called "weak connections" among network participants, may provide benefits for those participants in terms of spillovers from network channels. As represented in Table 3-1, one may categorise networks in terms of both degree of formalisation and types of collaboration.

Table 3-1 Four types of inter-organisational k-networks

	Formal network	Informal network
Resource sharing network	Type 1: e.g. patent co-author network	Type 3: e.g. informal alliances and partnerships
Spillover network	Type 2: e.g. scientist mobility network	Type 4: e.g. industry network

In summary, my research focused on external, formal, resource-sharing networks (Type 1 in Table 3-1), represented by the patent co-authorship network. To understand why the patent co-authorship network was chosen in my research, the variety of the networks and techniques to identify them are introduced.

3.1.1.2.2. Identifying inter-organisational knowledge networks

To show the variety of networks and techniques that have been used to identify them, this section provide a review of the previous research on k-networks among firms. In summary, there are five different types of techniques that have been used in the literature: archive news, name generators and interpreters, simulation, patent co-authorship network and web crawling. Each of these techniques is introduced with examples. Then a summary of analysis of these techniques is reported in a comparison Table 3-2 in order to highlight why the most appropriate way to conduct this research is the co-authorship network.

a. Archive news

In this technique, the researcher tries to extract relevant data on firms/industry partnerships and alliances that have been reflected in public media. For instance, to map the k-network of large leading companies in the chemical industry of US, Japan and Western Europe, Ahuja (2000) focused on news on collaboration and partnerships reflected in public media.

Likewise Owen-Smith and Powell (2004) used BioScan, an industry publication that reports information on firms and the formal arrangements in which they are involved. Even though the application of this method provides advantages in the analysis of phenomena, challenges still remain in its applications, particularly in SMEs. This technique is extremely difficult for SMEs as there is no available and reliable data in the public media (Table 3-2).

Table 3-2 Examples of using archival news to collect the collaboration activity

Year	Author	Topic	Industry(ies)	Level of analysis	Research method
2000	Ahuja	A longitudinal study on structural holes and innovation	Chemical industry	Industry	Patenting activities of 97 large leading companies in the US, Japan and Western Europe
2004	Owen-Smith and Powell	K-networks, the effects of spillovers	Biotechnology industry in a region (Boston USA)	Industry	Patenting activities of 58 biotechnology firms, 19 public research organisations, and 37 venture capitalists

b. Name generators and interpreters

The name generator is a common technique which has been used extensively in the network literature. Name generators ask the respondent – the focal firm, which is sometimes also called ego – to recall actual contacts in order to explore the network of the ego (or focal firm). This technique generates a list of contacts ranging from three to five, or as many as volunteered by the ego. These people in the ego's social circle are called 'alters'. Subsequent questions elicit information directly about the persons named and about the relationship between the ego and each alter. In an imitation of sociometric whole network approaches, ego-net researchers may also ask the ego to report proxy information about pair-wise relationships among alters they have named – 'alter-alter' relationships (Marsden 2005). This technique in k-network research may be adopted in different ways like snowball sampling and survey:

b.1. By using snowball sampling

Snowball sampling (Frank 2005) is designed to trace ties from a source to an end: an ego firm (actor), or a few firms, are chosen among the set of potential actors. After this first step, every chosen actor reports on the actors to whom she/he has a link, according to the

relation under examination. For instance, Sammarra and Biggiero (2008), studied 33 SMEs and large companies (Table 3-3) in an industrial cluster within the aerospace industry in Rome. Although this approach is very good when the boundary of the network is not clear from the beginning, the main problem with sampling is that any procedures can alter or lose relations inside the considered group. Further discussion on this challenges can be found, for instance, in Martino and Spoto (2006). This technique is risky and time-consuming to map the network comprehensively.

Table 3-3 Example of using snowball sampling to collect the collaboration activity

Year	Author	Topic	Industry(ies)	Level of analysis	Research method
2008	Sammarra and Biggiero	Heterogeneity and specificity of inter-firm knowledge flows in innovation networks	Aerospace industry	Industry	33 SMEs and large companies in industrial cluster of Rome

b.2. By using survey

This technique is used when the research has focused on a pre-defined group, for example on managers of pre-defined firms to ask about their supply chain partners, for instance Burt (2004) in Table 3-4. In this technique, researchers develop list of questions about alters of the ego, and the relationships between them.

Table 3-4 Example of using survey to collect the collaboration activity

year	Author	Topic	Industry(ies)	Level of analysis	Research method
2004	(Burt)	Structural holes and good ideas	Electronics industry	Supply chain of a company	Supply chain of a large company, 455 out of 673 managers responded

c. Simulation

The most commonly used simulation models for the flow of knowledge or information through networks are based on an analogy with the diffusion of a disease (Bailey 1975; Diekmann and Heesterbeek 2000; Hethcote 2000).

Table 3-5 Example of using simulation to collect the collaboration activity

Year	Author	Topic	Industry(ies)	Level of analysis	Research method
2010	Baggio & Cooper	Knowledge transfer in a tourism destination: the effects of a network structure	Tourism industry	Region – The island of Elba, Italy	Computer simulations

The wide availability of computing power and of efficient programming languages, coupled with much simpler access to data has, in recent decades, greatly enlarged the amount of attention given to these methods and their practical uses (Castellano, Fortunato and Loreto 2009). The reliability and credibility of these techniques are generally considered problematic. An example of using this technique in analysis of k-networks can be found in Baggio and Cooper's work (2010) as illustrated in Table 3-5.

d. Patent co-authorship network

In terms of types of data collection, this technique is similar to archive news, but here patenting is considered as the sign of the collaboration activity which led to an explicit knowledge creation process. If two companies have registered a patent with each other, it means that they had innovation-driven collaboration, though with a one or two year delay. This criterion (i.e. patent co-authorship) can represent the formal innovation-driven collaborations characterised by legal arrangements e.g. non-disclosure agreements and exclusive licensing contracts that transfer intellectual property rights. Two examples of research (Table 3-6) which has adopted this method are Fleming, King and Juda (2004), and Cantner and Graf (2006).

Table 3-6 Examples of using a patent co-authorship network to collect the collaboration activity

Year	Author	Topic	Industry(ies)	Level of analysis	Research method
2004	Fleming et al.	Small world of innovators	Different industries within a region	Region	Patent co authorships of inventors within an industrial cluster
2006	Cantne and Graf	The network of innovators in Jena: An application of social network analysis	Different industries within a region	Network of Jena, Germany in the period from 1995 to 2001.	Network was identified by three approaches: 1. Technological overlap: patent in the same technological class. 2. Cooperation: when there is more than one assignee mentioned on a patent, 3. Scientist mobility: whenever a specific inventor has worked for both.

e. Web crawling

This is a type of archival technique where the main source to acquire data on firms' collaboration partners are the firms' websites. For instance, Pitt, van der Merwe, Berthon,

Salehi-Sangari and Caruana (2006), by visiting and recording all hyperlinks of few companies, studied the informal networks in an international business-to-business environment (Table 3-7).

Table 3-7 Examples of using web crawling to collect the collaboration activity

Year	Author	Topic	Industry(ies)	Level of analysis	Research method
2006	Pitt et al.	A comparison of biotechnology SMEs in Sweden and Australia	Biotechnology industry	Region – in Sweden and Australia	Web crawling-snowball sampling

They classified the hyperlinks provided on one website to go to one of the other websites as the links between these nodes or actors. This technique, like others except name generator and interpreters, has little to say about the details of the collaboration. However it is an efficient way to map the firms' relationships.

f. Summary

A summary of all the techniques that have been used so far to research inter-organisational k-networks, is presented in Table 3-8. Given the characteristics of my research which studies k-networks of the knowledge-based industry which includes many SMEs, patent co-authorship network was chosen to identify Australian biotechnology industry.

The other techniques, as shown in Table 3-8, were not selected mainly because of the characteristics of the research cohort. For instance, SMEs do not have sufficient records to use archive news. The actors are not pre-defined therefore it was not possible to use name generators and interpreters. By scrutinising the websites of many biotechnology SMEs, it became clear that the web crawling technique was also not a useful approach for two reasons. 1) The informal collaborations that can be identified from web crawling may represent a wide range of partnerships, e.g. with customers, and not all of them are relevant to the knowledge creation process. 2) There are substantial numbers of SMEs in the industry which have no web pages or have not provided any information about their partnerships. By using the patent co-authorship network, my research captured a knowledge creation network with the resource sharing and formal collaborations as shown in Table 3-8.

According to statistics provided in the previous section (3.1.1.1), Australian biotechnology is more innovative compared to other industries. They use patenting to protect their [innovative] intellectual property. In this regard, to define the k-network, my research focused on patent co-authorship networks which represent innovation-driven collaborations within the Victorian biotechnology industry.

To understand the k-networks of high-tech industry, my research selected biotechnology actors who had published at least one patent during 2001–2010. If two companies or any other actors (like hospitals or even individual inventors) had registered a patent with each other, it means that they had innovation-driven collaboration, although with a one or two year delay.

Although this criterion (i.e. patent co-authorship) can represent the formal innovation-driven collaborations, only relationships characterised by legal arrangements (e.g., non-disclosure agreements and exclusive licensing contracts that transfer intellectual property rights) can be addressed. This method (patent co-authorship network) has been used in the collaboration network literature to represent innovation-driven networks e.g. Cantner and Graf (2006); Fleming, King and Juda (2007).

Table 3-8 Summary of the techniques used in inter-firm innovation driven-collaborations

Techniques	examples	Unit of analysis	Basic assumption	Strengths	Weaknesses
Name generators and interpreters (NGI) – survey or interview	Sammarra and Biggiero 2008, Burt 2004	Industry-firm-individual	People can and wish to recall main partners	Good for small networks, both formal and informal, unclear boundary (snowball sampling), details of collaboration	Time-consuming, difficult to capture the data
Archive news	Ahuja 2000, Owen-Smith and Powell 2004	Industry-firm	There is available and reliable data on public media.	Easy access compared with NGI	Difficult for SMEs, no information on details of collaboration

Techniques	examples	Unit of analysis	Basic assumption	Strengths	Weaknesses
Patent co-authorship network	Fleming 2004, Cantne and Graf 2006	Industry-firm	Innovation projects lead to patenting process	Easy access compared with NGI	No clue on informal networks, no info on details of collaboration
Website crawling	Pitt et al 2006	Industry-firm	1. Firms have active website 2. Main partners exchange hyperlinks and 3. Hyperlinks represent social relations	Easy access compared with NGI	Reliability, no info on details of collaboration
Simulation	Baggio and Cooper 2010	Industry-firm-		Wide availability of computing power and of efficient programming languages	Reliability and credibility of the techniques, no information on details of collaboration

3.2 Development of the conceptual model

Building on the characteristics of the cohort, the conceptual model is designed in this section to study the patent co-authorship network of the Victorian biotechnology industry.

Following the literature reviewed in Chapter 2, Section 2.3, this research argues that knowledge content, collaborative process and structure of k-networks are three areas of research that seem to be not independent but inter-related. Hence my research, by focusing on knowledge-based industries, set out to define first the characteristics of each of these three constructs in the patent co-authorship network and then to study the integration of all these three inter-related areas in the context of knowledge creation among Victorian biotechnology industry. Regarding the structure of the network as explained in Chapter 2 (Sections 2.2 and 2.3); there are two elements of the network structure that have inter-relations with content and collaborative process of the network: centrality and density of the ego-network. As a result, the conceptual model was developed as illustrated in Figure 3-2. In the k-network of the Victorian biotechnology industry, SMEs have the largest number of participants, yet large size organisations like universities and companies are also operating in these networks. Moreover these actors are not all the same. As explained

before, government research institutes and universities labelled as public research organisations (PROs), pharmaceutical-bio firms (PBF), hospitals (H), or even individual innovators (Individual) are participating in this network. To have a clear understanding of the research problem (discussed in Chapter 1), type is another factor that added to the model (Figure 3-2). The association between the constructs are presented later in term of set of hypotheses (Section 3.2.2).

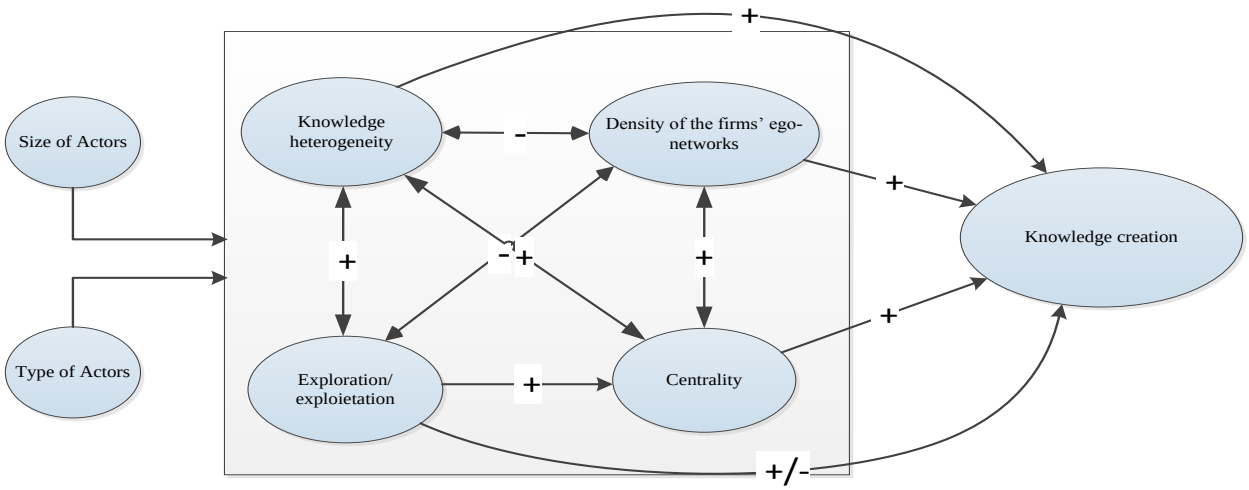


Figure 3-2 My conceptual model

3.2.1 Research questions

Given the literature reviewed in Chapter 2, to understand the targeted gap in the literature, the main research question is articulated as below:

How do knowledge networks contribute to knowledge creation?

To answer this question, as explained in Chapter 1 – Figure 1-1, I started to review the literature by following these two sub-questions to lead the research

1. What are the characteristics of the knowledge networks constructs of content, collaborative process and structure?
2. How do the interactions of these constructs support knowledge creation?

From the literature review (Chapter 2 Section 2.2.3), four constructs of k-networks which are represented in Figure 3-2 were identified. Here to understand characteristics of k-networks, my research focused on how the size, and type of actors that have participated in the Victorian patent co-authorship network – influence each of four constructs. Moreover the possible associations of any of the constructs with each other and with the patenting as a representative of knowledge creation were considered. Then, using the results of these analyses, my research sought to find out how these constructs and their possible interactions contribute to knowledge creation within the selected k-networks. As discussed in the Chapter 2 (Section 2.1), knowledge bases are high-tech industries with certain characteristics for instance: Asheim and Coenen (2005); Moodysson et al. (2008); Plum and Hassink (2011). As explained above (in Section 3.1.1) to study these questions, my research was focused on the patent co-authorship network (Chapter 2, Section 2.2) of the Victorian biotechnology industry.

3.2.2 Hypotheses

Given the literature review represented in Chapter 2 (section 2.3), to answer the research questions, a series of hypotheses was formulated to address the effect of size and type of actor (i.e. participants in the network) on the research constructs as well as the inter-play among these constructs and then their possible contribution to knowledge creation in terms of patents. The relation between research questions and hypotheses are addressed in Table 3-9.

The main focus of my research was on the interaction of the constructs as reflected in Hypothesis 15, although other hypotheses were tested to provide a more details. First to understand the characteristics of the k-networks constructs, it is needed to define the role of size of actor (SMEs vs. large organisations) and type of actors (like private companies, public research organisations or hospitals). The details of how these factors may influence on the k-network constructs are formulated in the below hypotheses.

Table 3-9 Summary of the hypotheses

Research question:			Content	Collaborative process	Centrality	Density	Interactions
Research question 1	Actor size		H1a	H6a	H10a	H13a	
	Actor type		H1b	H6b	H10b	H13b	
	Mutual role of size and type		H1c	H6c	H10c	H13c	
Research question 2	Inter-play with other constructs	Content	-				
		Collaborative process	H2	-			
		Centrality	H3	H7	-		
		Density	H4	H8	H11	-	
	Contribution to knowledge creation		H5	H9	H12	H14	H15

3.2.2.1. Hypothesis 1: *Actor size and type with content*

SMEs are reported as firms with lower levels of resources (e.g. Jutla et al. 2002; Levy and Powell 2005). Hence in terms of technological knowledge, they are also expected to have access to lower levels of knowledge due to their lower levels of resources such as human and monetary resources. In the Victorian biotechnology industry, there are different types of organisations participating in the patent network e.g., hospitals, universities and pharmaceutical-biotechnology firms. As mentioned by Owen-Smith and Powell (2004), non-commercial actors like universities have differences from commercial companies. For instance, non-commercial actors are more diverse and more open to acquiring and disseminating knowledge compared to commercial actors. As a result it is expected that:

H1a: In a patent co-authorship network, SMEs have a lower level of knowledge diversity compared to larger actors.

H1b: In a patent co-authorship network, the level of knowledge diversity is not the same across actors of different types.

H1c: In a patent co-authorship network, pharmaceutical-biotechnology SMEs have a lower level of knowledge diversity compared to large pharmaceutical-biotechnology actors.

3.2.2.2. Hypothesis 2: *Content inter-play with collaborative process*

In Chapter 2 (Section 2.3.4.2), the summary of research on interactions between content and collaborative process of the k-network has been discussed. More precisely, knowledge diversity as an element of knowledge content seems associated with partner diversity as measure of the collaborative process (Chapter 2 Section 2.3.2). The more an actor possesses diverse knowledge, the more the actor is able to participate with diverse partners. Moreover access to diverse partners may increase access of the actor to more diverse knowledge.

H2: In a patent co-authorship network, the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is positively associated with the exploration collaborative process.

3.2.2.3. Hypothesis 3: *Content inter-play with network position*

In Chapter 2 (Section 2.3.4), the summary of research on interactions between content and structure of the k-network has been discussed. To understand the structure of k-networks (Chapter 2 Section 2.2.2), this research has focused on network position and ego-network structure. Knowledge diversity of an actor seems associated with the position of the actor in the network. Central actors have a better chance to acquire heterogeneous knowledge.

H3: In a patent co-authorship network, the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is positively associated with central position of the actors.

3.2.2.4. Hypothesis 4: *Content inter-play with ego net structure*

Actors who possess a sparse network can enjoy the link to more new knowledge hence one may expect them to possess more heterogeneous knowledge compared to actors tapped into closed networks.

H4: In a patent co-authorship network, the level of knowledge heterogeneity of actors including pharmaceutical-biotechnology SMEs is negatively associated with ego-network density of the actors.

3.2.2.5. Hypothesis 5: *Content association with patents*

By reflecting on Schumpeter's claim that innovation is making new combinations of knowledge, Kraaijenbrink et al. (2007) argue that any organisations need external

knowledge to be innovative. Hence knowledge creation in terms of patents is expected to be linked with diversity of actors' knowledge.

H5: In a patent co-authorship network, the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is positively associated with the number of patents of the actors.

3.2.2.6. Hypothesis 6: *Actor size and type with process*

SMEs are reported as firms with lower level of resources – e.g. Jutla et al. (2002); Levy and Powell (2005). In terms of diversity of partners, they are also expected to access lower levels of resources like people and capital to explore new partners. In the Victorian biotechnology industry, there are different types of organisations participating in the patent network, e.g. hospitals, universities and pharmaceutical-biotechnology firms. Owen-Smith and Powell (2004) also mentioned that non-commercial actors like universities are more open to collaborate with diverse partners compared to commercial actors. Overall, although non-commercial actors are expected to be more keen on exploration in terms of working with more diverse partners, non-commercial SMEs may have not enough resources to afford multiple relationships with various partners. Given the role of size and type, it is expected that:

H6a: In a patent co-authorship network, SMEs have lower levels of collaborative process compared to the larger actors.

H6b: In a patent co-authorship network, the level of knowledge diversity is not the same across actors of different types.

H6c: In a patent co-authorship network, SMEs regardless of the type have the same level of exploration.

3.2.2.7. Hypothesis 7: *Process inter-play with network position*

In Chapter 2 (Section 2.3.4.3), the summary of research on interactions between process and structure of the k-network was discussed. To understand the structure of the k-network as discussed in Chapter 2 (Section 2.2.4), my research has focused on network position and ego-network structure.

Collaborative process of an actor seems associated with the position of the actor in the network. Central actors have a better chance to find new partners and such new partnerships will increase their centrality.

H7: In a patent co-authorship network, the level of collaborative process of actors including pharmaceutical-biotechnology SMEs is positively associated with central position of the actors.

3.2.2.8. Hypothesis 8: *Process inter-play with ego net structure*

Normally actors in dense ego-networks have close relationships. Except large university and other non-commercial actors, it is not expected for other actors, particularly SMEs, to have frequent and close relationships with various partners. Hence one may argue that:

H8: In a patent co-authorship network, the level of collaborative process of actors including pharmaceutical-biotechnology SMEs is negatively associated with ego-network density of the actors.

3.2.2.9. Hypothesis 9: *Process association with patent*

Complementing knowledge and other capabilities is one of the frequent reasons for a partnership. However there is no evidence for either explorative or exploitative firms to be more innovative (e.g. Li et al. 2008), because there are actors who choose to reuse their current knowledge and exploit their existing partners, so knowledge creation in terms of patents is not expected to be linked with diversity of actors' partners.

H9: In a patent co-authorship network, the level of collaborative process of actors including the pharmaceutical-biotechnology SMEs is not associated with the number of actors' patents.

3.2.2.10. Hypothesis 10: *Actor size and type with centrality*

SMEs are reported as firms with lower level of resources (e.g. Jutla et al. 2002; Levy and Powell 2005). In terms of the position in the network, they are also not expected to be located within the centre of the network. Given the different types of organisations that participate in the patent network e.g. hospitals, universities and pharmaceutical-biotechnology firms, previous research showed that universities are the centre of the

networks. As mentioned by Owen-Smith and Powell (2004), non-commercial actors like universities are more diverse and more open to partnership with other actors. As a result it is expected that:

H10a: In a patent co-authorship network, SMEs have lower levels of centrality compared to their larger counterparts.

H10b: In a patent co-authorship network, the level of centrality is higher in non-commercial actors compared to commercial actors (i.e. pharmaceutical companies).

H10c: In a patent co-authorship network, pharmaceutical-biotechnology SMEs have lower levels of centrality compared to their larger counterparts.

3.2.2.11. **Hypothesis 11:** ***Centrality inter-play with ego net structure***

Benefits of central position are likely to be higher for actors with dense ego-networks. As explained by Soh (2010) there are two reasons for this relation: first, having a central position may enable actors to access diverse knowledge and opportunities, while being in a dense ego-network is supposed to improve the value of the knowledge; second, central actors who are located in a dense network have better support from their partners to exploit these opportunities. Regarding the characteristics of SMEs, it is expected that SMEs are less likely to be able to enjoy the benefits of a central position in a dense network.

H11: In a patent co-authorship network, there is a positive association between centrality and density; however for pharmaceutical-biotechnology SMEs, this association is not strong.

3.2.2.12. **Hypothesis 12:** ***Association of centrality with patents***

Central position in a network, is supposed to facilitate access to new knowledge, therefore it can improve knowledge creation. Hence, knowledge creation of an actor in terms of patents is expected to be linked with the centrality of the actor.

H12: In a patent co-authorship network, the level of centrality of actors including pharmaceutical-biotechnology SMEs is positively associated with SMEs innovativeness.

3.2.2.13. **Hypothesis 13:** ***Actor size and type with ego-network density***

SMEs are reported as firms with lower level of resources (e.g. Jutla et al. 2002; Levy and Powell 2005). To access more supportive network, SMEs are expected to maintain closed and frequent relationships with their partners. On the other hand, having a dense ego-network has its own costs regarding contracting and coordination with partners (Bae and Gargiulo 2004). As mentioned by Owen-Smith and Powell (2004), non-commercial actors (sometimes also called public research organisation (PROs)), such as universities, are more diverse and more open to new partners, hence they are more likely to substitute their partners than are commercial actors. As a result it is expected that:

H13a: In a patent co-authorship network, SMEs have no more dense ego-networks compared to large actors.

H13b: In a patent co-authorship network, the level of ego-network density is not the same across actors of different types.

H13c: In a patent co-authorship network, pharmaceutical-biotechnology SMEs have the same level of ego-networks density compared to large pharmaceutical-biotechnology actors and individual inventors.

3.2.2.14. Hypothesis 14: *Association of ego-network density with patent*

Although the dense network brings its own benefits like trust and higher levels of support, it is not as strong as the sparse ego-network in terms of providing access to new knowledge required for knowledge creation. Hence knowledge creation of an actor in terms of patents is expected to be linked negatively with the density of the actor's ego-network. However, in regard to the characteristics of SMEs, it is expected that SMEs are less likely to be able to enjoy the benefits of the sparse ego-network.

H14: H14: In a patent co-authorship network, the level of ego-network density of actors is negatively associated with the number of actors' patents; however for pharmaceutical-biotechnology SMEs this association is not strong.

3.2.2.15. Hypothesis 15: *Interactions of all constructs*

As reflected in the previous hypotheses, and reported in Chapter 2 (Section 2.3), it is expected that the combinations of content, process and structure of k-networks affect the

knowledge creation in terms of patents. Moreover, the size and type of the actors can be considered as controlling variables.

H15: In a patent co-authorship network, the level of knowledge creation of actors (including SMEs) is influenced by the interactions of knowledge diversity, collaborative process, centrality and density of their network.

3.3 Summary

Following the literature review in Chapter 2 (section 2.1.2 and 2.1.3), the Victorian biotechnology industry is introduced here as a knowledge-based industry representing the setting of the research. The patent-authorship network as a knowledge creation focused type of k-network, is also discussed to represent the cohort of the research. Then, given this cohort, a main research questions along with three sub-questions were defined and fifteen hypotheses were also formulated accordingly. To show how the research attempted to answer these questions and to test the hypotheses, the method of the research is addressed in the next chapter.

Chapter 4
Research Design

Outline of Chapter 4

After defining the research question and theoretical framework in Chapters 2 and 3, this chapter reports the way that I tested the hypotheses and answered the research questions.

In this chapter, firstly the pragmatic worldview is described as my philosophical viewpoint to the research questions. Then, it is explained how the nature of the research question required a mixed method approach and how this approach was applied to answer the research question scientifically.

More specifically, the design of the research is articulated in three sequential phases. The nature of data and their sources, the procedures for data analysis and finally the limitations of methods and ethical issues are explained for each phase. Finally, the rigor of this research method in terms of the quality of design and explanation is discussed to show how the method is suitable, adequate and sufficiently powerful to provide quantitative and qualitative inferences. The rigor of the integrative inference to combine both quantitative and qualitative inferences is discussed as well.

4.1 Introduction

How do knowledge networks contribute to knowledge creation? To answer this question, this chapter proposes a sequential mixed method approach to the research design in three phases.

This chapter discusses why this approach was taken and how it contributes to the research question. In this regard, the starting point is the research questions then the philosophical aspects of the research are discussed. After defining the scope of the research, the three-phase research design is explained. The purpose of each phase, data collection, method for analysis, and the research limitations and ethical issues are explained for each phase. Finally the reliability and validatity of the research method is examined.

4.2 Research questions

This research was intended to study the role of inter-organisational k-networks in innovation-driven collaboration by actors in the high-tech industry. To do so, content, process, and structure of such networks were focused on. Therefore at first there was a need to understand the characteristics of these k-networks constructs. Then it was intended to analyse how these constructs contribute to knowledge creation within k-networks. The research question was: How do knowledge networks contribute to knowledge creation? This main research question is elaborated into two leading questions:

1. What are the characteristics of the knowledge networks constructs of content, process and structure?
2. How do the interactions of these constructs support knowledge creation?

To answer the questions, 15 hypotheses were developed in Chapter 3. To address these questions, a sequential mixed method was designed, which is described and analysed in the following sections.

4.3 Philosophical paradigm and strategies of inquiry

To have a structured way to discuss the research design and its validity, my research followed the guidelines provided by Venkatesh, Brown and Bala (2012). Their seminal study which have recently published detailed guidelines in MISQ, reviewed the existing literature on the mixed method research, hence it was used extensively in my research.

4.3.1 Ontology and epistemology of the research: Why mixed method?

A mixed method approach is one kind of multiple method approach that always requires multiple worldviews, for instance positivism and interpretivism. Having multiple worldviews in a single research inquiry may cause paradigm incommensurability – the so-called 'incompatibility thesis' (Howe 1988). However many researchers think that there is no philosophical contradiction if the research is registered to a pluralistic paradigm like the pragmatic worldview. Some scholars even believe that possible contradictions in the philosophical basis of different paradigms should not stop any research so long as the nature of the research is justifiable (Onwuegbuzie and Leech 2005).

Venkatesh et al. (2012) claim there is no consistent and well-accepted agreement regarding the usage, design, and inference quality of mixed method approaches. However there is a substantial consensus of views with respect to how and why researchers should employ a mixed methods approach in their research (Creswell and Clark 2007; Tashakkori and Teddlie 2008). This general agreement refers to *context, objectives and research question* as criteria that a researcher should use to select an appropriate method (Creswell and Clark 2007; Mingers 2001; Ridenour and Newman 2008; Teddlie and Tashakkori 2003, 2009 cited by Venkatesh et al. 2012). Hence I discuss why understanding the impact of content, process, and structure of k-network (research questions) in the context of innovation-driven collaboration in the Victorian biotechnology industry (context) could fit with a mixed method approach.

Knowledge diversity as a characteristic of content has been treated as an objective reality in the prior research (Beckman and Haunschild 2002; Wadhwa and Kotha 2006). However, for two reasons having the objective epistemology of knowledge diversity could be

problematic, or at least, it may not able to provide a comprehensive picture to understand the content of k-networks. First, in addition to the knowledge diversity, there could be other important characteristics of content in the eyes of actors in the context of Victorian biotechnology. Second, the knowledge diversity itself may require a more context driven understanding as followed by some scholars like McEvily and Marcus (2005). Hence, in terms of the epistemology, I assume that the content of k-networks could be considered as *constructivism* (Crotty 1998). In this epistemology, it is believed that there is an objective reality out there, but one can only know the reality from his/her own subjective perspective. Moreover, the ability of people to know the reality is imperfect. Therefore, to improve the scientific approximations and increase the validity and accuracy to understand the content of k-networks, I believe that using a mixed method approach can provide a more comprehensive answer.

Likewise, the exploration/exploitation process is the other aspect of k-networks which has been studied in the literature by scholars with an objective epistemology (Lavie and Rosenkopf 2006; Tiwana 2008; Rothaermel and Alexandre 2009) and a non-objective epistemology (Swan et al. 1999). I also believe that the exploration/exploitation process is an embedded concept in the context of the actors. Therefore, in this research the epistemology of the process of k-networks, again, has been considered as constructivism (Crotty 1998). Hence, while the exploration/exploitation process may have an objective reality, it will be more valid and accurate if it is studied in a mixed method approach.

The final construct in this research inquiry is k-network structure. Although the structure of networks, in terms of centrality and ego-network density, has been studied mainly from the objectivist epistemology and has been treated as an objective reality (e.g. Ahuja 2000; Beckman and Haunschild 2002; Soh 2010), to know why actors like SMEs have formed a particular network structure in the given context of the Victorian biotechnology industry, it seems there is a need for more comprehensive perspective from SMEs owner/managers.

Given the discussed ontology and epistemology of the research as summarised in Table 4-1, it seems that a pluralistic worldview needed to be taken accordingly and a mixed method methodology would be appropriate. In this regard, it is reported in the next section how a

pluralistic paradigm can provide a basis for a mixed method inquiry as a combination of qualitative and quantitative methods or the integrative methods (Morgan 2007).

Table 4-1 Ontology, epistemology and the methodology in this research

	Ontology	Epistemology	Methodologies
In my research	Modified objective as it is assumed by the researcher that there is an objective reality regarding the k-network though the experience of the reality does count as well	Constructivism since ability to know the reality is imperfect and depends on the interaction between the researcher and the participants	A mixed method approach to offer a broader understanding which allows participants to provide their views

4.3.2 Mixed method via pluralistic worldview

The philosophical basis of mixed method research in a single research inquiry has been questioned in the literature (Guba and Lincoln 1994; Morgan 2007). To deal with the so-called 'incompatibility thesis" (Howe 1988), there are three alternative approaches that have been developed (Creswell and Clark 2007; Tashakkori and Teddlie 2008): 1) Pragmatic stance: simply ignores philosophical paradigmatic issues; 2) Multiple paradigm approach: claims that alternative paradigms can be used in the one research project and there is no incompatibility; and 3) Single paradigm approach: believes that both quantitative and qualitative research can be accommodated under a single paradigm.

Given the recommendation of Venkatesh et al. (2012), finding plausible and theoretically sound answers to a research question and to develop substantive theory should not be challenged by the concept of paradigm. They argued that researchers should be able to mix and match their paradigmatic views and still conduct rigorous mixed methods research. However to understand the [hidden] assumptions that a researcher has, it is important to know the underlying paradigm. In mixed method research there are at least three paradigms which one can choose from: pragmatism, transformative–emancipatory, and critical realism (Venkatesh et al. 2012). A detailed discussion of each of these paradigms is beyond the scope of my thesis but can be found in the works of Creswell, Plano Clark, Gutmann and Hanson (2003); Creswell and Clark (2007); Morgan (2007); Tashakkori and Teddlie (2008).

For my research, there is no superiority of any particular paradigm over two others. However, given the specific concerns of transformative–emancipatory and critical realism regarding the justice and marginalised peoples/communities here pragmatism is chosen mainly because it is focused on solving problems rather than on assumptions about the nature of reality/experience. Moreover, there are debates about accepting transformative–emancipatory and critical realism as independent and well elaborated paradigms. For instance Guba and Lincoln (1994) consider critical realism as a post-positivist ontology.

Given the goals of this research, the paradigm and methodological issues are discussed in this secion. This study is based on micro-level data collected in the context of Victorian biotechnology actors in Australia while the level of analysis in this research is actors who participated in the patent co-authorship network of the Victorian biotechnology industry (discussed also in Chapter 3, Section 3.1.2).

From a methodological viewpoint, given the three philosophical paradigms in mixed method research, this study adopted the pragmatic paradigm (i.e. a mixed method) which "instead of focusing on methods", allows researchers to adopt all approaches available to study the research problem (Creswell et al. 2003, p: 10). The important point in this paradigm, as mentioned by several scholars cited by Morgan (2007), is the research problem. And using pluralistic approaches, researchers in this paradigm need to derive required knowledge about the problem (Creswell et al. 2003). These features of the pragmatic paradigm are consistent with my research approach, since this paradigm opens the door to multiple forms of data collection and analysis e.g. statistical and text analysis which is used in the different phases, without arguing about the duality between the nature of the reality and the experience/knowledge of reality (Maxcy 2003).

4.3.3 Purpose of the mixed method

According to Venkatesh et al. (2012), the summary of the different purposes for having a mixed method inquiry can be summarised as shown in Table 4-2. It is argued that many of the mixed method inquiries can be placed in multiple purpose categories (Greene, Caracelli and Graham 1989; Creswell et al. 2003; Tashakkori and Teddlie 2008). Also, Venkatesh et al. (2012) showed that a research study that was placed in the corroboration/confirmation

category could also be placed in the expansion category since, in addition to confirming the findings of the quantitative study, the purpose of the qualitative analysis was to "possibly gain additional insights into the nature and causes of the hypothesised associations" (p. 6).

In my research, the purpose of having a mixed method approach is corroboration/confirmation, as shown in Table 4-2. In particular, some of the findings of the quantitative phase were also studied via qualitative approach to be confirmed in the selected cases. There are several similar mixed method research projects with this aim in the literature for instance Bhattacherjee and Premkumar (2004) used content analysis as a qualitative technique to confirm their findings in their first quantitative phase.

Table 4-2 Purposes of mixed method studies
Note: Adapted fromVenkatesh et al. (2012) * Applied to this research

Purpose	Definition
Complementarity	Mixed methods are used in order to gain complementary views about the same phenomena or relationships.
Completeness	Mixed methods designs are used to make sure a complete picture of a phenomenon is obtained.
Developmental	Questions for one strand emerge from the inferences of a previous one (sequential mixed methods), or one strand provides hypotheses to be tested in the next one
Expansion	Mixed methods are used in order to explain or expand upon the understanding obtained in a previous strand of a study.
Corroboration/ Confirmation *	Mixed methods are used in order to assess the credibility of inferences obtained from one approach (strand).
Compensation	Mixed methods enable researchers to compensate for the weaknesses of one approach by using the other.
Diversity	Mixed methods are used with the hope of obtaining divergent views of the same phenomenon.

In this research, the qualitative case studies were used to triangulate quantitative findings with qualitative case analysis. The concept of triangulation has come to have different meanings (Morgan 1998), therefore following her analysis this research used convergence or confirmation when referring to integration of both qualitative and quantitative data. These terms were proposed by Morgan (1998) for the qualitative analysis. Using a mixed method approach with this purpose is also reported in the several top information systems journals, for example (Dennis and Garfield 2003).

4.3.4 Strategy for the mixed methods design

There are two major design strategies in the mixed method inquiry, namely concurrent and sequential (Creswell et al. 2003). Each of these strategies has its own advantages and

disadvantages, however as recommended by Venkatesh et al. (2012) a design strategy needs to be developed in line with the research questions and objectives.

In my research, findings from the quantitative study inform the later qualitative study theoretically and empirically. Therefore this research followed a sequential mixed methods design. In this regard the quantitative and qualitative data collection and analyses were implemented in different phases and each was integrated in a separate phase (Table 4-3). However in a continuum of a qualitative-quantitative approach (Newman & Benz 1998), this study tends to be more quantitative than qualitative. In fact, by using a combination of existing theoretical lenses, my research, studied a particular phenomenon (i.e. k-network) in a relatively novel way.

Table 4-3 The mixed methods design strategy to answer the research questions

Research questions	Quantitative inquiry	Qualitative inquiry
Research question 1: Characteristics of content, process and structure	Initial characteristics of content, process, and structure examined with hypotheses H1, H6, H10, and H13	New constructs and contextual factors added to understand the characteristics
Research question 2: Interaction of the constructs to support knowledge creation	Hypotheses H2, H3, H4, H7, H8, H11, H5, H9, H12, H14 and H15	Contextual factors added to understand the impact of k-network constructs
How do knowledge networks contribute to knowledge creation?	Integration of both quantitative and qualitative inquiries were synthesised to provide comprehensive answer in the context of the Victorian biotechnology of Australia	

4.4 Research design

Given the considerations provided in previous sections, the research design is discussed in more detail in this section. To meet the main goals of this study, a three-phase approach was designed. In this section, the major phases of this research are explained in terms of: method to accomplish each phase; targeted respondents and the way that they were selected; data that were collected through each phase; the way that such data were analysed; and the results that were achieved after data analysis in each phase.

4.4.1 Phase 1: Introductory study

In parallel with reviewing the literature and defining the conceptual framework of the research, this initial empirical phase was undertaken mainly because it was necessary to understand the setting of the research including the issues, the importance of k-networks, patenting and partnerships, before the research framework and the approach of the research could be designed. The details of purpose and participants are discussed in this section.

4.4.1.1 The purpose

Phase 1 mainly shaped the conceptual framework and research method of this study. Two informants in the Victorian biotechnology were interviewed to make sure that the proposed research was tackling something meaningful and significant from the biotechnology industry point-of-view (Gray 2009) as well as from the theory point-of-view. Throughout this phase, the structure of the Victorian biotechnology industry, the importance of patents to them and also useful and reliable websites for collecting data, were identified. Moreover, the significance of the research framework, research questions and hypotheses were examined and improved in this phase.

4.4.1.2 Participants and Data collection

In this phase the researcher met two informants in service provider companies in the Victorian biotechnology industry. These meetings were conducted in three sessions and took more than 12 hours. These sessions not only discussed the research framework, but also provided substantial information about the patent process, the technical terms in patent applications like Patent Cooperation Treaty (PCT), legal agents that help SMEs and other actors for protecting their intellectual properties.

The first phase also identified useful and reliable websites for collecting data. These sources were the online membership list of AusBiotech[7], a biotechnology industry organisation, which represents over 3,000 members, covering the human health, agricultural, medical devices, bioinformatics, environmental and industrial sectors in

[7] http://www.ausbiotech.org

biotechnology; the online membership list of Bio Melbourne portal[8], as a membership-based industry development and promotions agency for the Victorian biotechnology industry; and finally the Australia Stock Exchange (ASX) with focus on pharmaceuticals, biotechnology and life sciences companies. IPAustralia (AusPat[9]), a database which records all Australian patents published since 1904, was also used in this phase.

4.4.2 Phase 2: Network study

The second phase used a quantitative approach to test the hypotheses that were formulated in Phase 1 and reported in Chapter 3. The detail of this analysis which is targeted at the actor level (as discussed in Chapter 2 Section 2.2.3.2) is reported here in terms of purpose, data collection and analysis, limitation and ethical concerns.

4.4.2.1 The purpose

This phase intended to answer all sub-questions about the content, process, and structure characteristics of k-networks and also to find out on how the interrelationships of these three elements may contribute to knowledge creation. Later on, in the third phase, these results became confirmed and examined particularly in the context of SME cases.

4.4.2.2 Participants and data collection

To define the innovation driven k-network, this research focused on patent co-authorship network. If two actors have registered a patent with each other, it means that they had innovation-driven collaboration, though with a one or two year delay.

Participants

All the Victorian biotechnology actors who had published at least one patent from 2001–2010 were considered as the targeted participants. In this phase it was intended to collect data from the whole network. To do so, a snowball sampling approach was used to get the list of all the actors. The following described the search process that was implemented:

Step 1. There is no pre-existing list of Victorian biotechnology actors, so my own initial list of actors was created based on the three main sources:

[8] http://www.biomelbourne.org
[9] http://www.ipaustralia.gov.au/auspat/index.htm

- Online membership list of AusBiotech
- Online membership list of Bio Melbourne portal
- List from the Australia Stock Exchange (ASX) – with a focus on pharmaceuticals, biotechnology and life sciences companies

Step 2. Then AusPat was searched for the names of actors and data collected

Step 3. If there was a partner for the actor and the partner was located in Victoria, then the partner was added to the main list of actors and its patents were sought as explained in step 2.

It is reasonable to argue that for some large enterprises like Monash University, we cannot assume that all their patents are relevant to biotechnology. Therefore to collect data on the actors' patents, another criterion was added about the technological domain of the patent identified by International Patent Classification (IPC). In the biotechnology industry, there are 30 groups of technologies that are identified by OECD (2005) (see Appendix 2). This classification helped me to check for the patents of large enterprises like universities and hospitals. In this research, if an IPC of one actor's patent belonged to the OECD list then the patent was considered a biotechnology patent. Otherwise the patent was ignored. Given these considerations for collecting appropriate patents, I was able to derive the whole picture of co-authorship patent network of Victorian biotechnology industry.

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omise columns/data Include specification text search context? Results per page 50

Application number	Applicant(s)	Inventor(s)	Filing date	Application status	PCT number	First IPC mark
2006901643	Monash University	Not Given	2006-03-30	LAPSED		
2006900800	Monash University; Polychip Pharmaceuticals Pty Ltd	Not Given	2006-02-17	LAPSED		
2006900799	Monash University; Polychip Pharmaceuticals Pty Ltd	Not Given	2006-02-17	LAPSED		
2006900798	Monash University; Polychip Pharmaceuticals Pty Ltd	Not Given	2006-02-17	LAPSED		
2006900091	Monash University	Not Given	2006-01-09	LAPSED		
2006301864	Ofidium Pty Ltd	Armstrong, Jean; Lowery, Arthur	2006-10-12	SEALED	PCT/AU2006/001511	H04B10/00
2006287123	Ofidium Pty Ltd	Armstrong, Jean; Lowery, Arthur	2006-09-01	SEALED	PCT/AU2006/001282	H04B10/04
2006265769	Monash University; DuluxGroup (Australia) Pty Ltd	Serelis, Algirdas Kazimieras; Robinson, Andrea Jane; Jackson, William Roy; Patel, Jim; Such, Christopher Henry	2006-06-30	SEALED	PCT/AU2006/000930	C08G61/00
2006261600	Monash University	Orr, Michael	2006-06-23	LAPSED	PCT/AU2006/000889	G10L11/06

Figure 4-1 The sample data that can be captured from Auspat

Also other information was collected about the content and process of the k-network. To get a better understanding of all these data, the sample data that can be captured from AusPat, is illustrated in Figure 4-1. By using AusPat, I was able to determine whether the actors had published any patents from 2000–2010, and if so, with whom. The applicant name in this database represents the name of the firm/actors. The inventor name is also provided. The patent column lists the patents that were registered between the years 2000–2010. The applicants' column shows the name of the actors (e.g. firms or hospitals) while in the list, the name of people who were involved in that patent are reported in the inventor(s) column. The collaborations of each applicant or actor in each year were extracted from the applicant column. From this information a database was developed to understand the k-network of biotechnology actors. The concept of structural exploration/exploitation as the collaborative process is also extracted based on diversity of the partners. Here the more diverse range of partners was considered as identifiers of the more exploration oriented actors. The other column for PCT number refers to Patent Cooperation Treaty (PCT), an international agreement for simplifying the filing of patents. In this research only the PCT records were considered because they actually represent unique innovation patents or collaboration projects.

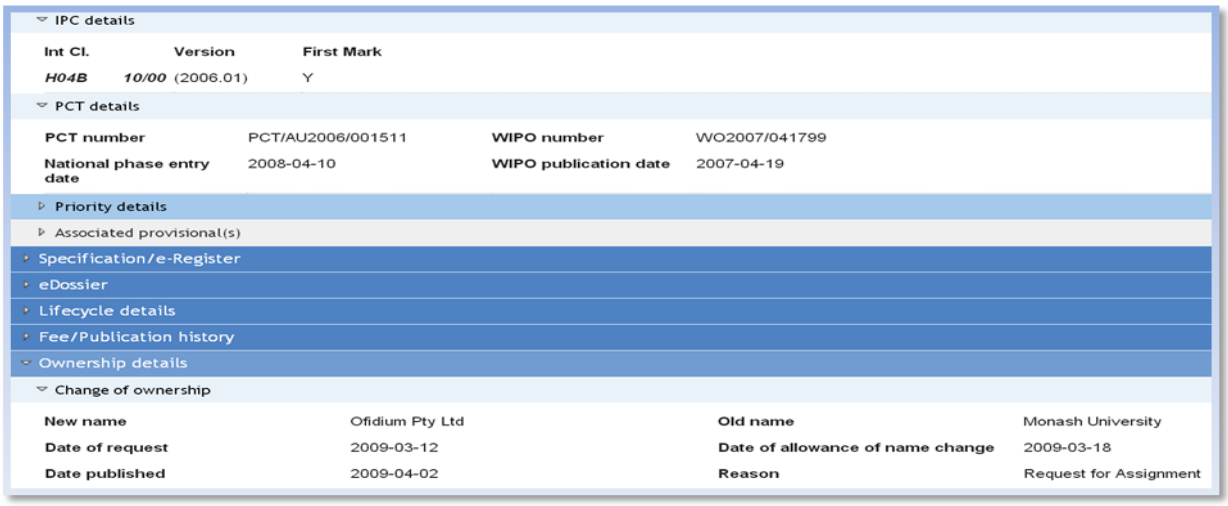
The last column refers to technological class of the innovation (i.e. patent). The International Patent Classification (IPC) class represents the group of technology. The IPC was developed by WIPO in 1971[10] and defined as:

> *a hierarchical system of language independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain*

Given the IPC, the potential networks of relationships were defined, which is discussed in Chapter 5 (Section 5.2.1). The IPC was used as a measure to understand the technological knowledge of actors. The more diverse range of IPC groups was considered as more heterogeneous knowledge.

[10] Strasbourg Agreement accessable from the WIPO website: http://www.wipo.int/treaties/en/text.jsp?file_id=291858

Also by clicking on each patent record, a sample of which is shown in Figure 4-1, I gathered more details about the records. This new page, as shown in Figure 4-2, was used to identify any possible change in the names of the actors, or possible mergers and acquisitions that might have happened for the actors.



IPC details

Int Cl.	Version	First Mark
H04B	*10/00* (2006.01)	Y

PCT details

PCT number	PCT/AU2006/001511	WIPO number	WO2007/041799
National phase entry date	2008-04-10	WIPO publication date	2007-04-19

Priority details

Associated provisional(s)

Specification/e-Register

eDossier

Lifecycle details

Fee/Publication history

Ownership details

Change of ownership

New name	Ofidium Pty Ltd	Old name	Monash University
Date of request	2009-03-12	Date of allowance of name change	2009-03-18
Date published	2009-04-02	Reason	Request for Assignment

Figure 4-2 Details about patents records

Note: Used to identify any possible change in the name of the actors, or possible mergers and acquisitions

4.4.2.3 Data Analysis

There were substantial data collected in this phase, and I used several techniques to analyse these data in order to answer the research questions. Here some of the main techniques and their rigour and relevance are explained. A summary of the quantitative procedures and techniques used in this phase is illustrated in Table 4-4.

Social network analysis

The primary aim of using social netwoork analysis (SNA) in my research was to understand the pattern of relationships between actors and also to study the implications of these relationships on the innovation among SMEs. SNA has been used in KM research like Cross et al. (2002) and Anklam (2003) with networks based on collaborations or co-authorship. This technique deals explicitly with relationships between entities like firms or individuals.

Using UCINET6 (Borgatti et al. 2002) as a software package, SNA was applied here to draw the whole collaboration network, the potential network was also used to calculate the centrality element as one of the two structural characteristics of the k-network.

Table 4-4 Summary of quantitative procedures and techniques used in Phase 2

Procedures in Phase 2	Purpose of using in this research	Explanation of values	Software	References
Social network analysis	Mapping k-networks and also calculating their structural characteristics	There is no statistical test but calculating structural elements like density and centrality	UCINET 6 Tnet in R	(Borgatti et al. 2002; Opsahl and Panzarasa 2009)
Factorial analysis of variance	To study the differences among content, process and structure in terms of size and type of actors	α = > .05: the variances between groups are not significantly different α < .05 the variances between groups are significantly different	SPSS 20	(Jaccard 1998)
Spearman correlation coefficient analysis	To test a statistical measure of the strength of a relationship between constructs	α = < .05 indicated significant relationship and α = >.05 indicated non-significant relationship ρ indicated the strength and direction of relationships	SPSS 20	(Pérez-Cano 2013)
Moderated multiple regression (MMR)	Modelling the constructs and to test the possible interactions	α = > .05: the variances between groups are not significantly different α < .05 the variances between groups are significantly different Results for .01 and .1 are reported as well	SPSS 20	(West and Aiken 1991; Irwin and McClelland 2001)
Harman's single-factor	When a single data source to measure both dependent and independent variables, there would be a risk of common-method bias (CMB)	Variance < .5 There is no significant biases in the method Variance = > .5 There is a significant bias	SPSS 20	(Podsakoff, MacKenzie, Lee and Podsakoff 2003)
Kolmogorov -Smirnov and Shapiro-Wilk	To test the Gaussian or normal distribution of data	=> .05: the distribution of data is significantly normal < .05: the distribution of data is not significantly normal	SPSS 20	(Razali and Wah 2011)
Non-parametric Levene's Test	To test the homogeneity of variances when the distribution of data is not normal	P-value at 0.01 > .01: the variances between groups are not significantly different = < .01 the variances between groups are significantly different	SPSS 20	(Nordstokke, Zumbo, Cairns and Saklofske 2011)
Rank transformation	Used to transform the data in order to have a better fit and analysis in F-ANOVA	> .05: the variances between groups are not significantly different = < .05 the variances between groups are significantly different	SPSS 20	(Del Vecchio, Doerr and Gaughan 2012)
Tolerance or Variance Inflation Factors (VIF)	To check for non-multicollinearity as a required assumption for implementing a multi regression analysis	VIF < 10: there is no significant multicollinearity VIF > 10: there is a significant multicollinearity among constructs	SPSS 20	(O'Brien 2007)
Koenker test	To test homoscedasticity of data as an assumption behind linear regression	Chi-square < .05: there is no significant homoscedasticity among constructs Chi-square <. 05: there is a significant homoscedasticity	SPSS 20	(Koenker and Bassett Jr 1982)

However to calculate density as the other structural characteristic, a code was run in R[11], the open-source statistical programme which allows researchers to create stand-alone programmes, since SNA software like UCINET and Pajek do not have any packages to calculate density in a valued network or clustering in weighted networks as named by Opsahl and Panzarasa (2009).

Factorial analysis of variance

In this research data were collected about the entire Victorian actors who had published at least one patent between 2001 and 2010. This whole network includes different types of actors and firms of different sizes. However the main focus of this research is on pharmaceutical-biotechnology SMEs. To focus this study on pharmaceutical-biotechnology SMEs, there was a need for a technique to distinguish the role of size and type and also the interaction of all these factors. To achieve this aim, I used factorial analysis of variance (factorial ANOVA).

Factorial ANOVA is an extended form of one-way ANOVA and is used to study the differences among groups when there is more than one independent variable (Jaccard 1998). Here a three-way ANOVA was used with SPSS 20, to check the impact of size (like large, SME), organisational type of actors (like hospitals or PROs), and collaborative behaviour (whether the actor was isolated or participated in the whole network) to answer to the research questions (hypotheses H1, H6, H10, H13). By using this analysis, it was intended to check whether the diversity of the knowledge or collaborative process, or central position or density in SMEs were the same as those of large actors or not; likewise whether the knowledge or collaborative process, or central position or density in SMEs were the same as those of other types of actors. And finally the main effects of size and type can be studied. The details of these analysis including the validity and requirement for using the analysis to answer sub-question 1 by testing hypotheses (H1, H6, H10, H13, reported in Chapter 6–8). For this analysis 0.01significance level was used to be more conservative in order to protect the analysis form the type I error. This consideration is discussed in Chapter 6 (Section 6.2).

[11] http://toreopsahl.com/tnet/software/

Spearman correlation coefficient analysis

This analysis is to test a statistical measure of the strength of a relationship between paired data. Its values fall within the range of -1 and 1. While values close to 1 indicate a strong positive association, those approaching -1 point out a strong negative association (e.g. Pérez-Cano 2013). This test is similar to Pearson's correlation test; however it is not tight with the assumptions of Pearson's test. These assumptions for conducting Pearson's test are: interval or ratio level; linearly related; and bivariate normally distributed. In this research, the data does not necessary meet the above assumptions so the Spearman's correlation coefficient analysis was used, which does not require those assumptions (Diamantopoulos and Schlegelmilch 1997).

The possible association among structure, content and process of an actor and its knowledge creation, is the main point of interest that is reflected in the several hypotheses (i.e. H2, H3, H4, H5, H6, H7). The reports of this test and their discussion are reported in Chapters 5–8.

Moderated multiple regression (MMR)

Moderated multiple regression (MMR) is frequently employed to analyse interaction effects between continuous predictor (independent) variables. In other words, this technique allows the simple relationship between the dependent variable and an independent variable to depend on the level of another independent variable (Irwin and McClelland 2001).

Is there any interaction among structure, content and process of an actor's k-networks and its knowledge creation? If yes, how do the interactions of these three elements contribute to knowledge creation? These are the main concerns of the interaction analysis in this research, which is captured in hypothesis H15. This research applied MMR including a negative binomial multiple regression analysis followed by the interaction analysis (West and Aiken 1991). A negative binomial as an extension of the Poisson multivariate regression analysis by SPSS 20 was conducted. Since the dependent variable (i.e. number of published patents) is a counted variable (number of patents), linear regression was not appropriate in modelling such data as discussed in Chapter 9 (Section 9.2).

Interaction analysis is used to analyse the interaction among all constructs (West and Aiken 1991). The validity of the model and considerations to interpret the results (Irwin and McClelland 2001; Dalal and Zickar 2012) are all discussed in Chapter 9.

4.4.2.4 The limitations of the quantitative phase

Collecting secondary and publicly available data is not always straightforward and has its own drawbacks. This is particularly the case for for SMEs, since the age of these companies sometimes is too short for several reasons like mergers and acquisitions so substantial effort is required to track all data, particularly for retrospective research.

In this phase all the data about the demographics of actors like size and type, and also the patent information acquired through publicly available sources including governmental websites, ASX, industry networks, and the websites or web pages of actors. To control the quality of data or, in other words to collect complete and correct data, I spent substantial time on triangulating data. Sometimes I had to contact the companies directly to acquire data about their size and type of business.

The analysis of these data required using several software packages including SPSS, UCINET6 (SNA), and R (open-source statistical programme), and each of these packages need their own format to analyse the data.

There are also some limitations in terms of statistical analysis. Although data were collected for the whole Victorian biotechnology industry (126 actors), only 69 actors had participated in the patent k-network. The low number of this dataset provides some challenges for analysis. There are more techniques required for such analysis (Chapters 5–9) and always there are some risks for generalising the results (Chapter 11).

4.4.2.5 Ethical issues

There is no foreseeable risk associated with this phase since all the data are collected from a publicly available database. Moreover the detailed analysis of each actor is not discussed in this thesis in an identifiable manner.

4.4.3 Phase 3: Case study

Following the recommendation of Coviello (2005) to have a bi-focal approach in network research, after the quantitative data analysis in Phase 2, this research employed an in-depth multiple case study approach in Phase 3. This approach has also been applied in the network research of the SME sector (e.g. McAdam, Moffett, Hazlett and Shevlin 2010). The main purpose of having multiple case studies, the details of case selection, data collection and analysis are discussed here.

4.4.3.1 The purpose of the case study

There are two main goals pursued in this phase:

- Expansion: The case studies were used to explain or expand upon the understanding obtained in the quantitative Phase 2. Through the case studies, I explained the implications of the research findings for each case to enhance the understanding of k-networks.
- Confirmation: The case studies were also used to assess the credibility of inferences obtained from the quantitative Phase 2, particularly for SMEs. Given the multiple type and size of actors in the whole k-network, some of the findings might not be able to be specifically applied to SMEs. This phase has focused exclusively on SMEs to verify the findings for this sector as the dominant actors in the Victorian biotechnology industry.

4.4.3.2 Recruiting participants and data collection

To reach these goals, Phase 3 was started by recruiting SMEs with special considerations. Given the resultant framework from Phase 2 (Chapter 9, Section 9.5), I aimed to study SMEs with different sorts of k-network characteristics or configurations. This purposeful selection of cases from multiple groups of SMEs, which is recommended in a multiple case study approach in the mixed method research (e.g. Ivankova, Creswell and Stick 2006), is described later in the detail in Chapter 10. Given the various configurations discussed in Chapter 10 (Section 10.5), all actors were classified with three types of configurations.

- Type I (favouring configurations): These actors possess the sort of k-network configuration that favours the innovation projects.
- Type II (mix-impact configuration): This type refers to actors whose k-network configuration seems to provide mixed results. In other words some characteristics of their networks support their innovation project, however some other aspects do not.
- Type III (neutral configuration): This group includes actors whose particular k-network configurations provide neutral impact toward their innovation projects.

To conduct the research, six groups can be distinguished based on three organisational types (public research organisations, pharmaceutical-biotechnology firms, and hospitals) and two organisational sizes (SMEs and large organisations). These six groups also can be studied in three types of configurations, therefore for all, 18 cases would have been required. To avoid the complexity of characteristics of each group, I had to select one group. Among all the actors, pharmaceutical-biotechnology SMEs were selected because: a) they had the majority in terms of the number of players in the whole network, and b) the importance of the SME sector as discussed in the literature.

In this group, the list of candidate SMEs was prepared and all of them contacted via phone and/or emails. It was planned to interview with three types of informants including: a) senior manager/CEOs, b) project leaders and/or innovators involved in the projects and c) informants from the SMEs partners.

In summary, each case was studied through: 1) in-depth interviews with managers/innovators and their partner companies in the network, 2) visiting their sites, 3) reviewing their documents like presentation files and annual reports, and 4) patent data were collected from patent documents provided by AusPat.

Four pharmaceutical-biotechnology SMEs and their partners, accepted to participate in this Phase. A total of five informants were interviewed (over eight hours as explained in Chapter 10) mainly because in each case SME, there were less than five people in the company, and the informants were all C-level managers (mostly CEOs) who had participated in all or most of the company's patent projects. Only in one case, I managed to interview one large size partner of a selected SME.

All the available data on each SME were also collected before and after the interviews. These documents often were published reports that described the firms' activities and policies. However in two cases, some other documents/presentations were shared with me. Additionally, quantitative data about the selected SMEs and their partners was studied in detail, as recommended by Creswell and Clark (2007).

4.4.3.3 Interview protocol

Given the three types of informants, three versions of the interview protocol were developed. However these protocols had to be further customised for each SME as well, since it was planned to share the case exclusive findings from the quantitative analysis in Phase 2 with the representative(s) of that SME case. The summary of the interview topics for each informant is provided in Table 4-5. A sample of the interview protocol can be found in Appendix 7. These interview protocols were emailed to the participant prior to the interview date. A copy was also given to the participant in each interview.

Table 4-5 Summary of the interviewee roles and interview topics for each case

Position	Topics for interview	Expected length of interview
A: Senior manager/CEOs	Project(s) and company background, attitude to knowledge sharing and inter-organisational collaboration	1 hour
B: Project leaders and innovators involved in the projects	Issues and approaches of knowledge sharing and inter-organisational interactions during the project(s) mainly with focus on content, purpose and actions of knowledge sharing, interactions with external partners, detailed practices of knowledge sharing and collaboration	2 hours
C: Informants from the SME's partners	Issues and approaches of knowledge sharing and inter-organisational interactions during the project(s) mainly with a focus on content, purpose and actions of knowledge sharing	2 hours

The main component of the interview protocol was slightly different for each informant. However the common aspects were:

- Organisation's business environment: This included questions about the main activities of the organisation and possible changes in their direction since 2001. Also, details of the number of personnel and the organisation's revenue, the organisational chart and possible changes during the last 10 years were explored.

- Attitude toward patent-based inter-organisational collaboration: This section started with reviewing the collected records about the SME's patent-based collaborations to check the correctness and completeness of my data. Then, for each partner, the purpose, the frequencies and types of interactions during the patent projects, the influences of these relationships and the challenges/difficulties were addressed.
- Attitude to knowledge acquiring/creating: Here I asked the informants to describe the ways in which their company acquired, created, shared and harnessed information during their patent-based partnerships. Other questions pertained to the objectives of such activities and to the nature of the collaborative process. When asked how they could describe their firm's intention regarding their patent-based partnerships, some firms intended to explore new knowledge/products and create new opportunities, while others intended to reuse existing knowledge (technology/product) to refine and extend their existing competencies and technologies. Questions also addressed the type of information/knowledge in terms of codified and non-codified knowledge, and also the possibility of exchanging non-technological knowledge like market knowledge.
- Discussing the findings from the Phase 2: In this part, I shared the findings in terms of content, process, and structure and the influence of their interactions on the knowledge creation in the case and asked cases to explain about these subjects.

4.4.3.4 Ethical issues

To respect the privacy of interviewees and their companies and to avoid any source of risk, I committed to the Monash University Human Research Ethics Committee (MUHREC) guidelines. This involved defining all the foreseeable risks and also measures to manage such risks. MUHREC ethics approval meant that the participant SMEs could be confident that the ethics requirements of the research were satisfied and that their privacy was guaranteed. Although reports of the study may be submitted for publication, individual participants and companies would not be identifiable in these reports. As part of MUHREC requirements, I prepared the explanatory statements and consent forms as contained in Appendix 7. These were designed to give the participants in-depth information about: the aim of the research and possible benefits; how their contact details were obtained; how the

privacy of their personal and organisational information was to be assured; the length of the interview; the importance of their participation; storage of data; and finally the conditions of their right to withdraw their participation at any time without any penalty (Appendix 7).

4.4.3.5 Data analysis and integration

As mentioned above, there were two types of qualitative data in this phase of the research: the various documents and the interviews. The documents were reviewed and relevant information was extracted mainly before the interviews. However, sometimes during the interview, other documents were shared with me. Prior to analysis, each recorded interview was transcribed. Here I used the theoretical framework reported in Chapter 3, to identify the *propositions* (Yin 2003) or the *issues* (stake, 1995, cited by Baxter and Jack 2008). Also the written text was exported to NVivo (version 9) for further coding and categorising and theme development.

Following Creswell‘s (2002) guidelines, the process of qualitative data analysis included: 1) preliminary exploration of the transcripts; 2) coding the data by segmenting and labelling the text; 3) using codes to develop themes by aggregating similar codes together; 4) connecting and interrelating themes; and 5) constructing a narrative. To analyse the case data, a thematic analysis was conducted at two levels: within case analysis and across case analysis (e.g. Ayres, Kavanaugh and Knafl 2003; Yin 2003). First, each SME case was analysed for the themes. Then, all the cases were analysed for themes that were either common or different. The process of “constant comparative analysis” (Boeije 2002, p.396) was followed. Although this technique originated in grounded theory (Glaser and Strauss 1967), it has become the basis for several qualitative techniques (Thorne 2000).

4.4.3.6 The limitations of the qualitative phase

Several limitations associated with this qualitative phase must be noted. Encouraging companies to participate in academic research has always presented substantial challenges.

Ethical challenges: Interviewing and collecting information about patenting and innovation from people in a highly competitive industry like biotechnology always has some challenges regarding anonymity and confidentiality issues. Also certain factors that may

impact on the interviewee ability/intention to give valid consent are more prevalent in SMEs. In my interview protocol considerations made to avoid any sensitive discussion. However validity concerns are always present, particularly with elite interviewees (like C-level managers) as a data source (Berry 2002).

Also there could be some reliability issues with the interviewees. In this research interviewees were asked about the patents that they had published from 2001–2010. Some issues may arise from failures in the interviewee's memory (Richards 1996). In similar way, there is risk associated with "selective memory", individuals remember *"what they want" and "how they want" to remember things. Or perhaps, they do not want to be "seen under a poor light" or "have an axe to grind"* (Richards 1996, cited by Telleria 2011, p. 75).

Interview sample: In this qualitative phase, despite the great deal of care that was taken in encouraging SMEs to participate, only five involving four SMEs were completed. Therefore there is a possibility that SMEs who might have provided alternative answers were left out. This problem may be due to:

- Availability: given the specific framework that I used to select SMEs, in some categories only one or two SMEs existed. In some cases they refused the request for an interview. In this research, it is found that refusing to participate was not the only form of availability problem. In one of my interviews, when I asked about the relationship with a particular partner, the interviewee said "*I have a legal problem with [that company] and I don't like to talk about them*".
- Access: two of the candidate SMEs had moved their office (after 2010) to other state or overseas. However, to not lose these informants, I interviewed them over Skype.

The summary of the three phases is illustrated in Figure 4-3. This figure is also used later on to define the position of the following chapters, where the analysis and discussion of these phases are presented.

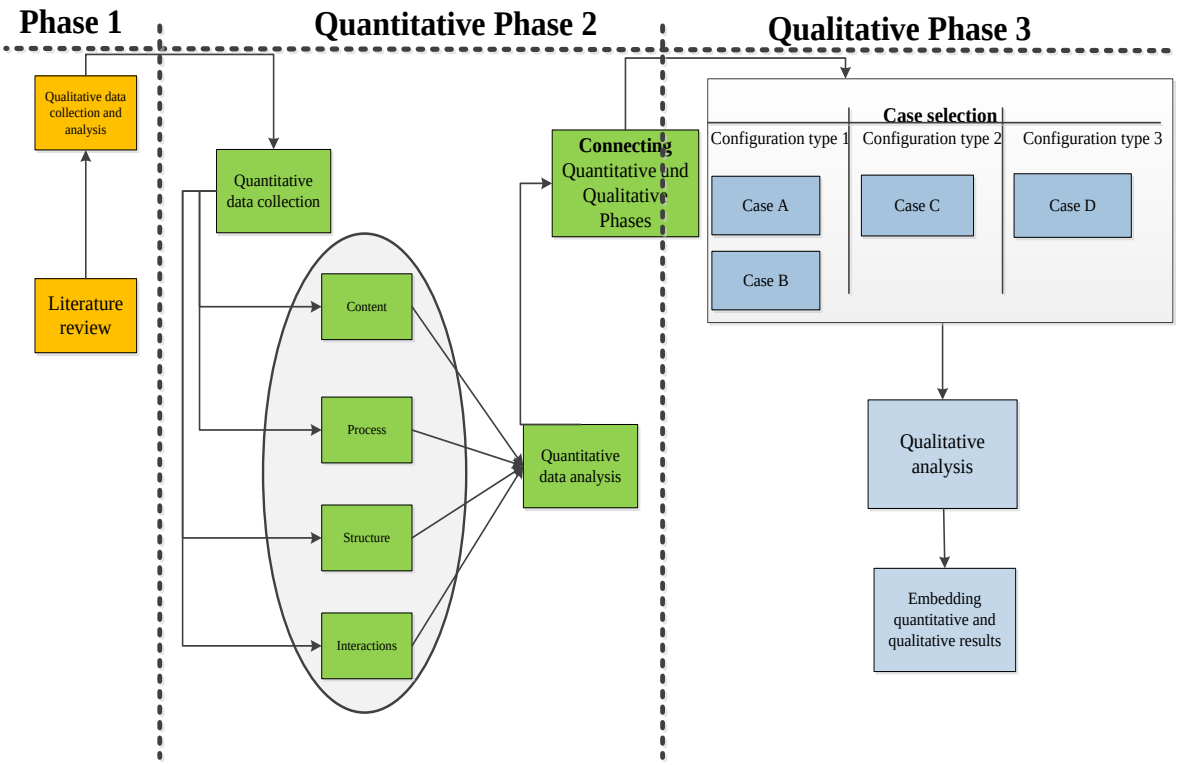


Figure 4-3 The mixed method inquiry within the three phases of the research design

4.4.4 Reliability and validation of the research design

Given the guidelines on validation of mixed method research, reviewed by Venkatesh et al. (2012) (who elaborated the work of Tashakkori and Teddlie 2008 and Teddlie and Tashakkori 2003, 2009), the quality aspects of the research can be understood by quality in design and quality in explanation. The summary of the inference quality in my research is illustrated in Table 4-6.

Table 4-6 Integrative framework for mixed methods inference quality
Note: Adapted from Venkatesh et al. (2012)

Quality aspects	Quality criteria
Design quality:	Design suitability/appropriateness
	Design adequacy
	Analytic adequacy
Explanation quality:	Quantitative inferences
	Qualitative inferences
	Integrative inference/meta-inference

4.4.4.1 Design quality:

This aspect was considered from the perspectives of design suitability, design adequacy, and analytic adequacy.

Design suitability/appropriateness

This is defined as "*the degrees to which methods selected and research design employed are appropriate for answering the research question"*(Venkatesh et al. 2012, p: 24). In this research, a sequential mixed method was followed, with the first quantitative phase informing the second qualitative one. In terms of method, in the quantitative phase, first, SNA was used as an appropriate method for studying networks including collaboration networks (e.g. Scott 2000), and second, a set of statistical analyses like factorial ANOVA (Jaccard 1998) and MMR (West and Aiken 1991; Irwin and McClelland 2001) were applied to test the hypotheses and define the interactions. Likewise, explanatory case study (Yin 2011) including interviews with managers of a company and analysis of the documents and records of the company to confirm and expand on the quantitative findings is a widely used and appropriate method.

Design adequacy:

Quantitative: *"The degree to which the design components for the quantitative part (e.g. sampling, measures, data collection procedures) are implemented with acceptable quality and rigor. Indicators of inference quality include reliability and internal validity"* (Venkatesh et al. 2012, p. 24). In my research, reliability needs to be examined in relation to: sampling, factorial ANOVA and MMR.

Sampling: In the quantitative phase of the research, there was no sampling since I studied the whole biotechnology industry of Victoria, which was the cohort of the research. The question is whether these 126 companies covered all the biotechnology companies who have published at least one patent during 2001–2010. As described in Section 4.4.2, by using the list of three main sources of Victorian biotechnology, I believe the list of 126 companies shows quite an accurate picture of the whole Victorian industry. This method emerged, and was discussed and approved by two people from the field: a professor and a practitioner in this industry, during the first two interviews which were conducted in Phase 1.

Factorial analysis of variance: The main factor influencing the validity of this technique is summarised in three concepts of Keselman and Lix (2012): *independence*, *normal distributed*, and *homogeneity of variances*. In regard to the first criterion, there was no reason for considering dependency among these 126 actors. To address the Gaussian or normal distribution of data, as the second criterion, there is a wide variety of tests that can be performed, though Kolmogorov-Smirnov and Shapiro-Wilk are the most common tests used (Razali and Wah 2011). Regarding the homogeneity of variances, this concept is often tested by Levene's Test by using one-way-ANOVA on the absolute value (or sometimes the square) of the residuals (e.g. Čudanov, Jaško and Jevtić 2009); since the data for main constructs are distributed far from a normal shape, to check the equality of variances I used a non-parametric Levene's Test (Nordstokke et al. 2011) by calculating the difference of diversity ranks from the mean of the corresponding group (e.g. size).

Spearman correlation coefficient analysis: The common way to test the correlation is Pearson's r, however there are some assumptions and limitations in this method. In my research the most challenging assumption of Pearson's r refers to normal distribution of

variables and also linearity of the relations. From the results on content, process and structure, discussed in Chapters 6–8, the non-normal distribution of these constructs became clear. Moreover, there is no reason to assume linearity of the possible relation among these constructs. The scatter plots, and details of of these associations are also discussed Chapters 6–8.

Moderated multiple regression (MMR):

Qualitative: *The degree to which the qualitative design components are implemented with acceptable quality and rigor. Indicators of inference quality include credibility and dependability* (Teddlie and Tashakkori 2009, cited by Venkatesh et al. 2012, p. 24). In this research, all possible configurations were defined based on the results of the quantitative phase (Chapter 9, Section 9.5). Then in the qualitative phase, among all 18 possible groups discussed above (Setion 4.3.2), I planned to study the group of pharmaceutical-biotechnology SMEs with all possible configurations to cover all types of SMEs in this network. So the qualitative phase of this research focused on four pharmaceutical-biotechnology SMEs and their partners who were willing to participate in the research.

Analytic adequacy:

This is discussed in both quantitative and qualitative phases:

Quantitative: *The degree to which the quantitative data analysis procedures/strategies are appropriate and adequate to provide plausible answers to the research questions. An indicator of inference quality is statistical conclusion validity* (Shadish et al. 2002, cited byVenkatesh et al. 2012, p. 24). The quantitative phase of this research firstly provided answers to all research questions, and secondly, offered the basis to understand the whole picture of the Victorian biotechnology industry. Without this phase, it would not have been possible to define the possible network configurations of the actors, which was used in Phase 3 to provide a more comprehensive view of the k-network, particularly in the context of SMEs.

Qualitative: *The degree to which qualitative data analysis procedures/strategies are appropriate and adequate to provide plausible answers to the research questions.*

Indicators of quality include theoretical validity and plausibility (Venkatesh et al. 2012, p: 24). Through the qualitative phase, I was able to get more in-depth insights from the pharmaceutical-biotechnology SMEs in the Victorian biotechnology industry. The results of this phase were mainly used to confirm and elaborate what had been learnt in the quantitative study of the whole network. In other words, through the quantitative phase I defined all possible configurations of the network, which also highlighted various attitudes towards the content and process of their k-networks. In this phase, by studying SME cases and their partners in each type of configuration, I was able to provide more comprehensive answers for the research questions.

4.4.4.2 Explanation quality

This is defined as *"The degree to which credible interpretations have been made on the basis of obtained results"* (Lincoln and Guba 2000; Tashakori and Teddlie 2003, cited by Venkatesh et al. 2012, p. 24). The details of explanation quality are discussed for both quantitative and qualitative phases:

Quantitative inferences: *"The degree to which interpretations from the quantitative analysis closely follow the relevant findings, consistent with theory and the state of knowledge in the field, and are generalizable. Indicators of quality include internal validity, statistical conclusion validity, and external validity."* (Venkatesh et al. 2012, p. 24). Given the details literature review, the constructs of the research were chosen as reported in Chapter 2 (Section 2.3). The measured for testing the hypotheses were also all have been used in the prior research as reported in Chapter 5 (Section 5.2). Validity of the statistical conclusion is supported by several tests as listed in Table 4-4. Confidence interval (or in similar way *p-value)*, is the key concept here to make plausible inferences. In the k-network literature, p-value of 0.05 has used widely (Rodan and Galunic 2004; Gilsing, Nooteboom, Vanhaverbeke, Duysters and Van Den Oord 2008). Given the fact that my sample sizes were different in different groups of actor size and actor type, and also the standard deviation of the different group were different and some of the large standard deviations refer to small sample sizes, for this analysis I considered 0.01 significance level to be more

conservative in order to protect my analysis form the type I error (i.e. accepting a result which is not statistically significant).

For instance, regarding the factorial ANOVA, I checked the major validity concerns of this test including: independence, normal distribution, homogeneity of variances (Keselman and Lix 2012). In regard to the first criterion, there is no reason for considering dependency among these 126 actors. To address the Gaussian or normal distribution of data, as the second criterion, there is a wide variety of tests that can be performed, though Kolmogorov-Smirnov and Shapiro-Wilk as the most common tests used (Razali and Wah 2011). The details of using factorial ANOVA for examining content, process and structure is explained in Appendices 3–5. In a similar way, for multivariate regression analysis and negative binomial regression in SPSS 20, I addressed the main concerns that have been discussed in the literature. First, heteroscedasticity was tested by the macro written for SPSS (Marta 2002) and second, risk of common-method bias (CMB) was examined by using harman's single-factor technique (Podsakoff et al. 2003).

Qualitative inferences: *"The degree to which interpretations from the qualitative analysis closely follow the relevant findings, consistent with theory and the state of knowledge in the field, and are transferable. Indicators of quality include credibility, confirmability, and transferability"* (Venkatesh et al. 2012, p. 24).

After transcribing the recorded interviews was finished, I asked the interviewees to check them to make sure my understanding was consistent with their views. Also an independent colleague was asked to validate the emergent coding although the theoretical framework was mainly used to define the coding scheme.

Integrative inference/meta-inference: This is considered with three concepts of integrative efficacy, inference transferability and integrative correspondence:

Integrative efficacy: *"The degree to which inferences made in each strand of a mixed methods research inquiry are effectively integrated into a theoretically consistent meta-inference"* (Venkatesh et al. 2012, p. 24). As mentioned in the interview protocol section (4.4.3), I discussed the findings from the quantitative Phase 2 with interviewees in terms of content, process, and structure and the influence of their interactions on their innovation projects. According to Boeije (2002, p.396) "constant comparative analysis" was used to analyse the data from the interviews and qualitative findings. Given that the purpose of the qualitative phase was to confirm the findings, I believe that the inference quality of meta-inferences is substantially high.

Inference transferability: *"The degree to which meta-inferences from mixed methods research are generalizable or transferable to other contexts or settings"* (Venkatesh et al. 2012, p : 24). The context of this research was the Victorian biotechnology industry. Although in Phase 2, the whole k-network of the industry was analysed, Phase 3 the cases were selected from among SMEs as major participants of the whole network industry, as explained above (Section 4.4.3). Hence, the generalisability of findings to other groups could be problematic. There should be caution in generalising the results to the other groups of SMEs as only four cases were involved in this study. The boundary conditions of the context and generalisability of the findings is discussed in Chapter 12 (Section 12.3).

Integrative correspondence: *"The degree to which meta-inferences from mixed methods research satisfy the initial purpose for using a mixed methods approach"* (Venkatesh et al. 2012, p : 24). Integrative correspondence is important to ensure that researchers employing a mixed method approach are able to meet their research objectives. As mentioned above (Section 4.3.3), there are two aims that were pursued in the sequential mixed method approach – confirmation and expansion. Through the case studies, I looked for more detailed explanation in the cases and looked for any unexplored aspects.

The representation of the mixed method sequential explanatory design procedures is shown in Table 4-7. Overall, the mixed method approach was effectively applied to provide a more comprehensive answer to the research question, as discussed in more detail in Chapter 11.

Table 4-7 Visual representation of the mixed method sequential explanatory design procedures

Phase	Activity	Objective	Procedure	Product
Phase 1	Qualitative data collection and analysis	Getting the local knowledge of cohort regarding the research questions	Interviews with two industry informants	Verified method and conceptual framework
Phase 2	Quantitative data collection	Understanding the whole picture of the Victorian biotechnology industry To test the hypotheses	126 actors via snowball sampling	Numeric data
	Quantitative data analysis		Data screening (univariate, multivariate) Social network analysis via UCINET 6 Factorial ANOVA Spearman correlation coefficient analysis Moderated multiple regression (MMR) Harman's single-factor Kolmogorov-Smirnov and Shapiro-Wilk Non-parametric Levene's Test Rank transformation and log transformation Tolerance or Variance Inflation Factors (VIF)	Descriptive statistics Tested hypotheses
	Connecting Quantitative and Qualitative Phases		Purposefully selecting one SME from each group (n = 4) based on typical response and maximal variation principle Developing interview questions	Four cases selected based on the results of Phase 2 Interview protocol
Phase 3	Qualitative data selection	Confirmation and expansion of results obtained in Phase 2 Deeper understanding of the k-network in the context of selected SMEs	Individual in-depth interviews with five participants Email/phone follow-up interviews Patent documents Documents and websites	Text data (interview transcripts, documents)
	Qualitative analysis		Coding and thematic analysis Within-case and cross-case theme development Cross-thematic analysis NVivo 9	Visual model of multiple case analysis Codes and themes Similar and different themes and categories Cross-thematic matrix
	Integration of quantitative and qualitative results		Interpretation and explanation of the quantitative and qualitative results	Discussion Implications Future research

4.5 Summary

This chapter has reported the main elements of the research design. On the basis of pragmatic view point, it is discussed why a sequential mixed method approach was needed to answer the research questions and how this mixed method research was matched with pragmatism as a worldview of this research. Moreover the details of the research design including three phases of the research are explained in terms of data collection, data analysis and the validation of analysis not only in each phase but in the integration analysis as well.

Chapter 5
Whole Knowledge Network of the Victorian Biotechnology Industry

Outline of Chapter 5

This chapter reports two areas: First, it introduces all the constructs of my research regarding the patent co-authorship network of the Victorian biotechnology industry. It discusses how the main constructs that were introduced in Chapter 3, are examined in the Victorian biotechnology industry. It explains that how the three constructs of content, process, and structure of k-networks are measured in order to test the hypotheses formulated in Chapter 3. The validity of each measure is also discussed.

Second, by providing an overview to the industry co-authorship network as the whole k-network of the industry, and comparing it with the potential network, this chapter provides further insights into the k-network. Overall, this chapter provides the 'big picture' for the actors' k-networks that are reported in the following chapters (i.e. Chapter 6, 7, 8, and 9). All these chapters together (i.e. Chapters 5–9) report the findings of the quantitative Phase 2, as illustrated in Figure 5-1.

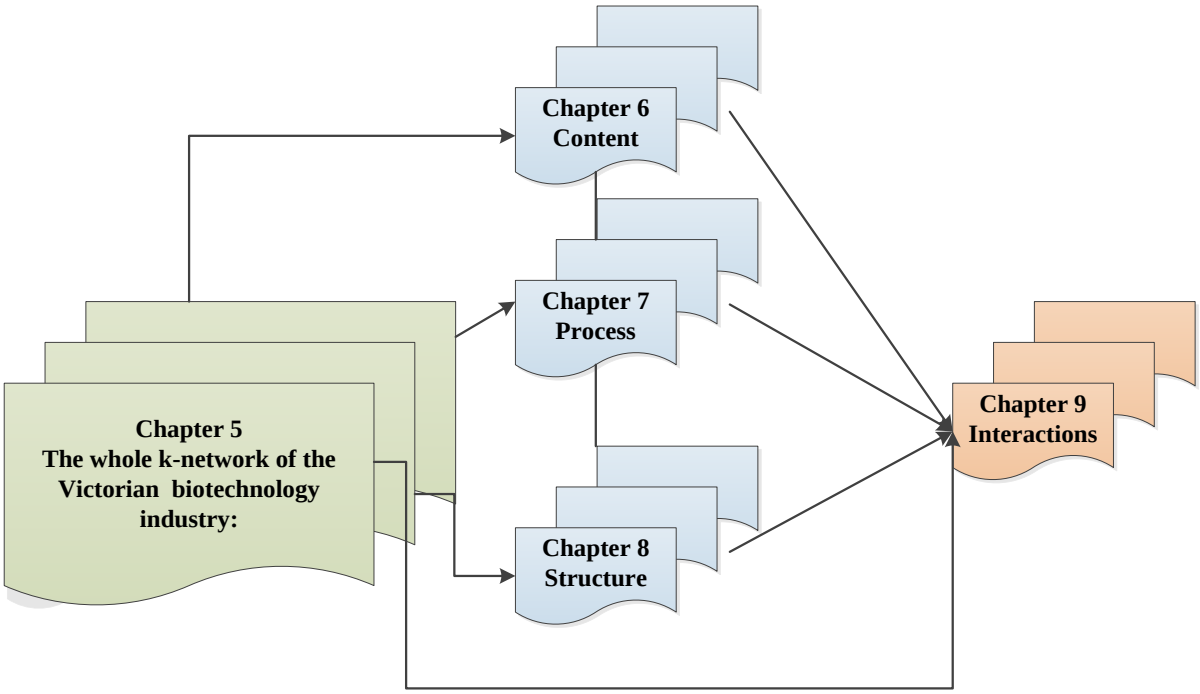


Figure 5-1 Structure of the four chapters that present the findings of the quantitative phase 2

5.1 Introduction to the k-network of the Victorian biotechnology industry

As described in the conceptual model (Chapter 3), the constructs of content, process, structure and knowledge creation of the k-network are the focus of this research. This chapter introduces the constructs and the measures used to study them. This chapter also analyses the characteristics of the whole k-network as the industry k-network. Indeed, this industry k-network included small k-networks of Victorian actors or ego-networks of Victorian biotechnology actors.

5.1.1 Victorian biotechnology patent co-authorship network

In the Victorian biotechnology patent co-authorship network, links are defined by co-authorship patenting. If two companies have registered a patent with each other, it means that they had innovation-driven collaboration.

Based on the snowball sampling method introduced in Section 3.1.2 and in more detail in Section 4.4.2, this research identified the participants in the whole k-network of the industry. In this regard, 126 actors were identified in Victoria, as the focal actors studied in this research. There were also 61 actors that were identified as the partners of the focal Victorian actors. Among these, 34 were headquartered in other states of Australia, while 27 were located in other countries. The patent-based collaboration of these actors is illustrated in Figure 5-2. All the green boxes are Victorian actors, while the red boxes illustrate Australian non-Victorian actors and the blue boxes represent non-Australian actors.

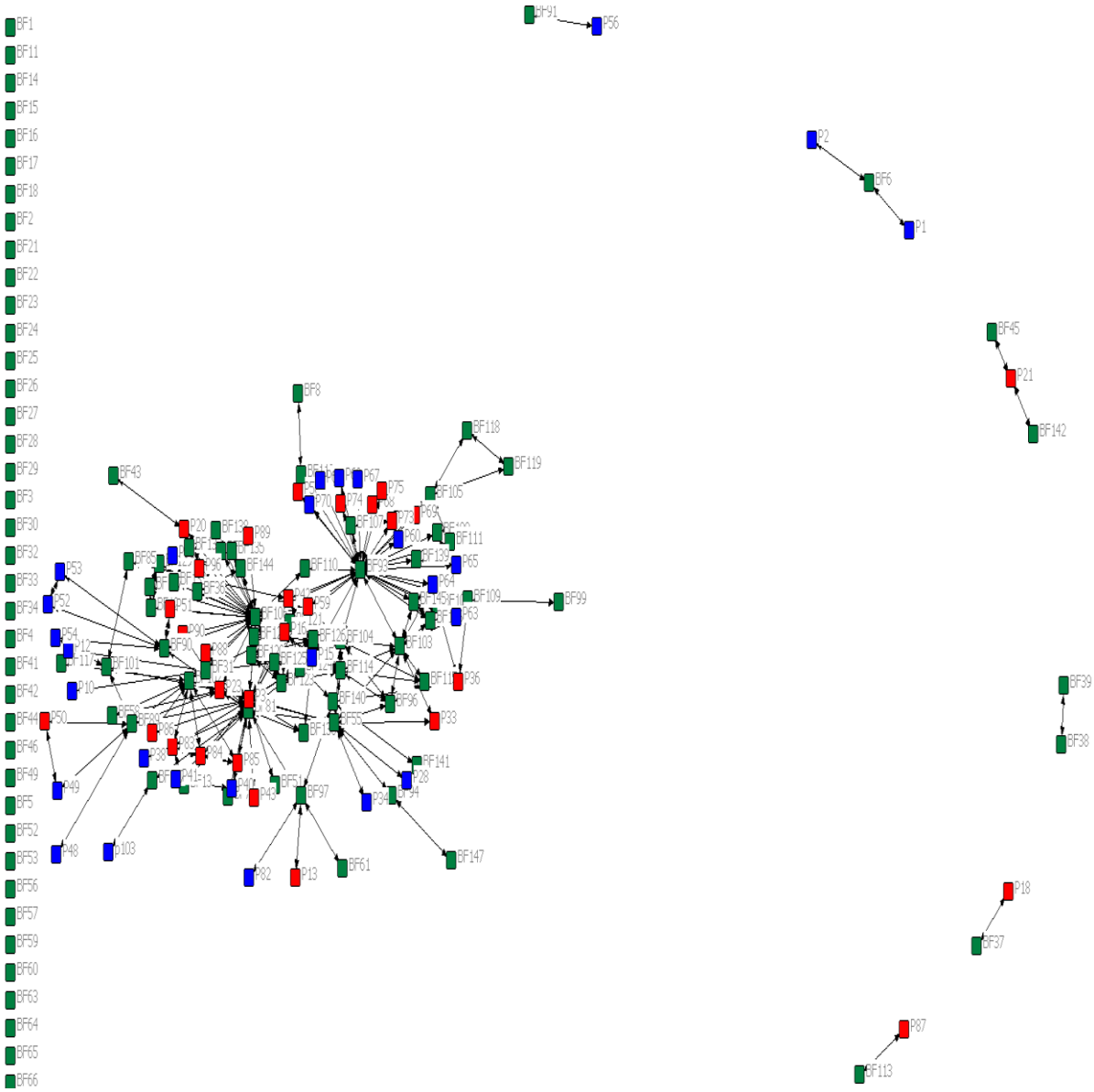


Figure 5-2 The whole k-network of the Victorian biotechnology industry

Note: Green boxes: Victorian actors; Red boxes: Australian non-Victorian actors; Blue boxes: non-Australian actors.

5.1.1 Demographic characteristics

There is no available information about the demographics of the Victorian biotechnology industry, therefore I had to collect all these data from available information on the web, including websites of these actors, AusBiotech[12], Bio Melbourne portal[13], and the

[12] http://www.ausbiotech.org
[13] http://www.biomelbourne.org

Australian Stock Exchange (ASX). In some cases, I contacted the company via phone to make sure about the size of the company. AusBiotech and Bio Melbourne are biotechnology industry organisations, which represent over 3,000 members, covering the human health, agricultural, medical device, bioinformatics, environmental and industrial sectors in biotechnology.

These 126 companies can be categorised into public research organisations (PRO) like universities and governmental agencies (PRO – 22), pharmaceutical-biotechnology firms (PBF – 80), hospitals (H – 6), and individual innovators (Individual – 18). Regarding the size, there are 30 large actors, 78 small and medium enterprises (SME), and 18 individual innovators. As shown in Chapter 2 (Section 2.4), SMEs in the biotechnology industry of Australia, can be defined as companies or organisation with less than 200 employees. The demographic characteristics are summarised in Table 5-1.

Table 5-1 Demographic characteristics of Victorian biotechnology actors

Size \ Types	PROs	Pharmaceutical-biotechnology firms	Hospitals	Individual	Total	Percent
Large	12	12	6	-	30	23%
SME	10	68	-	-	78	63%
Individual	-	-	-	18	18	14%
Total	22	80	6	18	126	100

5.2 Constructs: content, process and structure of k-networks

In this section I explain how each construct is measured, and then the characteristics of each of constructs in the Victorian biotechnology industry are discussed.

5.2.1 Content: knowledge diversity of firms

Diversity of knowledge is an essential element of knowledge content (e.g. Rodan and Galunic 2004). According to the discussion in Chapter 2 (section 2.3.1), this is an important aspect of content that has been mentioned in the literature as a contingent factor to explain the role of k-networks in knowledge creation. In general, firms might need different areas of managerial, technological and organisational knowledge (Sammarra and Biggiero 2008), however the singular focus of this research is technological knowledge. To calculate the degree of knowledge diversity of a firm's technological knowledge, the international patent

classification (IPC) has been considered as a representative indicator. IPC shows the technological knowledge area which is relevant to the patents that firms have published. To calculate the degree of diversity, the Simpson's diversity index was used. This method is an economic concept which widely applied in competition law, and also technology management to define the diversity (Jost 2006). This method has been used in a variety of other fields including KM research (Demirkan, Deeds and Demirkan 2012). Access to numerous area of knowledge in terms of IPCs, would result in higher rate of diversity for companies while having only one area of knowledge means zero diversity. This index is represented with D:

$$D = 1 - \sum_{i=1}^{N} p_i^2$$

Where:

p = proportion of particular knowledge areas (IPCs) in the ego-network[14] of firm i.

N = total number of IPCs which are shared by firm i.

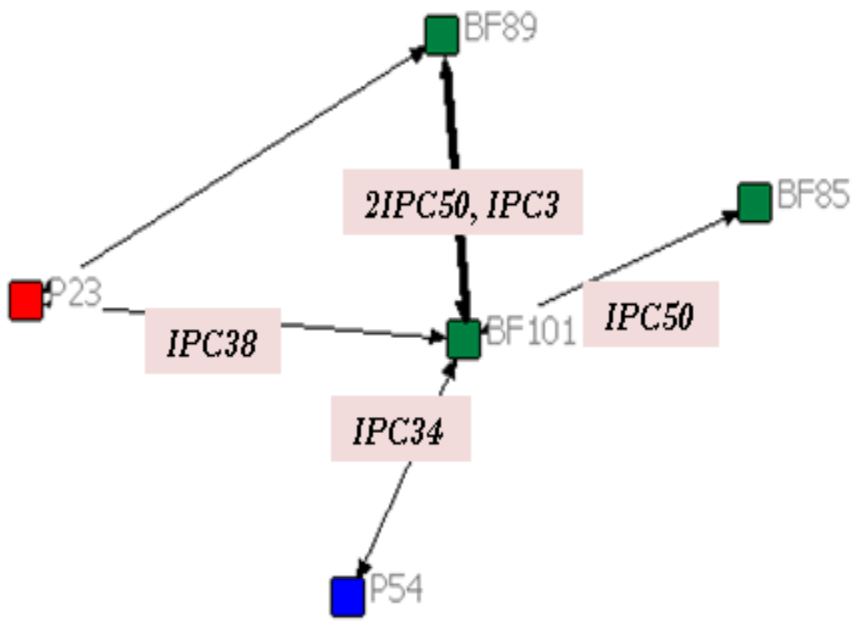


Figure 5-3 Knowledge diversity as measured for actor BF101

[14] Ego-network is the immediate network of the actor as defined in Chapter 2 (Section 2.2.2)

For instance, in Figure 5-3, the knowledge diversity is measured for actor BF101. This firm has four partners (coded with BF89, BF85, P54 and P23). The IPC or technological knowledge area and the frequency of the published patents in each partnership are represented in both Figure 5-3 and Table 5-2.

Table 5-2 Calculation of the diversity index for actor BF101

Patent Ties	Main IPC	IPC Code	Pi^2	diversity index
BF101-P54	C07D471/04	IPC34	(1/6)^2	1-[(1/6)^2+ (3/6)^2+(1/6)^2+(1/6)^2] = 1-12/36=0.67
BF101-BF85	C12N15/12	IPC50	(3/6)^2	
BF101-BF89	C12N15/09	IPC50		
BF101-BF89	C12N15/09	IPC50		
BF101-BF89- P23	A01H5/00	IPC3	(1/6)^2	
BF101-P23	C07H21/04	IPC38	(1/6)^2	

5.2.2 Process: firms' exploration/exploitation process

To understand how firms process their knowledge in terms of exploration and exploitation (March and Levinthal 1993), partner diversity has been used in the literature (as discussed in Chapter 2, Section 2.3.2). Lavie and Rosenkopf (2006) identified three domains of exploration and exploitation, these being function, attribute and structure. Structural exploration has focused on diversity of the partners, i.e. whether a firm was forming an alliance with a new partner that has no prior ties to the firm or keeps recurrent alliances with a partner that has prior ties to the firm. The intention of this research is to study the exploration/exploitation process itself. This allowed me to represent the actors' intention to process their knowledge and the tendency to find new partners to fill knowledge gaps. This approach did not intend to capture the exploration/exploitation nature of the whole network, but the ego-network of each actor, as the unit of analysis is the actor in the inter-organisational network (as discussed in Chapter 2, Section 2.3.2). The other dimension of the exploration/exploitation process is the attribute of the partner. Lavie and Rosenkopf (2006) refer to the attribute domain by which organisational characteristics of partners

differ from those of the other partners of the firm. Here the exploration may come from differences in organisational attributes like size and industry focus.

In this research there is no complete data to discuss the function domains. However, the structural domain can be studied as a representative element of the exploration/exploitation process (Li et al. 2008). To calculate the exploration/exploitation index of firms, again the Simpson's diversity index was used.

$$D = 1 - \sum_{i=1}^{N} p_i^2$$

Where:

p = proportion of particular partner in the ego-network of firm i

N = total number of all partners which were collaborating by firm i.

For instance, Figure 5-4 shows how structural exploration is measured for Actor BF101. This firm has six partnerships with four partners, including three partnerships with BF89, and one partnership with each of BF85, P54 and P23. The summary of the calculation is shown in Table 5-3.

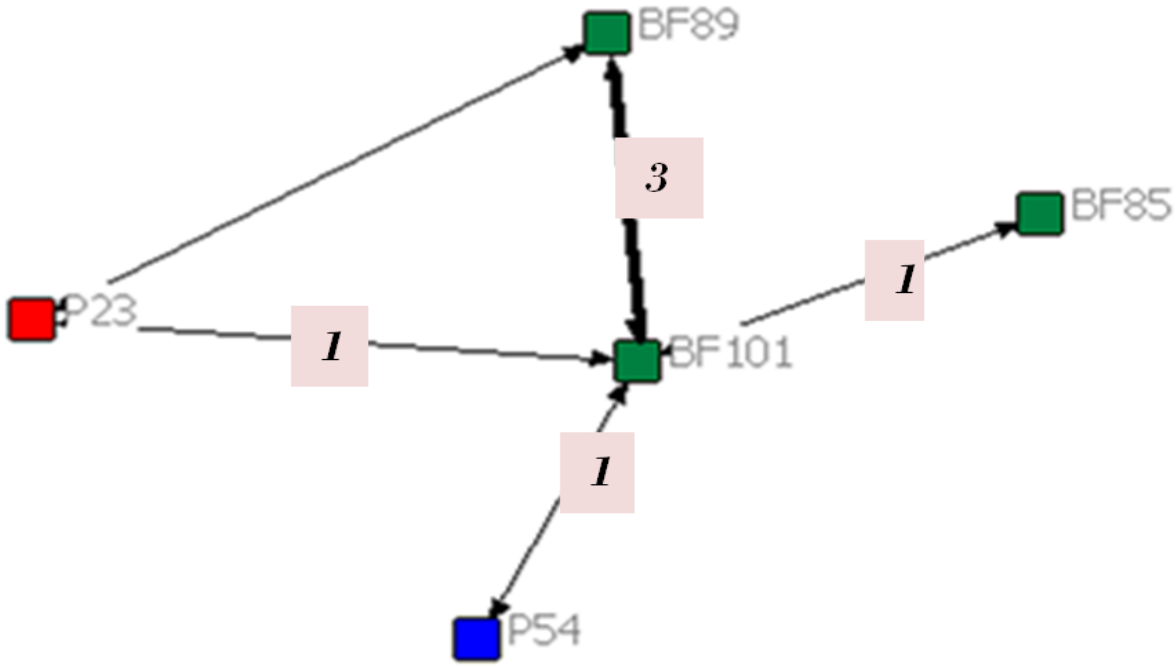


Figure 5-4 Structural exploration as measured for Actor BF101

Note: Numbers show the frequency of collaboration between partners

Table 5-3 Calculation of the exploration/exploitation index for actor BF101

Partnership of BF101	Year	Pi^2	Structural exploration/exploitation index
BF101-P54	2008	(1/6)^2	1-[(1/6)^2+ (3/6)^2+(1/6)^2+(1/6)^2] = 1-12/36=0.67
BF101-BF89	2008	(3/6)^2	
	2005		
	2001		
BF101- P23	2005	(1/6)^2	
BF101-BF85	2001	(1/6)^2	

5.2.3 Structure: firms' network centrality and density

Centrality of firms is a structural property that has been presented in the literature as an influencing factor on knowledge transfer through inter-organisational relationships e.g. (Ahuja 2000). There are several measures (methods) to calculate centrality like degree, eigenvector, closeness, and betweenness centrality. The degree of a firm in a given network is calculated by total number of ties shared by the focal firm with other members of the network. For example the degree of firm number 94 (BF94 in Figure 5-5) with three ties is three. In this research, all these measures were calculated by UCINET6, one of the SNA software packages.

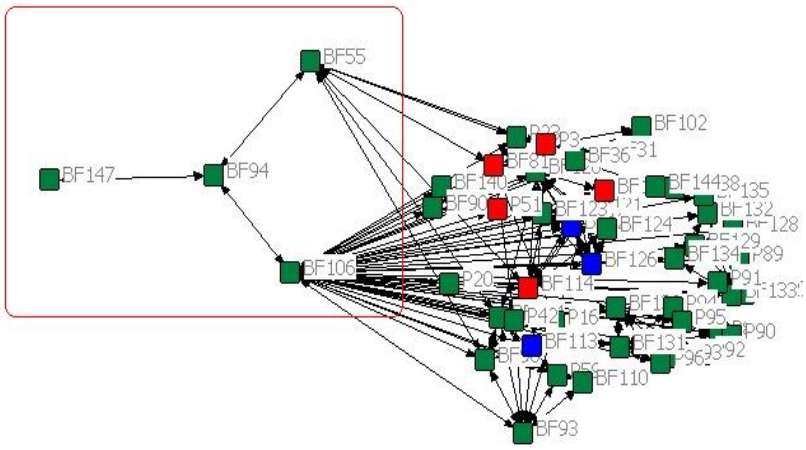


Figure 5-5 Ego-network of BF94

Density (ego-network density of a firm) as mentioned earlier, has been argued in the literature (Cross and Cummings 2004) as an influencing factor on knowledge transfer through inter-organisational relationships. In my research, ego-network density was calculated by two methods. First, ego-network analysis in UCINET6 (Borgatti et al. 2002) was used to calculate the density for each node. The highest density is one and the lowest is zero. The density measure for firms without any triangle relations like BF94 (Figure 5-5) is zero. In this method, density is measured by number of existing triangles divided by all possible triangles. For instance as shown in Figure 5-6, BF109 with its four partners has two triangles; however it is possible to have six triangles. In this regard, the density of BF109 is 2/6=0.33. Hence, the density of BF109 is 0.33, or in the ego-network of this actor, 33% of the relationships are closed.

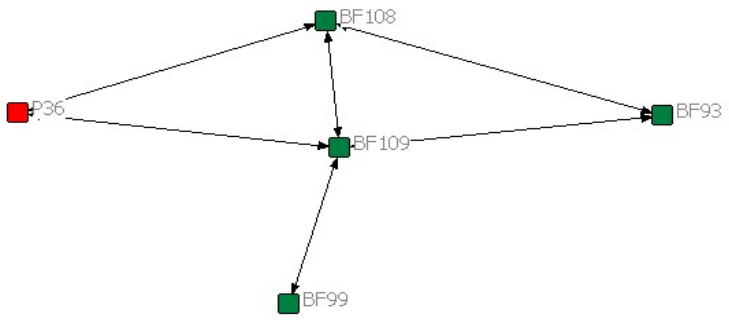


Figure 5-6 Ego-network of Actor BF109

While this method is quite common in similar ego-network analysis (e.g. Kane and Alavi 2008), there is one big assumption behind it. This method assumes that all the values or frequencies of the partnerships do not affect the density of the ego-network. For instance, Actor BF109 in Figure 5-6, had two partnerships with BF108, and three partnerships with BF99. To take into account these multiple partnerships there is a need for another method, which was recently proposed by Opsahl and Panzarasa (2009).

To calculate ego-network density in a valued network or clustering in weighted networks as named by Opsahl and Panzarasa (2009), there are four existing techniques: arithmetic mean, geometric mean, maximum and minimum, as illustrated in Figure 5-7.

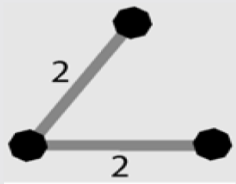
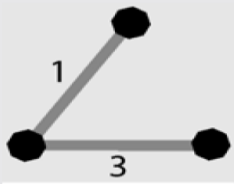
Method		
Arithmetic mean	$(2+2)/2 = 2$	$(1+3)/2 = 2$
Geometric mean	$\sqrt{2 \times 2} = 2$	$\sqrt{1 \times 3} = 1.73$
Maximum	$\max(2, 2) = 2$	$\max(1, 3) = 3$
Minimum	$\min(2, 2) = 2$	$\min(1, 3) = 1$

Figure 5-7 Four techniques for calculating value density network

Source: Opsahl and Panzarasa (2009)

In my research, these measures were calculated by using the following code in R, the open-source statistical programme which allows researchers to create stand-alone programmes. Since SNA software like UCINET and Pajek do not have any packages to calculate density in a valued network, I used tnet in R[15] (Opsahl and Panzarasa 2009). I calculated the ego-density using all four methods. Based on the nature of the network, I chose geometric mean for the rest of the calculation; since it is more sensitive to the number of partnerships as discussed by Opsahl and Panzarasa (2009). However the Maximum and Minimum and Arithmetic mean methods provide different figures for the ego-density of each actor, the final analysis of these figures in terms of correlation with other constructs is the same as those of geometric mean.

5.2.4 Knowledge creation

Firms need to create knowledge and be innovative to survive, particularly in the high-tech industry. Patenting, as discussed in Chapter 2 (section 2.1.3), is commonly pursued in biotechnology firms (Gardet and Fraiha 2012) to protect new knowledge in both large enterprises and small and medium enterprises (Levy and Powell 2005) as well.

As shown in the demographic section of this chapter, 77% of all 126 actors are individual inventors and SMEs.

[15] http://toreopsahl.com/tnet/software/

The number of patents a firm has published is considered a meaningful measure for knowledge creation (Ahuja 2000), particularly in the biotechnology industry (Wadhwa and Kotha 2006). In industries like biotechnology, using patents to protect knowledge is an effective and widely used approach (Arundel and Kabla 1998). Prior research also shows that the number of patents is closely related to new products, innovation and invention counts and sales and growth (Ahuja 2000). However, there are some limitations with counting patents for knowledge creation:

1. Industry type influences product patent propensity (Arundel and Kabla 1998). In this research, all the actors were chosen from a single industry to avoid this issue.
2. The full range of each firm's knowledge creation will not be captured based on the firm's patents. Some created knowledge may not be patentable but still have economic value (Arundel and Kabla 1998). Patents have been shown to be an important innovation mechanism in the biotechnology industry. In this research, which sought to understand the role of k-networks on the published patents, the same measure is used for all actors.
3. The concept of quality of knowledge creation is not captured by counting the number of patents. This research does not address the quality of the patents and focuses on how certain characteristics of k-network can contribute to knowledge creation in terms of patents.

In this regard, the number of patents was calculated for all 126 actors who have published at least one patent within 2001–2010. The lowest number is 1 and the highest is 72 for the University of Melbourne. The mean and standard variance is 7.07 and 10.89. The descriptive statistics show that the majority (90%) of actors have 15 or fewer patents within the ten year period.

5.3 Characteristics of the whole industry network: actual vs. potential k-network

As discussed in Chapter 2 (section 2.2.2), the whole network consists of all the ego-networks of all participants. Before the details of the content, process, and structure are discussed, it is important to see the 'big picture' and identify the whole network. Based on

the analysis of the data from patent documents, it is possible to describe several characteristics of the patent co-authorship network of the Victorian biotechnology industry. Also it is interesting to see the potential k-network vs. the actual one. As shown in Figure 5-2, the actual k-network of the Victorian biotechnology industry is a very sparse network. One possible reason could be due to the fragmented areas of technologies that these companies work on. To understand this, it is necessary to know how the potential k-network could look. Hence the characteristics of the both actual and potential k-network of the industry are discussed here.

5.3.1 Actual k- network of the Victorian biotechnology industry

The summary of the overall density, and some facts about the patent co-authorship network of the Victorian biotechnology industry, are shown in Table 5.4. To gain more insight into the network, following similar research in the literature (Cantner and Graf 2006) the whole period is split into two periods of 2001-2005, and 2006-2010.

Table 5-4 Overall density of the whole k-network within two five year periods

	Period 1: 2001–2005	**Period 2: 2006–2010**	**Entire period**
Density	0.0261	0.0143	0.0240
Average degree	4.1500	1.6348	4.5079
Total nodes	156	115	185
Victorian actors	114	89	126
Australian (non-Victorian) actors	24	17	34
Non-Australian actors	18	11	25

The overall density of this network for the study period is very low; however the second period shows much lower degree of density. Seventy six members were permanent in 2001-2010, while the total number of participants (i.e. nodes) was reduced by 26% in the second period (i.e. 2006-2010), and the overall density has dropped by 37%. It means, the level of patent collaboration has dropped in this network. This also is shown by average degree of collaborations within the two different periods. The average number of partners in patent-driven collaborations has declined from 4.5 to 2 partners. Moreover, the trend of number of firms who published at least one patent was declining and correspondingly the number of their non-Australian and non-Victorian partners was decreasing.

5.3.2 Potential k- network of the Victorian biotechnology industry

Studying the potential k-network, provides insights to understand the context in three ways including: appropriateness of the cohort, seminal potential of public research organisations and finally the level of intensity for collaboration in the cohort.

To draw the potential network, I assume that if two companies work in the same area of expertise, they have the potential to collaborate with each other. Based on this assumption, I could have a rough idea about the possible k-network. According to the technological areas (IPC) been recorded in each actor's patents documents, it is possible to map a technological overlap network or a potential k-network. In this network two companies will link together if they published their patents in the same field of technology. For instance if actor A and B work in a same group of technology, let say IPC number 3, I assume that these two actors have the potential for collaboration. This network helps to have a better understanding of the Victorian biotechnology industry.

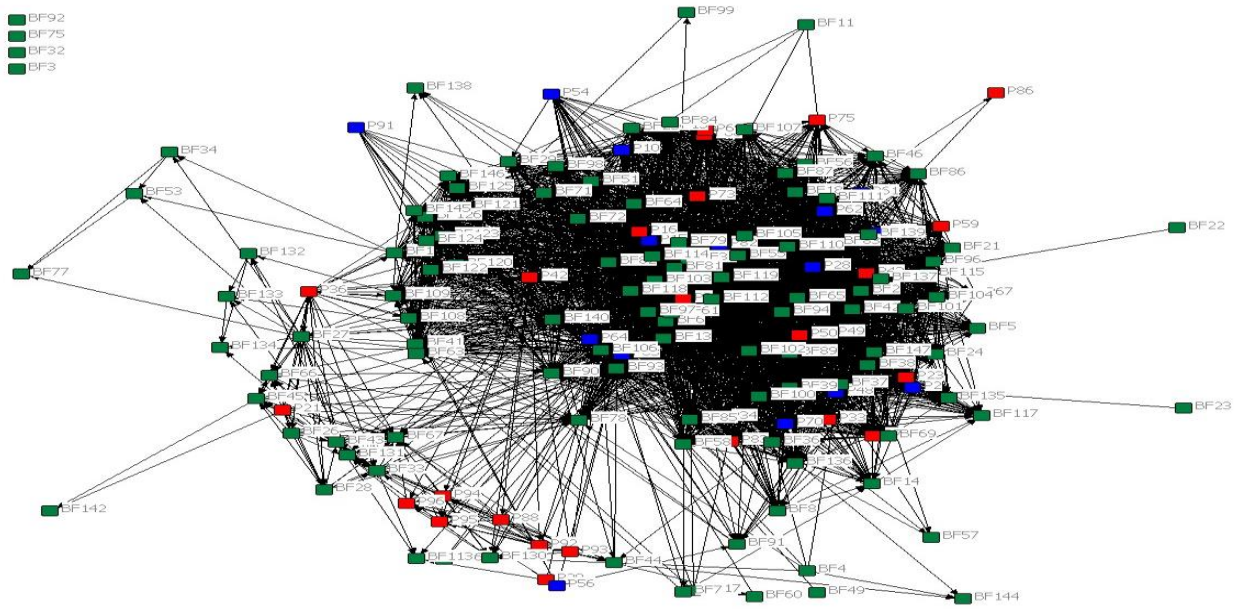


Figure 5-8 Map of the potential collaboration network for Victorian biotechnology industry
Note: Green boxes: Victorian actors; Red boxes: Australian non-Victorian actors; Blue boxes: non-Australian actors.

By drawing this network, it is possible to understand the big picture of the structure of the possible collaborative knowledge creation system in the Victorian biotechnology industry.

For example, it is interesting to see whether companies are all focusing on the few common technologies or there are several specialised groups of firms that form clusters in the periphery of the network? Moreover, it is possible to identify the organisations that play main/periphery roles within the industry. By this analysis we can see a potential k-network for the Victorian biotechnology industry.

Using IPC to represent the technological areas of expertise, all technological areas of the Victorian biotechnology industry were extracted. These include 160 areas within which all biotechnology actors in Victoria have published their patents. The results of the study show that the potential k-network could be seven times denser than the actual patent co-authorship k-network. The overall density of the actual k-network is 0.02 while the density of the potential k-network is 0.168 (Table 5-5). There are four companies that work in exclusive knowledge areas no other actors are working on. Not surprisingly, these four companies are isolated in the actual k-network as well.

Table 5-5 Overall density of the network with two five year-periods

Potential collaboration	Period 1: 2001–2005	Period 2: 2006–2010	Entire period
Density	0.1612	0.1386	0.1682
Average degree	25.6	15.8	26.5
Total nodes	156	115	185
Victorian actor (BF)	114	89	126
Australian (non-Victorian) partners	24	17	34
Non Australian partners	18	11	25

Using IPC to represent the technological areas of expertise, all technological areas of the Victorian biotechnology industry were extracted. These include 160 areas within which all biotechnology actors in Victoria have published their patents. The results of the study show that the potential k-network could be seven times denser than the actual patent co-authorship k-network. The overall density of the actual k-network is 0.02 while the density of the potential k-network is 0.168 (Table 5-5). There are four companies that work in exclusive knowledge areas no other actors are working on. Not surprisingly, these four companies are isolated in the actual k-network as well.

One could argue that in a very high-tech industries, not necessarily all the companies with different technological focus can collaborate with each other. However, this was not the

case in this study. A part from the four isolated companies, the potential network shows that the rest of the actors were working in related technological areas. Hence, considering the similar technological knowledge, these actors, has the potential to collaborate with each other. By studying the potential k-network, the seminal role of public research organisations as the main central partners for collaboration, is revealed. However, as it is shown in Figure 5-8, the whole potential k-network is very dense so in theory, these actors have the potential for collaboration and creating knowledge with each other.

5.4 Summary

This chapter explained that how the theoretical constructs of content, process, structure of k-network that were introduced in Chapters 2 and 3, were measured in order to test the hypotheses formulated in Chapter 3. The validity of each measure was also discussed. Also, by providing a 'big picture' of the whole k-network of the industry and comparing it to the potential one, this chapter offered an introduction for the detailed analysis of the actors' k-network reported in the following chapters (i.e. Chapters 6, 7, 8, and 9).

Chapter 6
Content of K-network in the Victorian Biotechnology Context

Outline of Chapter 6

Following Chapter 5 which provided an introduction to all the constructs and the whole k-network of the industry, this chapter reports the findings of Phase 2 regarding the content of the k-network. In particular, it tests the hypotheses of the conceptual model (Chapter 3) regarding the content of actors in the k-network.

In this chapter, five hypotheses are tested including: the possible effect of size and type on content (H1a, H1b and H1c), the possible association of content with other constructs of k-networks (H2, H3 and H4), and finally the possible association of content with knowledge creation (H5).

The results of this analysis show how content as a construct of the conceptual model is tested via a series of statistical data analyses. The position of the chapter within the wider research design is illustrated in Figure 6-1.

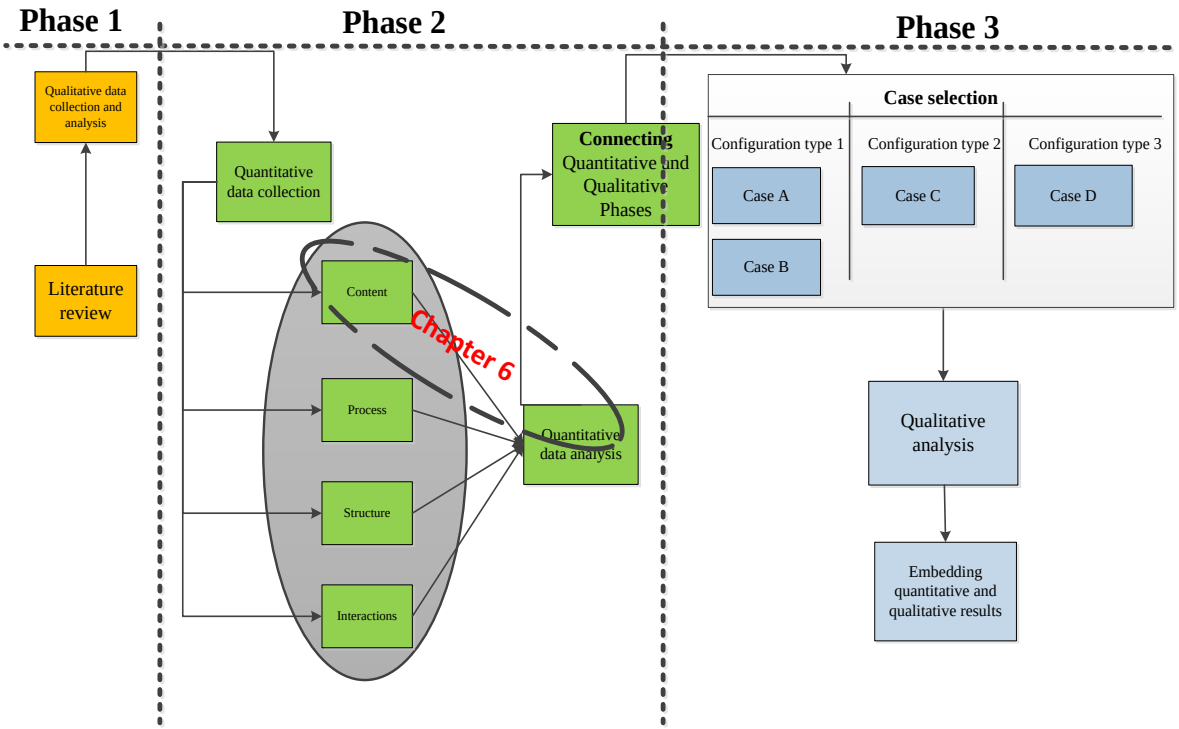


Figure 6-1 Position of Chapter 6 in the wider research design

6.1 Introduction

This chapter reports the data analysis and findings from the first quantitative phase on content of k-networks amongst actors in the Victorian biotechnology industry. Using the conceptual model in Chapter 3 (Section 3.2.2) to study the content of k-networks in terms of knowledge diversity, this study aimed to test a series of hypotheses represented in Figure 6-2. These hypotheses included the possible effect of actor size and type on content, the possible association of content with other constructs of k-networks, and finally the possible association of content with knowledge creation. The structure of the chapter is organised on the basis of each hypothesis, and the statistical techniques used to test the hypothesis. The validity of tests is discussed in Chapter 4 (Section 4.4.4), and the details are reported in Appendix 3.

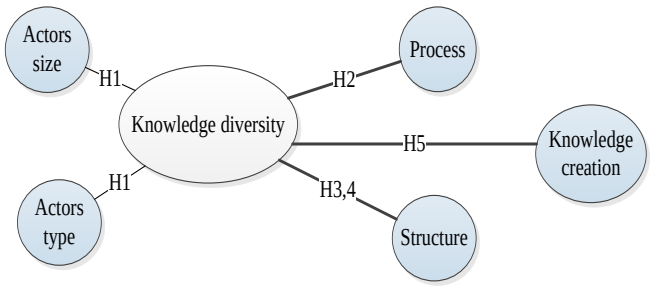


Figure 6-2 Series of hypotheses regarding knowledge diversity as the measure of content

It is worth noting here that, because the cases selected in Phase 3 (the qualitative phase after the quantitative Phase 2) were small to medium pharmaceutical-biotechnology firms (PBF-SMEs), this group has been studied in more detail in this quantitative analysis.

6.2 Effect of size and type on knowledge diversity

Do the size and type of actor influence the actor's knowledge diversity? To answer this question, factorial ANOVA was used (as explained in Chapter 4, Section 4.4.4 and Appendix 3). Factorial ANOVA is an extended form of one-way analysis of variance (ANOVA) and is used to study the differences among groups when there is more than one

independent variable (Jaccard 1998). Here a three-way ANOVA is used to check the impact of size, type, and whether the actor is isolated or participated in the whole network (here it is called collaborative behaviour) to test the first set of hypotheses (H1a, H1b and H1c).

As mentioned in Chapter 4, the concept of IPC was used to calculate knowledge diversity for all 126 actors. The lowest degree of diversity was 0 for actors with only one IPC, while the highest was .929 for the University of Melbourne. There were 33 actors with zero score for knowledge diversity, which means they only had focused on a single area of knowledge. Moreover, among these 126 actors, only 69 actors were collaborating with others. The remaining 57 actors were isolated. The histograms of the knowledge diversity for the whole industry, collaborative actors and the isolated actor are reported in Appendix 3. In terms of types of actor, as discussed in Chapter 3, there were four types identified in this industry. The description of all the control variables and number of the actors are shown in Table 6-1.

Table 6-1 Description of all the control variables and number of the actors

Control variables		Abbreviation	Number of actors
Actor type	Pharmaceutical-biotechnology firm	PBF	80
	Hospital	H	6
	Individual inventor	Individuals	18
	Public research organisation	PRO	22
Actor size	Individuals	Individuals	18
	Large size company/organisation	Large	30
	Small and medium sized company/organisation	SME	78
Collaboration	Firm had any patent partnerships from 2001–2010?	No (Isolated actors)	57
		Yes (collaborative actors)	69
Total			126

6.2.1. Role of size:

There are three groups of size including large organisationas, small and medium enterprises (SMEs), and Individuals in the industry (as discussed in Chapter 3). The results of tests of between-subjects effects show that there was no significant effect from size. Hence, it is not possible to say whether any group of large organisations, SMEs or Individuals had a significantly higher level of knowledge diversity compared to others ($F = .312$, and $\alpha = .577 > .01$). For this analysis, a 99% confidence interval was applied. The detail discussion

on why this significance level has been applied is also discussed in Chapter 4 (Section 4.4.4).

Table 6-2 Role of actor's size on content

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected model	2.432	10	.243	2.765	.004	.194
Intercept	5.131	1	5.131	58.339	.000	.337
Actor size	.027	1	.027	.312	**.577**	**.003**

This is a surprising result since, as formulated in Hypothesis 1 (H1), it was expected that SMEs would have a lower level of knowledge diversity compared to larger actors. To see the details of this analysis, the two common post hoc tests were applied, including the least significant difference test (LSD) and Scheffe's test. Using these tests I aimed to explore all possible pair-wise comparisons of means comprising a factor using the equivalent of multiple t-tests (Table 6-3). The results show that each of the two groups was significantly different. Regarding SMEs, the level of diversity is lower compared to large actors (α = .008 < .01). Likewise, large size actors had more diverse area of knowledge in comparison with Individuals (α = .00007). However knowledge diversity in SMEs was barely higher than those of individual inventors (α =.015 >.01).

Table 6-3 The post hoc tests to study the role of size on content

Multiple Comparisons

: khetro_rank_log

	(I) size	(J) size	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Scheffe	Individual	Large	-.8244*	.20323	.000	-1.3284	-.3204
		SME	-.4395	.17825	.052	-.8815	.0026
	Large	Individual	.8244*	.20323	.000	.3204	1.3284
		SME	.3850*	.14644	.035	.0218	.7481
	SME	Individual	.4395	.17825	.052	-.0026	.8815
		Large	-.3850*	.14644	.035	-.7481	-.0218
LSD	Individual	Large	-.8244*	.20323	.000	-1.2270	-.4219
		SME	-.4395*	.17825	.015	-.7926	-.0864
	Large	Individual	.8244*	.20323	.000	.4219	1.2270
		SME	.3850*	.14644	.010	.0949	.6750
	SME	Individual	.4395*	.17825	.015	.0864	.7926
		Large	-.3850*	.14644	.010	-.6750	-.0949

Based on observed means.
The error term is Mean Square(Error) = .465.

*. The mean difference is significant at the 0.05 level.

The reason that the first result of tests of between-subjects effects did not show the differences is probably because of the unequal and very different sample sizes. However the result of the post hoc test is more reliable (Keselman, Huberty, Lix, Olejnik, Cribbie, Donahue, Kowalchuk, Lowman, Petoskey and Keselman 1998).

To check for the overall importance of size for knowledge diversity, the Partial Eta Squared is reported in Table 6-2. Given this figure it is possible to see the role of size (0.003) is very weak to explain the variance in knowledge diversity.

One may arque that Individuals are not comparable to organisational actors (SMEs or large organisations) with regard to knowledge creation. To this end, I excluded all 18 Individuals and re-run the test. However the result did not change that much ($F = .298$, and $\alpha = .586 > .05$ and Partial Eta Squared = .003). It might also be possible to consider individual inventors as SMEs, in this way the result is also the same ($F = .312$, and $\alpha = .577 > .05$ and Partial Eta Squared = .003).

6.2.2. Role of type:

There are four types of group including pharmaceutical-biotechnology firm (PBF), hospital (H), public research organisation (PRO), and individual inventor (Individuals). The result of tests of between-subjects effects shows that there is no significant effect for type. Hence, it is not possible to say whether any group of H, or PRO, or Individuals has a significantly higher level of knowledge diversity ($F = .605$, and $\alpha = .548 > .05$; Partial Eta Squared = .010). The details of the test are shown in Table 6-4.

Table 6-4 Role of actor organisational type on content

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected model	2.432a	10	.243	2.765	.004	.194
Intercept	5.131	1	5.131	58.339	.000	.337
Actor's type	.106	2	.053	.605	.548	**.010**

This result could be subject to the unequal and very different sample sizes among different groups. To explore all possible pair-wise comparisons of means, again the post hoc tests of Scheffe and LSD are used as shown in Table 6-5.

The results from both tests are consistent, and show that there were some significantly differences among the four types, particularly for the individual inventors group.

Table 6-5 The post hoc tests to study the role of type on content

Multiple Comparisons

Dependent Variable: KHetero

	(I) OrgType	(J) OrgType	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	PBF	H	-.2513*	.12553	.048	-.5000	-.0027
		Individual	.1871*	.07737	.017	.0339	.3404
		PRO	-.1907*	.07140	.009	-.3321	-.0493
	H	PBF	.2513*	.12553	.048	.0027	.5000
		Individual	.4384*	.13980	.002	.1615	.7154
		PRO	.0606	.13659	.658	-.2099	.3312
	Individual	PBF	-.1871*	.07737	.017	-.3404	-.0339
		H	-.4384*	.13980	.002	-.7154	-.1615
		PRO	-.3778*	.09426	.000	-.5645	-.1911
	PRO	PBF	.1907*	.07140	.009	.0493	.3321
		H	-.0606	.13659	.658	-.3312	.2099
		Individual	.3778*	.09426	.000	.1911	.5645

Based on observed means.
The error term is Mean Square(Error) = .088.
*. The mean difference is significant at the 0.05 level.

Regarding pharmaceutical-biotechnology firms (PBF), as the main focus of this research, it is possible to conclude that the level of diversity was lower than those of public research organisations ($\alpha = .009 < 0.01$), while they were not significantly different from those of hospitals (H) or Individuals, at the 99% confidence interval. At the 95% confidence interval, PBFs had a significantly higher level of knowledge diversity compared to Individuals, but lower level than those of H and PROs.

Given the Partial Eta Squared reported in Table 6-4, it is clear that the role of type overall, is not very important (.010) in explaining the variance in knowledge diversity, however it was three times more than the effect of size. Therefore in general it is possible to argue that type of actor is more able to explain the level of knowledge diversity than size of actors.

6.2.3. Role of collaboration:

In the data set, there were 57 actors who were not participating in the k-network, while 69 had collaborated with at least one partner (i.e. had published at least one patent with other actors). The result of tests of between-subjects effects shows again that there is no

significant effect for network collaboration. Hence, it is not possible to say whether network participants have a significantly higher level of knowledge diversity than isolated actors (F = 2.213, and α = .140 > .05; Partial Eta Squared = .019) as reported in Table 6-6

Table 6-6 Role of participation in network

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected model	2.432a	10	.243	2.765	.004	.194
Intercept	5.131	1	5.131	58.339	.000	.337
Org type	.106	2	.053	.605	.548	.010
Collaborative	.195	1	.195	2.213	.140	**.019**

Similar to the analysis of size and type, this result also could be affected by the sample size of the two groups. Regarding participants in the network, as the main focus of this research, it is fair to say that the level of diversity is not significantly different with those of isolated actors, even at the significance level of .05. The point about the Partial Eta Squared (Table 6-6) is that the role of collaboration was not very important in explaining the variance in knowledge diversity. However it had a stronger effect compared to type or size to explain knowledge diversity. Therefore in general, it is possible to argue that network collaboration of actors is more able to explain their level of knowledge diversity than the type and size of actors.

6.2.4. Role of the interactions of size, type and collaboration

The result of tests of between-subjects effects shows that there is no significant effect for any of four possible interactions. Hence, it is not possible to say whether the combination of any of these control variables has any significant effect on knowledge diversity (Table 6-7)

Table 6-7 Role of the interaction of actors' size, type and participation in the network

Tests of Between-Subjects Effects

Dependent Variable: KHetero

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2.432[a]	10	.243	2.765	.004	.194
Intercept	5.131	1	5.131	58.339	.000	.337
OrgType	.106	2	.053	.605	.548	.010
Collaborative	.195	1	.195	2.213	.140	.019
size	.027	1	.027	.312	.577	.003
OrgType * Collaborative	.001	1	.001	.009	.926	.000
OrgType * size	.022	1	.022	.253	.616	.002
Collaborative * size	.101	1	.101	1.152	.285	.010
OrgType * Collaborative * size	.024	1	.024	.273	.602	.002
Error	10.115	115	.088			
Total	41.248	126				
Corrected Total	12.547	125				

a. R Squared = .194 (Adjusted R Squared = .124)

To test H1c and the explain the result, it was necessary to have a pair-wise comparison analysis. However, there is no biult-in test in SPSS. To do this test, I changed some codes of the built-in tests of between-subjects effects and run it in SPSS package. The results are portrayed in Table 6-8. There are further similar tests that compare the interactions that are reported in Appendix 3.

Table 6-8 The post hoc tests to study the role of the interaction of actor size and type

Pairwise Comparisons

Dependent Variable: KHetero

size	(I) OrgType	(J) OrgType	Mean Difference (I-J)	Std. Error	Sig.[e]	95% Confidence Interval for Difference[e]	
						Lower Bound	Upper Bound
Individual	PBF	H	.[a,b]	.	.	.	.
		Individual	.[a]	.	.	.	.
		PRO	.[a,b]	.	.	.	.
	H	PBF	.[a,b]	.	.	.	.
		Individual	.[a]	.	.	.	.
		PRO	.[a,b]	.	.	.	.
	Individual	PBF	.[b]	.	.	.	.
		H	.[b]	.	.	.	.
		PRO	.[b]	.	.	.	.
	PRO	PBF	.[a,b]	.	.	.	.
		H	.[a,b]	.	.	.	.
		Individual	.[a]	.	.	.	.
Large	PBF	H	-.235[c]	.148	.116	-.529	.059
		Individual	.[b]	.	.	.	.
		PRO	-.165	.177	.352	-.516	.185
	H	PBF	.235[d]	.148	.116	-.059	.529
		Individual	.[b,d]	.	.	.	.
		PRO	.070[d]	.197	.724	-.320	.459
	Individual	PBF	.[a]	.	.	.	.
		H	.[a,c]	.	.	.	.
		PRO	.[a]	.	.	.	.
	PRO	PBF	.165	.177	.352	-.185	.516
		H	-.070[c]	.197	.724	-.459	.320
		Individual	.[b]	.	.	.	.
SME	PBF	H	.[b]	.	.	.	.
		Individual	.[b]	.	.	.	.
		PRO	-.061	.109	.581	-.277	.156
	H	PBF	.[a]	.	.	.	.
		Individual	.[a,b]	.	.	.	.
		PRO	.[a]	.	.	.	.
	Individual	PBF	.[a]	.	.	.	.
		H	.[a,b]	.	.	.	.
		PRO	.[a]	.	.	.	.
	PRO	PBF	.061	.109	.581	-.156	.277
		H	.[b]	.	.	.	.
		Individual	.[b]	.	.	.	.

Based on estimated marginal means

a. The level combination of factors in (I) is not observed.

b. The level combination of factors in (J) is not observed.

c. An estimate of the modified population marginal mean (J).

d. An estimate of the modified population marginal mean (I).

e. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

To see the details of that analysis, it is useful to check the plots of these three factors. As illustrated in Figures 6-3, 6-4 and 6-5, it is possible to see that the level of knowledge

diversity is always higher for collaborative actors regardless of their type and their size. Moreover, according to all figures, it seems that the difference between level of knowledge diversity for isolated vs. collaborative Individuals is significantly higher than others. This means that Individualshave access to more diverse knowledge by participating in the network. For PROs, however, the collaboration in k-networks has not had a considerable effect in possessing diverse knowledge. By participation in the network, PBFs also may expect to acquire more diverse knowledge. Also there are no isolated hospitals in the network. No hospital had published a patent alone, but always looked for partners to publish a patent.

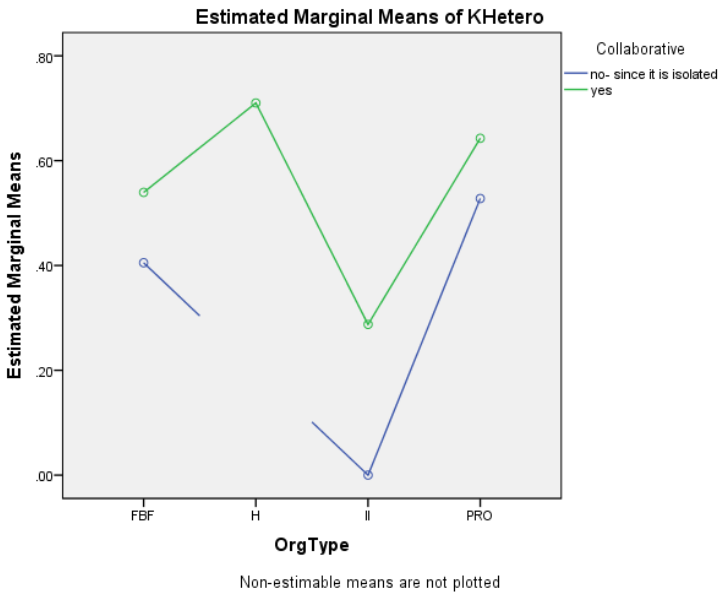


Figure 6-3 Knowledge diversity within four types of actors distinguished for isolated vs. collaborative actors

Also Individuals and large actors, compared to SMEs, had access to more diverse knowledge by participating in the k-network. SMEs, also possessed a higher level of knowledge diversity while they participate in the network, however, the extra diversity that they gained was not as much as individual inventors and large organisation actors. Moreover the large organisation-isolated actors had the same level of knowledge diversity as isolated SMEs. This seems to indicate that these isolated SMEs possessed enough knowledge so they did not need to collaborate with other actors to create new knowledge

through partnerships. This point is explored more in Chapter 10, where the purpose of partnerships is studied in four case SMEs.

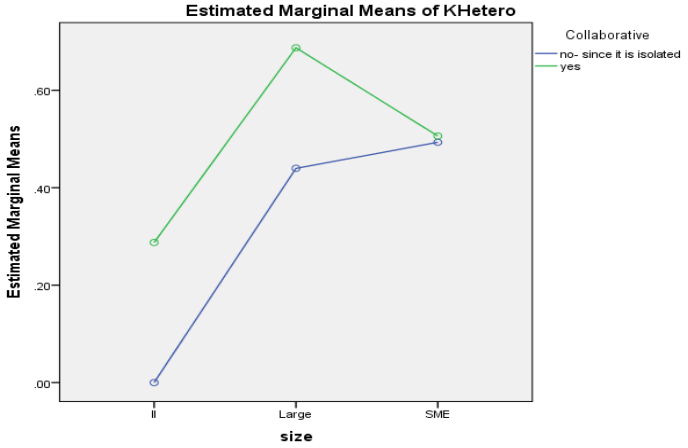


Figure 6-4 Knowledge diversity within three sizes of actors distinguished for isolated vs. collaborative actors

In the same way, although large actors generally possessed higher levels of knowledge diversity, the type of actor seems to play an influencing role. As shown in Figure 6-5, the level of knowledge in PBFs is almost the same for both large organisation and SME actors. However PROs enjoy a higher level of knowledge diversity.

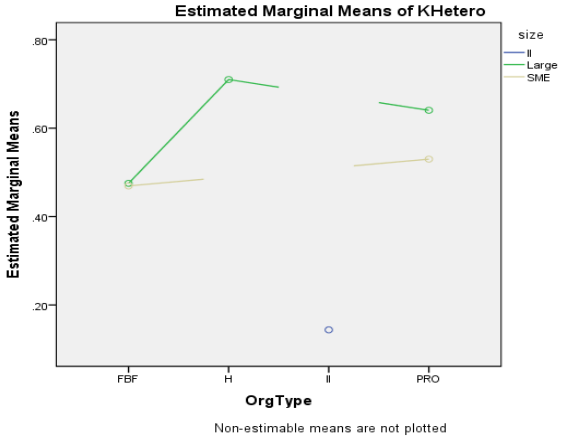


Figure 6-5 Knowledge diversity within four types of actors distinguished by size of actor

6.2.5. Summary of the findings on content in terms of size and types of actors:

Given the quantitative approach taken in Phase 2, a list of findings in relation to the role of size and type on the content of k-network is presented below:

1. *H1: In a patent co-authorship network, SMEs have a lower level of knowledge diversity compared to larger actors.*

The result showed that each of the two groups were significantly different. Regarding SMEs, the level of diversity was lower compared to large actors ($\alpha = .008 < .01$).

2. *H1b: In a patent co-authorship network, the level of knowledge diversity is not the same across actors with different types.*

Regarding PBFs, as the main focus of this research, it is possible to conclude that the level of diversity is lower than those of PROs ($\alpha = .009 < 0.01$), while it is not significantly different from those of Hospitals or Individuals, at the 99% confidence interval. However, at the 95% confidence interval, PBFs had a significantly higher level of knowledge diversity compared to Individuals, but lower level than those of Hospitals and PROs.

3. *H1c: In a patent co-authorship network, pharmaceutical-biotechnology SMEs have a lower level of knowledge diversity compared to large pharmaceutical-biotechnology actors.*

This hypothesis is rejected, given the analysis reported above. To the contrary, it was found that:

- For large actors, the levels of knowledge diversity among all four types of actors were almost the same. In SMEs, the level of knowledge diversity among all types of actors was the same.
- For PBFs, the levels of knowledge diversity were the same regardless of the size of PBFs. For PROs, the level of knowledge diversity was the same regardless of the size of PROs. PBFs also had the same level of knowledge diversity whether or not they had participated in network. This finding was also supported for other groups of actors (i.e. Individuals, PROs and Hospitals).
- For isolated actors, the levels of knowledge diversity among all groups were the same.

- For collaborative actors (non-isolated) the levels of knowledge diversity among all groups were not the same. Individual inventors had the lowest level of knowledge diversity; however the levels of knowledge diversity among other types were the same. The difference of knowledge diversity among large and small organisation was significant in .05 level but not significant at a 99% confidence level ($\alpha = .049 > .01$).
- SMEs had the same level of knowledge diversity whether or not they had participated in network. This finding was also supported for actors of other sizes (i.e. large organisation and Individuals).
- For collaborative PBFs, the levels of knowledge diversity were the same regardless of the size of the PBF. This was also supported for isolated PBFs.
- For collaborative PROs the levels of knowledge diversity were not significantly higher in large PROs compared to PRO-SMEs ($\alpha=.056 >.01$).
- For collaborative large actors (i.e. PBFs, Hospitals, and PROs) the levels of knowledge diversity were the same regardless of the organisational type of actor. This was also supported for isolated large actors.
- For collaborative SMEs (i.e. PBFs and PROs) the levels of knowledge diversity were the same regardless of the organisational type of SMEs. This was also supported for isolated SME actors.

6.3 Association of content with other constructs of the k-network

Hypotheses 2, 3 and 4 sought to examine possible inter-relationships between content of knowledge with other construct of the k-network (i.e. process (H2) and centrality (H3) and density (H3) of k-network structures). To test these hypotheses, correlation statistical techniques are available. As explained in Chapter 4 (Swction 4.4.4), here I used Spearman correlation coefficient analysis for two reasons: non-normal distribution of knowledge diversity as explored in the previous section (6.2), and there is no reason to assume linearity of the possible relation between knowledge diversity and other constructs (i.e. process and structure). The findings based on this test are reported here. It is worth noting that all hypotheses 2–4, were tested for 69 collaborative actors. As mentioned above (Section 6.2), among all 126 actors of the networks, only 69 actors were collaborating with others; the

other 57 actors were isolated. Hypotheses 2, 3 and 4 are not relevant to isolated actors, hence the rest of the analysis is examined for collaborative actors.

6.3.1 Content and process

The association of content and process is formulated in Hypothesis 2. In a patent co-authorship network, based on hypothesis 2, it is expected that the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is positively associated with the collaborative process (exploration). Given the data collected from the Victorian biotechnology industry, the scatter plot of these two constructs is illustrated in Figure 6-6.

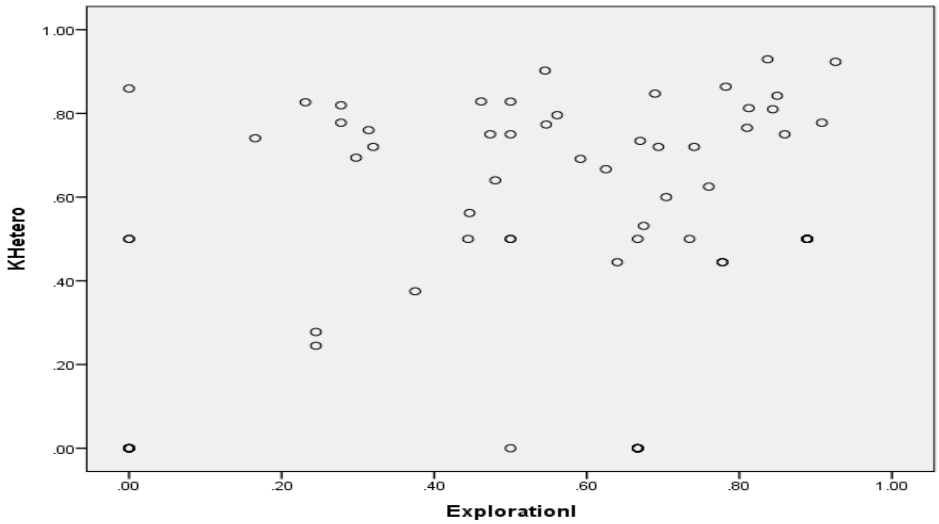


Figure 6-6 Scatter plot of content (Khetro) - collaborative process (explorationI)

Given the 69 measures from Victorian biotechnology industry, the association of knowledge diversity (mean = .5198, S.D =. 3045) with the structural exploration/exploitation process (mean = .5334, S.D = .2942) was tested. The Spearman correlation coefficient analysis revealed a weak positive correlation ($\rho = .243$, $\alpha = .044 < .05$). Actors who possessed more diverse knowledge showed a slightly greater intention to explore new partners as a sign of exploration collaborative process. This is the general finding for the whole Victorian biotechnology network. To analyse the situation for the pharmaceutical-biotechnology SMEs, the data was split according to size and organisational type.

First, it is clearly obvious that size of actor has an effect on the content-process relationship. To check the effect of size, the partial correlation shows an almost two-times higher positive correlation ($\rho = .442$, $\alpha = .000$) than the correlation of content and process in the whole network. But the result of the analysis for SMEs regardless of organisational type, was not significant ($\rho = .363$, $\alpha = .053$). This result was also the case for pharmaceutical-biotechnology SMEs ($\rho = .345$, $\alpha = .116 > .05$), as reported in Table 6-9. This means that there is no strong sign of a significant correlation between diversity of knowledge and diversity of partners in the pharmaceutical-biotechnology SMEs. This also can be seen in the scatter plot (Figure 6-7).

Table 6-9 Spearman test for content-process association with organisational size and type

Correlations

Size	OrgType				KHetero	Exploration!
Individual	Individual	Spearman's rho	KHetero	Correlation Coefficient	1.000	.774**
				Sig. (2-tailed)	.	.000
				N	17	17
			Exploration!	Correlation Coefficient	.774**	1.000
				Sig. (2-tailed)	.000	.
				N	17	17
Large	PBF	Spearman's rho	KHetero	Correlation Coefficient	1.000	.657
				Sig. (2-tailed)	.	.156
				N	6	6
			Exploration!	Correlation Coefficient	.657	1.000
				Sig. (2-tailed)	.156	.
				N	6	6
	H	Spearman's rho	KHetero	Correlation Coefficient	1.000	.714
				Sig. (2-tailed)	.	.111
				N	6	6
			Exploration!	Correlation Coefficient	.714	1.000
				Sig. (2-tailed)	.111	.
				N	6	6
	PRO	Spearman's rho	KHetero	Correlation Coefficient	1.000	.601
				Sig. (2-tailed)	.	.050
				N	11	11
			Exploration!	Correlation Coefficient	.601	1.000
				Sig. (2-tailed)	.050	.
				N	11	11
SME	PBF	Spearman's rho	KHetero	Correlation Coefficient	1.000	.345
				Sig. (2-tailed)	.	.116
				N	22	22
			Exploration!	Correlation Coefficient	.345	1.000
				Sig. (2-tailed)	.116	.
				N	22	22
	PRO	Spearman's rho	KHetero	Correlation Coefficient	1.000	.505
				Sig. (2-tailed)	.	.248
				N	7	7
			Exploration!	Correlation Coefficient	.505	1.000
				Sig. (2-tailed)	.248	.
				N	7	7

**. Correlation is significant at the 0.01 level (2-tailed).

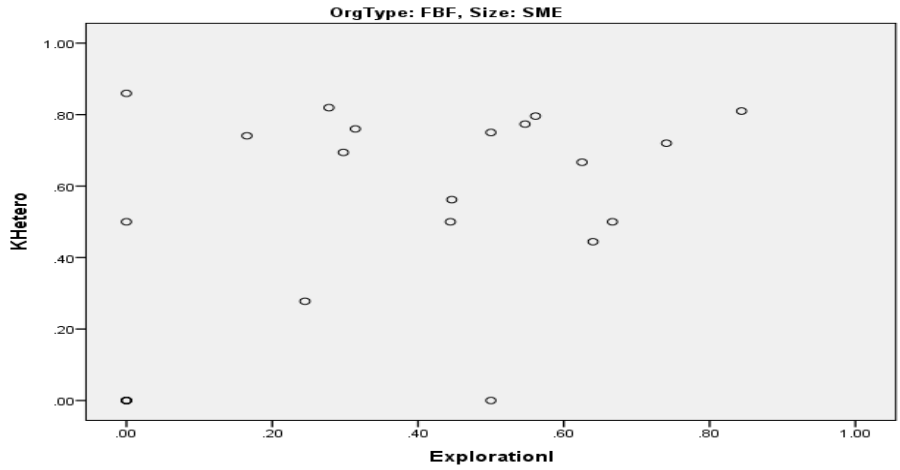


Figure 6-7 Scatter plot of content (Khetro)-process (explorationI) for pharmaceutical-biotechnology SMEs

6.3.2 Content and centrality

Hypothesis 3 (H3) concerns the association of knowledge diversity of an actor with the level of centrality (as described in Chapter 5) of the actor among the whole k-network. In a patent co-authorship network, this hypothesis predicts that the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is positively associated with central position of the actors. To test the possible positive relation among content and centrality as formulated in H3, here I used Spearman correlation coefficient analysis. The scatter plot of knowledge diversity and degree centrality seems to show a non-linear relation (Figure 6-8)

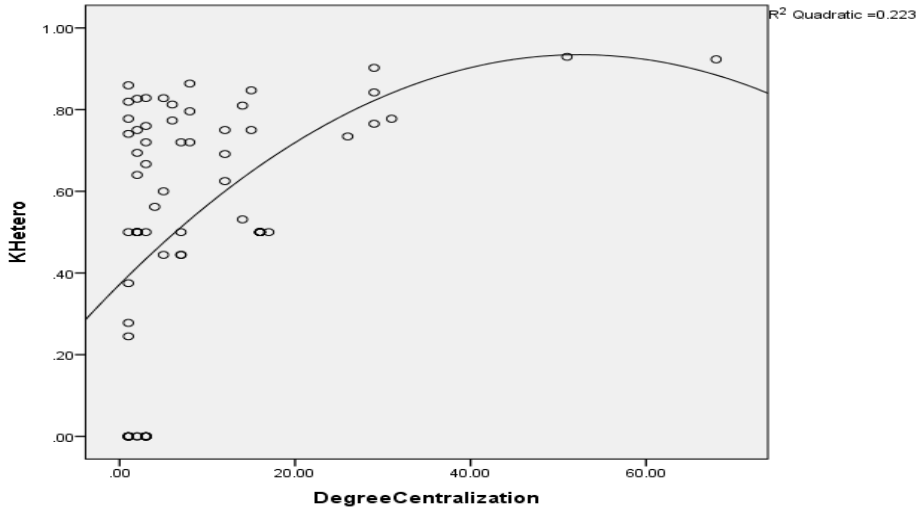


Figure 6-8 Scatter plot of content (Khetro)-centrality (Degree Centrality) of actors in the whole k-network

Given the 69 measures from the Victorian biotechnology industry, the association of knowledge diversity (mean = .5198, S.D = .3045) with the degree centrality (mean = 8.985, S.D = 11.982) was tested. A Spearman correlation coefficient analysis revealed a moderately positive correlation ($\rho = .431$, $\alpha = .000$). Actors located in a more central position tended to possess more diverse knowledge. This finding is supported by the literature as well (Ahuja 2000). The more central position may allow firms a higher chance of accessing various knowledge areas. This is the general finding for the whole Victorian biotechnology network. To analyse the situation for the 22 pharmaceutical-biotechnology SMEs, the data was split according to the size and organisational type of actors.

First, unlike the correlation between content and process, size of the actors did not strengthen the content-centrality relationship. The partial correlation to check the effect of size showed less positive correlation ($\rho = .359$, $\alpha = .003$). Moreover, the result of the analysis for the whole SME sector was significant ($\rho = .391$, $\alpha = .036$), but for pharmaceutical-biotechnology SMEs, this relation was not significant ($\rho = .383$, $\alpha = .078 > .05$) as shown in Table 6-10. Hence, for pharmaceutical-biotechnology SMEs there is not a strong sign to see a significant correlation between diversity of knowledge and network position. The scatter plot for this group, as illustrated in Figure 6-9, may represent a non-linear relation. This point is further elaborated in Chapter 9, when the interaction of all constructs is examined simultaneously.

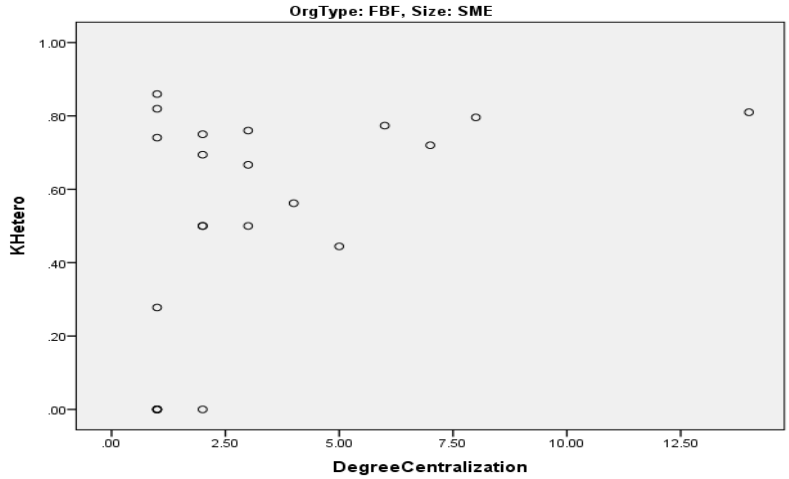


Figure 6-9 Scatter plot of content-centrality for pharmaceutical-biotechnology SMEs

Table 6-10 Spearman test for content-centrality association regarding the size and organisational type of actors

Correlations

Size	OrgType				KHetero	DegreeCentralization
Individual	Individual	arman's rho	KHetero	Correlation Coefficient	1.000	.763**
				Sig. (2-tailed)	.	.000
				N	17	17
			DegreeCentralization	Correlation Coefficient	.763**	1.000
				Sig. (2-tailed)	.000	.
				N	17	17
Large	PBF	Spearman's rho	KHetero	Correlation Coefficient	1.000	.516
				Sig. (2-tailed)	.	.295
				N	6	6
			DegreeCentralization	Correlation Coefficient	.516	1.000
				Sig. (2-tailed)	.295	.
				N	6	6
	H	Spearman's rho	KHetero	Correlation Coefficient	1.000	.899*
				Sig. (2-tailed)	.	.015
				N	6	6
			DegreeCentralization	Correlation Coefficient	.899*	1.000
				Sig. (2-tailed)	.015	.
				N	6	6
	PRO	Spearman's rho	KHetero	Correlation Coefficient	1.000	.838**
				Sig. (2-tailed)	.	.001
				N	11	11
			DegreeCentralization	Correlation Coefficient	.838**	1.000
				Sig. (2-tailed)	.001	.
				N	11	11
SME	PBF	Spearman's rho	KHetero	Correlation Coefficient	1.000	.383
				Sig. (2-tailed)	.	.078
				N	22	22
			DegreeCentralization	Correlation Coefficient	.383	1.000
				Sig. (2-tailed)	.078	.
				N	22	22
	PRO	Spearman's rho	KHetero	Correlation Coefficient	1.000	.524
				Sig. (2-tailed)	.	.227
				N	7	7
			DegreeCentralization	Correlation Coefficient	.524	1.000
				Sig. (2-tailed)	.227	.
				N	7	7

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

6.3.3 Content and density

The association of knowledge diversity with the valued density of the each actor's ego-network is of interest for Hypothesis 4 (H4). H4 predicts that in a patent co-authorship network, the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is negatively associated with ego-network density of the actors. To test this hypothesis, Spearman correlation coefficient analysis was used. The scatter plot of knowledge diversity and density seems to show a non-linear relationship (Figure 6-10)

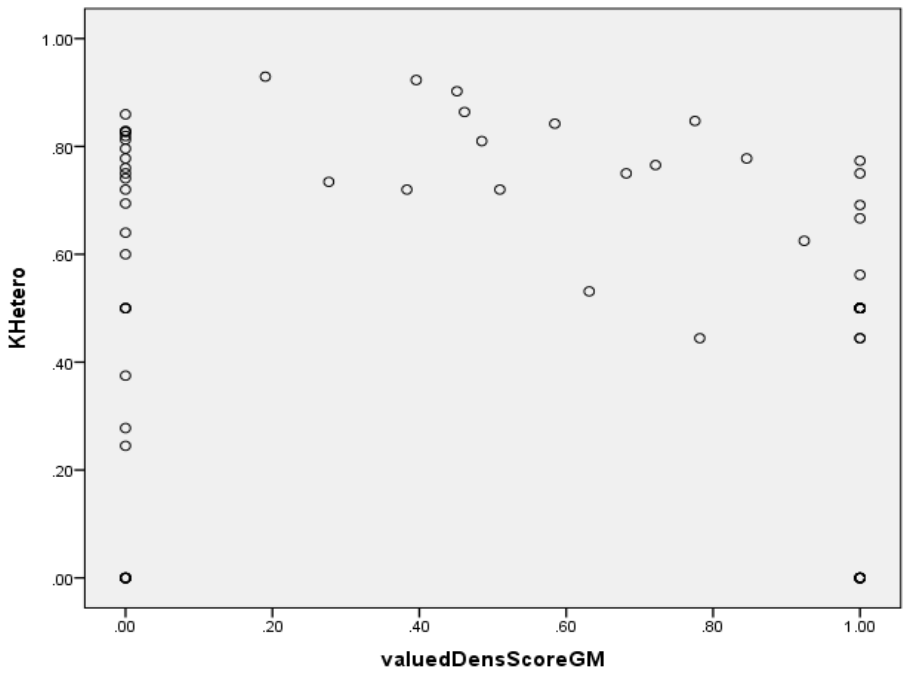


Figure 6-10 Scatter plot of content (Khetro)-density (Valued dense Score GM) of ego-network of actors

In the Victorian biotechnology industry, the association of knowledge diversity (mean=.5198, S.D=.3045) with the valued density (mean= .5078, S.D=.4534) was tested. A Spearman correlation coefficient analysis revealed weak negative correlation (ρ=-.269, α=.025). Actors who were located in a more sparse position tended to possess more diverse knowledge. This finding was in relation to the whole Victorian biotechnology network. To analyse the situation for the pharmaceutical-biotechnology SMEs, the data was split according to size and organisational type.

First like the correlation between content and centrality, size of the actors did not strengthen the content-density relationship. The partial correlation to check the effect of size was not significant (ρ =.036, α =.771). Likewise the results of the analysis were not significant for both the whole SME sector (ρ= -.160, α =.407) and for the pharmaceutical-biotechnology SMEs (ρ =-.063, α = .778 >.05) as shown in Table 6-11. Hence, in the pharmaceutical-biotechnology SMEs there is no evidence of a strong sign to see a significant correlation between diversity of knowledge and the density of actors' ego-network. This is also reflected in the scatter plot illustrated in Figure 6-11.

Table 6-11 Spearman test for content-density association between organisational size and organisational type

Correlations

Size	OrgType				KHetero	valuedDensScoreGM
Individual	Individual	Spearman's rho	KHetero	Correlation Coefficient	1.000	.281
				Sig. (2-tailed)	.	.275
				N	17	17
			valuedDensScoreGM	Correlation Coefficient	.281	1.000
				Sig. (2-tailed)	.275	.
				N	17	17
Large	PBF	Spearman's rho	KHetero	Correlation Coefficient	1.000	.395
				Sig. (2-tailed)	.	.439
				N	6	6
			valuedDensScoreGM	Correlation Coefficient	.395	1.000
				Sig. (2-tailed)	.439	.
				N	6	6
	H	Spearman's rho	KHetero	Correlation Coefficient	1.000	-.771
				Sig. (2-tailed)	.	.072
				N	6	6
			valuedDensScoreGM	Correlation Coefficient	-.771	1.000
				Sig. (2-tailed)	.072	.
				N	6	6
	PRO	Spearman's rho	KHetero	Correlation Coefficient	1.000	.468
				Sig. (2-tailed)	.	.146
				N	11	11
			valuedDensScoreGM	Correlation Coefficient	.468	1.000
				Sig. (2-tailed)	.146	.
				N	11	11
SME	PBF	Spearman's rho	KHetero	Correlation Coefficient	1.000	-.063
				Sig. (2-tailed)	.	.782
				N	22	22
			valuedDensScoreGM	Correlation Coefficient	-.063	1.000
				Sig. (2-tailed)	.782	.
				N	22	22
	PRO	Spearman's rho	KHetero	Correlation Coefficient	1.000	-.535
				Sig. (2-tailed)	.	.216
				N	7	7
			valuedDensScoreGM	Correlation Coefficient	-.535	1.000
				Sig. (2-tailed)	.216	.
				N	7	7

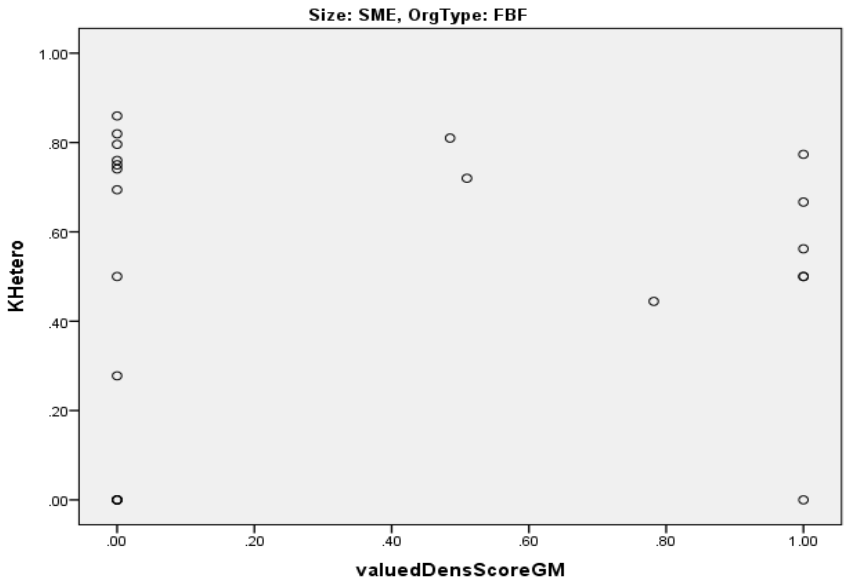


Figure 6-11 Scatter plot of content-density of ego-network of pharmaceutical-biotechnology SMEs

6.3.4 Summary of the findings on association of content with other constructs

Given the quantitative approach taken in Phase 2, a summary of findings in relation to the association of content with other constructs of k-networks is presented below. These are the results of tests for Hypotheses 2, 3 and 4:

1. *H2: In a patent co-authorship network, the level of knowledge diversity of actors is positively associated with the exploration collaborative process.*

The Spearman correlation coefficient analysis revealed a weak positive correlation ($\rho = .243$, $\alpha = .044 < .05$). Actors who possessed more diverse knowledge showed more intention for exploring new partners. However, there is no strong indication of a significant correlation between diversity of knowledge and diversity of partners in the pharmaceutical-biotechnology SMEs.

2. *H3: In a patent co-authorship network, the level of knowledge diversity of actors is positively associated with central position of the actors.*

The Spearman correlation coefficient analysis revealed a moderately positive correlation ($\rho = .431$, $\alpha = .000$). Actors located in a more central position tended to possess more diverse knowledge. However, in the pharmaceutical-biotechnology SMEs there was not a strong indication of a significant correlation between diversity of knowledge and the network position.

3. *H4: In a patent co-authorship network, the level of knowledge diversity of actors is negatively associated with ego-network density of the actors.*

A Spearman correlation coefficient analysis revealed a weak negative correlation ($\rho = -.269$, $\alpha = .025$). Actors located in a more sparse position tended to possess more diverse knowledge. However, in the pharmaceutical-biotechnology SMEs, there was not a strong indication of a significant correlation between diversity of knowledge and the density of actors' ego-network.

6.4 Association of content with knowledge creation

How is knowledge diversity of an actor associated with the actor's knowledge creation? Hypothesis 5 (H5) predicts that in a patent co-authorship network, the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is positively associated with the number of patents of the actors. To test this possible positive relation (H5) I used Spearman correlation coefficient analysis. Appendix 3 explains why this technique was selected and why the technique was rigorous and valid in this context. The findings based on this test are reported here. The scatter plot of knowledge diversity and number of patents is shown in Figure 6-12.

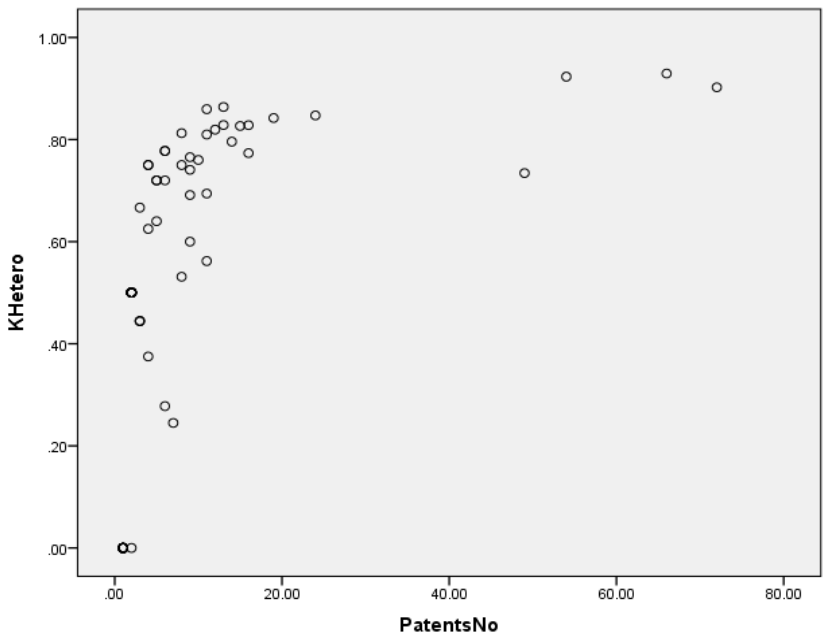


Figure 6-12 Scatter plot of content(Khetro)-knowledge creation(PatentNo)

Given the 69 measures from the Victorian biotechnology industry, the association of knowledge diversity (mean =. 5198, S.D = .3045) with knowledge creation (mean = 8.89, S.D = 13.97) was tested. A Spearman correlation coefficient analysis revealed very strong positive correlation ($\rho = .895$, $\alpha = .000$). Actors who possessed more diverse knowledge published more patents. However this finding was based on the whole Victorian biotechnology network. To analyse the situation for the pharmaceutical-biotechnology SMEs, the data was split according to organisational size and organisational type. First it is

clearly obvious that size of actors had a positive effect on the content-knowledge creation relationship. The partial correlation to check the effect of size shows that the ρ has dropped ($\rho = .382$, $\alpha = .001$). However the result of the analysis for the SME sector was still strongly significant ($\rho = .873$, $\alpha = .000$). This is also the case for pharmaceutical-biotechnology SMEs ($\rho = .864$, $\alpha = .000$), as shown in Table 6-12. There is a strong indication of a significant correlation between content and knowledge creation in the pharmaceutical-biotechnology SMEs (Figure 6-13).

Table 6-12 Spearman test for content-knowledge creation association according to actor size and type

Correlations

Size	OrgType				KHetero	PatentsNo
Individual	Individual	Spearman's rho	KHetero	Correlation Coefficient	1.000	.763**
				Sig. (2-tailed)	.	.000
				N	17	17
			PatentsNo	Correlation Coefficient	.763**	1.000
				Sig. (2-tailed)	.000	.
				N	17	17
Large	PBF	Spearman's rho	KHetero	Correlation Coefficient	1.000	.714
				Sig. (2-tailed)	.	.111
				N	6	6
			PatentsNo	Correlation Coefficient	.714	1.000
				Sig. (2-tailed)	.111	.
				N	6	6
	H	Spearman's rho	KHetero	Correlation Coefficient	1.000	.928**
				Sig. (2-tailed)	.	.008
				N	6	6
			PatentsNo	Correlation Coefficient	.928**	1.000
				Sig. (2-tailed)	.008	.
				N	6	6
	PRO	Spearman's rho	KHetero	Correlation Coefficient	1.000	.961**
				Sig. (2-tailed)	.	.000
				N	11	11
			PatentsNo	Correlation Coefficient	.961**	1.000
				Sig. (2-tailed)	.000	.
				N	11	11
SME	PBF	Spearman's rho	KHetero	Correlation Coefficient	1.000	.864**
				Sig. (2-tailed)	.	.000
				N	22	22
			PatentsNo	Correlation Coefficient	.864**	1.000
				Sig. (2-tailed)	.000	.
				N	22	22
	PRO	Spearman's rho	KHetero	Correlation Coefficient	1.000	.964**
				Sig. (2-tailed)	.	.000
				N	7	7
			PatentsNo	Correlation Coefficient	.964**	1.000
				Sig. (2-tailed)	.000	.
				N	7	7

**. Correlation is significant at the 0.01 level (2-tailed).

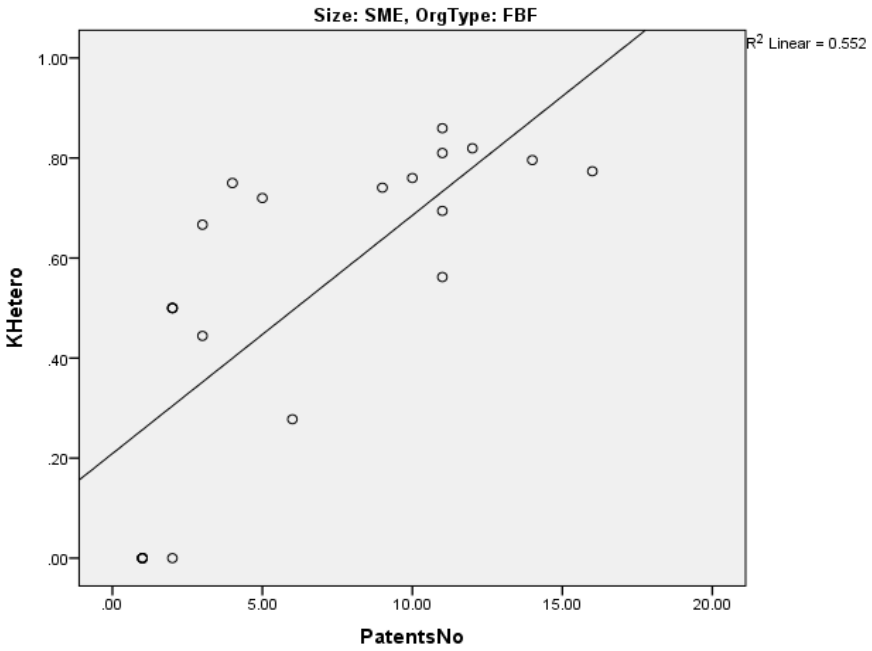


Figure 6-13 Scatter plot of content-knowledge creation for pharmaceutical-biotechnology SMEs

6.5 Summary

In this section, the content of the Victorian biotechnology industry network in terms of knowledge diversity of its actors, is analysed. Given the five hypotheses formulated in Chapter 3, this chapter reported the results of testing these hypotheses: first, the role of actor size and type; second, the association of content with other characteristics of k-networks; and third the association of content of actors with their knowledge creation. The summarised findings are reported in Table 6-13.

Table 6-13 Summary of the hypotheses on content of k-network

Hypothesis	Result	Description
H1a: In a patent co-authorship network, SMEs have a lower level of knowledge diversity compared to larger actors.	Not rejected	In the Victorian patent co-authorship network of the biotechnology industry, knowledge diversity was affected neither by the size nor by the type. The level of diversity was lower in SMEs compared to large actors. Pharmaceutical-biotechnology SMEs had the same level of knowledge diversity compared to large pharmaceutical-biotechnology actors, however for collaborative PROs the levels of knowledge diversity were higher for large actors compared to SMEs.
H1b: In a patent co-authorship network, the level of knowledge diversity is not the same across actors of different types.	Not rejected	
H1c: In a patent co-authorship network, pharmaceutical-biotechnology SMEs have a lower level of knowledge diversity compared to large pharmaceutical-biotechnology actors.	Rejected	
H2: In a patent co-authorship network, the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is positively associated with the exploration collaborative process.	Not rejected	Diversity of knowledge (content) had a weak positive correlation with diversity of partners (process). However this was not supported for SMEs including pharmaceutical-biotechnology SMEs.
H3: In a patent co-authorship network, the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is positively associated with central position of the actors.	Not rejected	Diversity of knowledge (content) had a weak positive correlation with the central position of actors. However this was not supported for all SMEs or Pharmaceutical-biotechnology SMEs.
H4: In a patent co-authorship network, the level of knowledge heterogeneity of actors including pharmaceutical-biotechnology SMEs is negatively associated with ego-network density of the actors.	Not rejected	Diversity of knowledge (content) had a weak negative correlation with valued density of actors' ego-network. However this was not supported for SMEs, including pharmaceutical-biotechnology SMEs.
H5: In a patent co-authorship network, the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is positively associated with the number of patents of the actors.	Not rejected	Diversity of knowledge (content) of actors had a strong positive correlation with knowledge creation of the actors. This was supported strongly for SMEs, including pharmaceutical-biotechnology SMEs.

Chapter 7

Process of K-network in the Victorian Biotechnology Context

Outline of Chapter 7

Similar to Chapter 6, this chapter reports the findings of Phase 2 but focues on process of the k-network. In particular, it tests the hypotheses of the conceptual model (Chapter 3) regarding process of actors in their k-networks.

In this chapter four hypotheses are tested including: the possible effects of organisational size and actor type on process (H6a, H6b and H6c), the possible association of process with other constructs of k-networks (H7 and H8), and finally the possible association of process with knowledge creation (H9).

The results of this analysis show how k-network process as a construct of the conceptual model is tested via a series of statistical data analysis. The position of the chapter within the entire research design is illustrated in Figure 7-1.

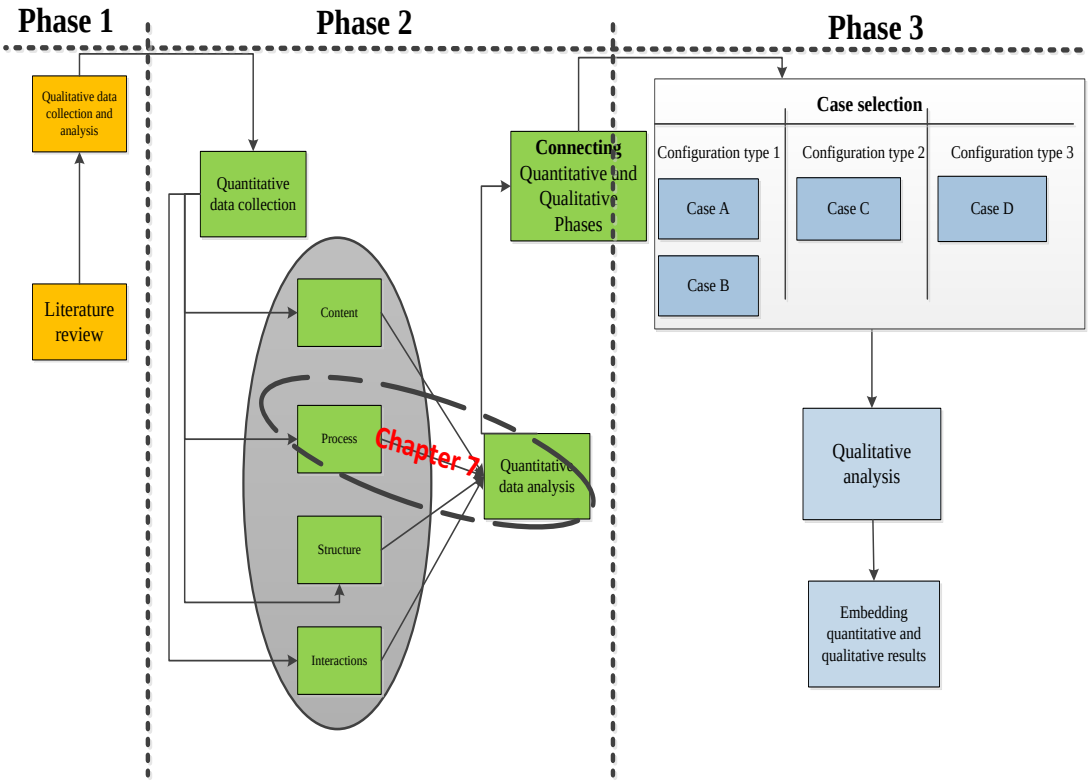


Figure 7-1 Position of Chapter 7 in the wider research design

7.1 Introduction

This chapter reports the findings from the quantitative Phase 2 on structural exploration/exploitation collaborative process of actors within k-networks. Based on the conceptual model in Chapter 3 (Section 3.2.2), the process of k-networks was studied by using the measure of partner diversity. Following this method, in a continuum of exploitation/exploration collaborative process, higher partner diversity was considered as an indication of higher focus on exploration. However, repeating collaboration with existing partners was interpreted as an indication of exploitation process. Using these concepts, my research aimed to test a series of hypotheses represented in Figure 7.2. These hypotheses include the possible effect of size and type on process, the possible association of process with other constructs of k-networks, and finally the possible association of process with knowledge creation. The structure of the chapter is organised on the basis of each hypothesis, and the statistical techniques used to test the hypothesis. The validity of tests is discussed in Chapter 4 (4.4.4), and the details are reported in Appendix 4.

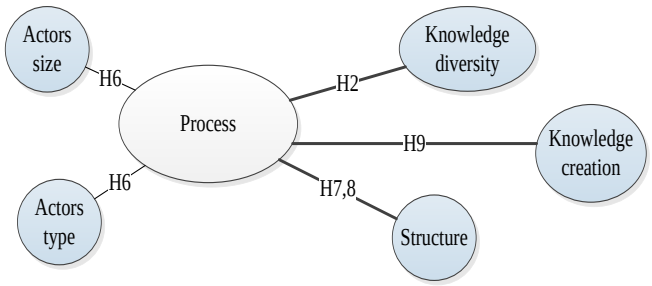


Figure7-2 Series of hypotheses regarding process of k-networks

It is worth noting that because the cases selected in the Phase 3 (the qualitative phase after the quantitative phase 2) were small-medium pharmaceutical-biotechnology firms (PBF-SMEs), in this quantitative analysis, this group has been studied at greater depth.

7.2 Effect of size and type on process

Does the size and type of actor influence the actor's partner diversity? To answer this question, as mentioned in Chapter 6 (Section 6.2.1), factorial ANOVA was used to test the set of hypotheses on size and type (H6a, H6b and H6c). The summary of findings are discussed first for the role of actor size, role of actor type, and then for the interaction of both size and type together. This analysis is similar to that used to test the hypotheses reported in Chapter 6. However unlike content, the concept of exploration/exploitation collaborative process of k-network is only defined for the collaborative actors, because isolated actors who have never collaborated with other actors, have no collaborative process of knowledge creation.

By using the concept of exploration/exploitation, collaborative processes of actors in the k-network was calculated for all 126 firms. The measure here is called exploration/exploitation index. The higher values of an actor's exploration/exploitation index represent a higher intention of that actor to engage in the exploration collaborative process. On the other hand, lower values for exploration/exploitation index indicate exploitation process. The lowest degree of exploration/exploitation index was zero for actors who kept their partner(s) for all the patents that they had published between 2001 and 2010. The highest was 0.926 for the University of Melbourne. The histogram and normal Q-Q plot for exploration/exploitation index was illustrated in Appendix 4. In Table 7-1, the descriptions of all the control variables and number of actors are shown.

Table 7-1 Description of all the control variables and number of actors

Control variables		Abbreviation	Number of actors
Actor type	Pharmaceutical-biotechnology firm	PBF	28
	Hospital	H	6
	Individual inventor	Individual	17
	Public research organisation	PRO	18
Actor size	Individuals	Individual	17
	Large size company/organisation	Large	23
	Small and medium sized company/ organisation	SME	29
Total			69

7.2.1. Role of size:

There are three size groups including large organisations, small and medium enterprises (SME), and individuals. The result of tests of between-subjects effects shows that there is a significant effect from size (F = 5.082, and α = .028 < .05) at the 95% confidence interval. However, given the more conservative approach that was taken as explained in Appendix 4, it is safer to explore a more detailed analysis. Generally this means that it is barely possible to say whether any group of large, SMEs or individual inventors has a significantly higher level of exploration/exploitation index (Table 7-2).

Table 7-2 Role of actor size on process

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected model	2.214	5	.443	7.596	.000	.376
Intercept	17.937	1	17.937	307.645	.000	.830
Actor's type	.404	2	.202	3.464	.037	.099
Size	.296	1	.296	5.082	.028	.075

In the analysis, the post hoc tests of least significant difference test (LSD) and Scheffe were applied. These tests involve all possible pair-wise comparisons of means comprising a factor, using the equivalent of multiple t-tests (Table 7-3). Regarding SMEs, it was possible to confirm that the level of exploration/exploitation index was lower in SMEs in comparison with individual inventors (α = .000 < 0.01) and also with large actors (α = .000 < 0.01). However large size actors had the same level of exploration/exploitation index as individuals, so the difference of the means of large organisations and individuals was not significant (α = .221).

Table 7-3 The post hoc tests to study the role of size on process

Pairwise Comparisons

Dependent Variable: exploration/exploitation Index

(I) size	(J) size	Mean Difference (I-J)	Std. Error	Sig.[d]	95% Confidence Interval for Difference[d]	
					Lower Bound	Upper Bound
Individuals	Large	.097[a,b]	.079	.221	-.060	.254
	SME	.376[a,b,*]	.079	.000	.219	.533
Large	Individuals	-.097[a,b]	.079	.221	-.254	.060
	SME	.279[a,b,*]	.074	.000	.131	.427
SME	Individuals	-.376[a,b,*]	.079	.000	-.533	-.219
	Large	-.279[a,b,*]	.074	.000	-.427	-.131

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. An estimate of the modified population marginal mean (I).

b. An estimate of the modified population marginal mean (J).

d. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

The reason that the first result of tests of between-subjects effects does not show a significant difference is probably because of the unequal and very different sample sizes. However the result of the post hoc test is more reliable (Keselman et al. 1998).

To check for the overall importance of size for process, the Partial Eta Squared was reported in Table 7-2. Given this figure, it is possible to see that the role of actor size (0.075) is not very important to explain the variance in the exploration/exploitation collaborative process of actors.

One may argue that individual inventors are not comparable to organisational actors (SME or large), so I excluded all 18 individuals and re-run the test. However, the result did not change that much ($F = 4.830$, and $\alpha = .033 < .05$ and Partial Eta Squared=.093). Also it maybe possible to consider individual inventors as SMEs, in this way the result was also remain the same ($F=5.082$, and $\alpha=.028 < .05$ and Partial Eta Squared=.075).

7.2.2. Role of Type:

There are four types of actors including pharmaceutical-biotechnology firm (PBF), hospital (H), public research organisation (PRO), and individual inventors. The result of tests of between-subjects effects shows that there is some effect from type ($F = 3.464$, and $\alpha = .037 < .05$) at the 95% confidence interval. However, given the conservative approach that I have taken, it is not safe enough to say there is a significant effect from the organisational type (Table 7-4)

Table 7-4 Role of actor's type on process

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected model	2.214	5	.443	7.596	.000	.376
Intercept	17.937	1	17.937	307.645	.000	.830
Org type	.404	2	.202	3.464	.037	.099

To explore all possible pair-wise comparisons of means here the Scheffe and LSD post hoc tests were used. The results from both were consistent and show that there are several significant differences among the four types particularly for the pharmaceutical-biotechnology firm (PBF) group (Table 7-5).

Table 7-5 The post hoc tests to study the role of type on process

Multiple Comparisons

Dependent Variable: exploration/exploitation index

	(I) OrgType	(J) OrgType	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	PBF	H	-.4482*	.10863	.000	-.6653	-.2312
		Individuals	-.3501*	.07424	.000	-.4985	-.2018
		PRO	-.1383	.07295	.063	-.2841	.0075
	H	PBF	.4482*	.10863	.000	.2312	.6653
		Individuals	.0981	.11466	.395	-.1310	.3272
		PRO	.3100*	.11383	.008	.0825	.5374
	Individuals	PBF	.3501*	.07424	.000	.2018	.4985
		H	-.0981	.11466	.395	-.3272	.1310
		PRO	.2119*	.08166	.012	.0487	.3750
	PRO	PBF	.1383	.07295	.063	-.0075	.2841
		H	-.3100*	.11383	.008	-.5374	-.0825
		Individuals	-.2119*	.08166	.012	-.3750	-.0487

Based on observed means.
The error term is Mean Square(Error) = .058.

Regarding PBFs, it is clear that the level of exploration/exploitation index was lower than that for hospitals ($\alpha = .000 < 0.01$) and for individual inventors ($\alpha = .000 < 0.01$), while is not significantly different from those of PROs. Moreover from the Partial Eta Squared (Table 7-4) the role of actor type to explain the variance in the exploration/exploitation collaborative process of actors, was not very substantial (close to 1%). This effect is similar to the effect of size as reported in Table 7-2.

7.2.3. Role of the interactions of size and type

The result of tests of between-subjects effects shows that there was no significant effect for any of four possible interactions ($\alpha = .206 > 0.01$). Hence it is not possible to conclude whether the combination of any of these control variables has any significant effect on the collaborative process of actors (Table 7-6)

Table 7-6 Role of the interaction of actors' size and type on process

Tests of Between-Subjects Effects

Dependent Variable: exploration/exploitation index

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2.214[a]	5	.443	7.596	.000	.376
Intercept	17.937	1	17.937	307.645	.000	.830
OrgType	.404	2	.202	3.464	.037	.099
size	.296	1	.296	5.082	.028	.075
OrgType * size	.095	1	.095	1.631	.206	.025
Error	3.673	63	.058			
Total	25.519	69				
Corrected Total	5.887	68				

a. R Squared = .376 (Adjusted R Squared = .327)

To test H6c and explain the result, a pair-wise comparison analysis was needed. However, there is no test in SPSS. Writing this syntax in SPSS package, I examined this hypothesis as reported in Table 7-7. Other similar tests that compare the interactions are reported in Appendix 4.

Confirming the H6c, the analysis showed that SMEs regardless of type have the same level of exploration collaborative process (Figure 7-3). However for the large size actor, Hospitals seem to be more focused on exploration collaborative process than PROs and PBFs. Then large PROs like Monash University and University of Melbourne, had the most inclination toward exploration collaborative process in their k-networks.

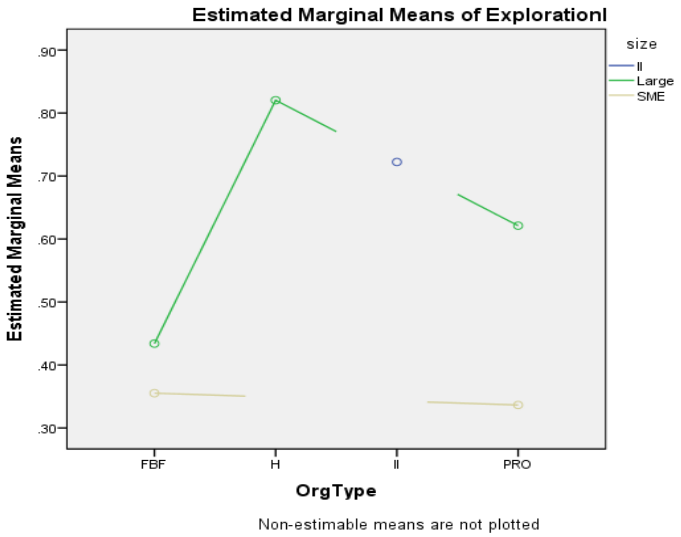


Figure 7-3 Process within four types of actors distinguished by size of the actors

Table 7-7 The post hoc tests to study the role of the interaction of actors size, and type on process

Pairwise Comparisons

Dependent Variable: exploration/exploitation index

size	(I) OrgType	(J) OrgType	Mean Difference (I-J)	Std. Error	Sig.[d]	95% Confidence Interval for Difference[d] Lower Bound	Upper Bound
Individuals	PBF	H	.[a,b]	.	.	.	.
		Individuals	.[a]	.	.	.	.
		PRO	.[a,b]	.	.	.	.
	H	PBF	.[a,b]	.	.	.	.
		Individuals	.[a]	.	.	.	.
		PRO	.[a,b]	.	.	.	.
	Individuals	PBF	.[b]	.	.	.	.
		H	.[b]	.	.	.	.
		PRO	.[b]	.	.	.	.
	PRO	PBF	.[a,b]	.	.	.	.
		H	.[a,b]	.	.	.	.
		Individuals	.[a]	.	.	.	.
Large	PBF	H	-.386*	.139	.007	-.665	-.108
		Individuals	.[b]	.	.	.	.
		PRO	-.187	.123	.132	-.432	.058
	H	PBF	.386*	.139	.007	.108	.665
		Individuals	.[b]	.	.	.	.
		PRO	.199	.123	.109	-.046	.444
	Individuals	PBF	.[a]	.	.	.	.
		H	.[a]	.	.	.	.
		PRO	.[a]	.	.	.	.
	PRO	PBF	.187	.123	.132	-.058	.432
		H	-.199	.123	.109	-.444	.046
		Individuals	.[b]	.	.	.	.
SME	PBF	H	.[b]	.	.	.	.
		Individuals	.[b]	.	.	.	.
		PRO	.019	.105	.858	-.191	.228
	H	PBF	.[a]	.	.	.	.
		Individuals	.[a,b]	.	.	.	.
		PRO	.[a]	.	.	.	.
	Individuals	PBF	.[a]	.	.	.	.
		H	.[a,b]	.	.	.	.
		PRO	.[a]	.	.	.	.
	PRO	PBF	-.019	.105	.858	-.228	.191
		H	.[b]	.	.	.	.
		Individuals	.[b]	.	.	.	.

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

To see the details of that analysis, it is useful to check the plots of these factors. As illustrated in Figure 7-3, it is possible to see that the level of exploration/exploitation index is always higher for large actors. It also seems that the difference between the level of exploration/exploitation index for PROs is dramatically higher than for PBFs. Since there is no small or medium size hospital in this network, my research was not able to analyses the role of size for collaborative process among Hospitals.

7.2.4. Summary of findings on process in terms of size and types of actors:

Given the quantitative approach taken in Phase 2, the findings in relation to the role of size and type on process of k-networks are presented below:

1. *H6a: In a patent co-authorship network, SMEs have a lower level of collaborative process compared with the larger actors.*

Regarding SMEs, it is strongly confirmed that the level of exploration/exploitation index was lower in SMEs in comparison with large actors ($\alpha = .000 < 0.01$).

2. *H6b: In a patent co-authorship network, the level of knowledge diversity is not the same across actors of different types.*

Regarding PBFs, it is clear that the level of exploration/exploitation index was lower than those of Hospitals ($\alpha = .000 < 0.01$) and Individuals ($\alpha = .000 < 0.01$), while is not significantly different from those of PROs.

3. *H6c: In a patent co-authorship network, SMEs regardless of type have same the level of collaborative process.*

SMEs regardless of the type had same level of exploration, as reported in table 7-7. It was also found that:

- Large PROs were more keen on exploration collaborative process than SME-PROs. However there was not much difference between large and SME-PBFs. It seems that the difference between levels of exploration/exploitation index for PROs was substantially larger than for PBFs. The exploration/exploitation index in large PROs

was far greater than in SME-PROs ($\alpha = 0.018$ a little more than 0.01), compared to the difference between large and SME–PBFs which was not significant at all ($\alpha = .111 > 0.01$).

- Among the large actors, Hospitals were more keen on exploration collaborative process particularly compared to PBFs ($\alpha = .007 < 0.01$). However the rest of the comparisons were insignificant.

7.3 Association of process with other constructs of the k-network

Hypotheses 2, 7 and 8 sought to examine possible inter-relationships between partner diversity as an indication of process with other constructs of the k-network (i.e. content and centrality and density of k-network structure). The association of process with content (H2), is discussed in Chapter 6 (6.3.1). To test other hypotheses (H7 and H8), I mainly used Spearman correlation coefficient analysis (for the same reason discussed in Section 6.3 and Appendix 4). The findings based on this test are reported here.

7.3.1 Process and centrality

Hypothesis 7 predicts that there is a positive association between exploration collaborative process of actors including pharmaceutical-biotechnology SMEs with having central position in k-networks. Given the data collected from the Victorian biotechnology industry, the association of exploration/exploitation process with centrality of the k-network is of interest. To test the positive relation among content and process as formulated in hypothesis (H7), the Spearman correlation coefficient analysis was used. The scatter plot of these two constructs is illustrated in Figure 7-4.

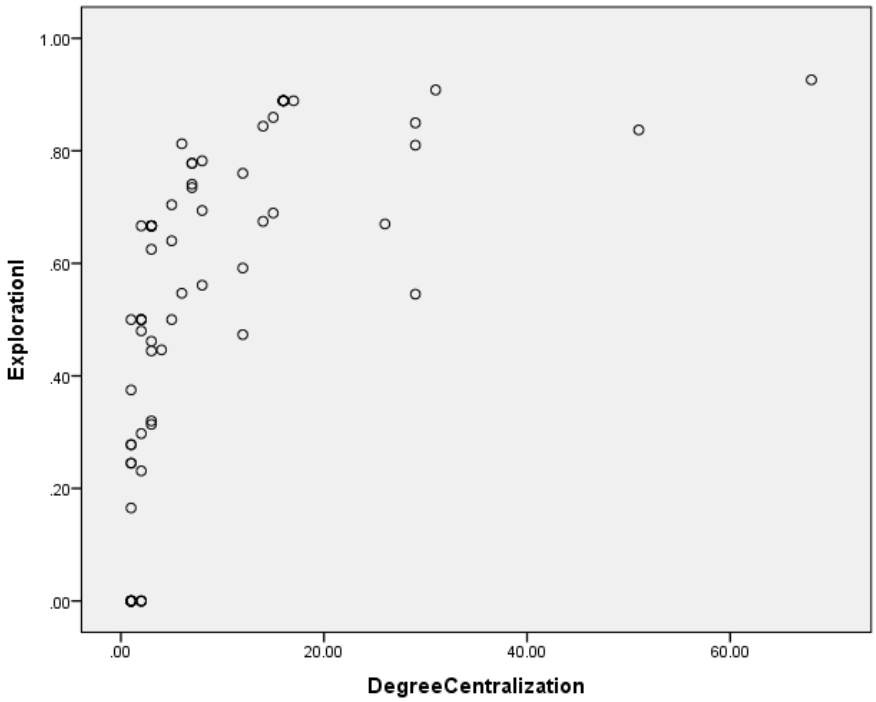


Figure 7-4 Scatter plot of process-centrality

Given the 69 measures from the Victorian biotechnology industry, the association of collaborative process (mean = .5334, S.D =. 2942) and centrality (mean = 8.985, S.D = 11.982) was tested. A Spearman correlation coefficient analysis revealed a very strong positive correlation (ρ = .863, α = .000). Actors who possessed a more central position in the k-network showed more intention of exploring for new partners. This is the general finding for the whole Victorian biotechnology network. To analyse the situation for the pharmaceutical-biotechnology SMEs, the data was split according to actor size and actor type.

First the partial correlation test was run to check the effect of size. The result showed a lower positive correlation ($\rho = .612, \alpha = .000$). However, the result of the analysis for the SME sector is strongly significant ($\rho = .807, \alpha = .000$). This was also the case for pharmaceutical-biotechnology SMEs ($\rho = .833, \alpha = .000$). There was a significant positive correlation between exploration collaborative process of a pharmaceutical-biotechnology SME and the central position of that SME (Table 7-8 and Figure 7-5).

Table 7-8 Spearman test for process-centrality association with actor size and actor type

Correlations

Size	OrgType				Exploration1	DegreeCentralization
Individuals	Individuals	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.986**
				Sig. (2-tailed)	.	.000
				N	17	17
			DegreeCentralization	Correlation Coefficient	.986**	1.000
				Sig. (2-tailed)	.000	.
				N	17	17
Large	PBF	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.880*
				Sig. (2-tailed)	.	.021
				N	6	6
			DegreeCentralization	Correlation Coefficient	.880*	1.000
				Sig. (2-tailed)	.021	.
				N	6	6
	H	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.812*
				Sig. (2-tailed)	.	.050
				N	6	6
			DegreeCentralization	Correlation Coefficient	.812*	1.000
				Sig. (2-tailed)	.050	.
				N	6	6
	PRO	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.630*
				Sig. (2-tailed)	.	.038
				N	11	11
			DegreeCentralization	Correlation Coefficient	.630*	1.000
				Sig. (2-tailed)	.038	.
				N	11	11
SME	PBF	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.833**
				Sig. (2-tailed)	.	.000
				N	22	22
			DegreeCentralization	Correlation Coefficient	.833**	1.000
				Sig. (2-tailed)	.000	.
				N	22	22
	PRO	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.680
				Sig. (2-tailed)	.	.093
				N	7	7
			DegreeCentralization	Correlation Coefficient	.680	1.000
				Sig. (2-tailed)	.093	.
				N	7	7

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

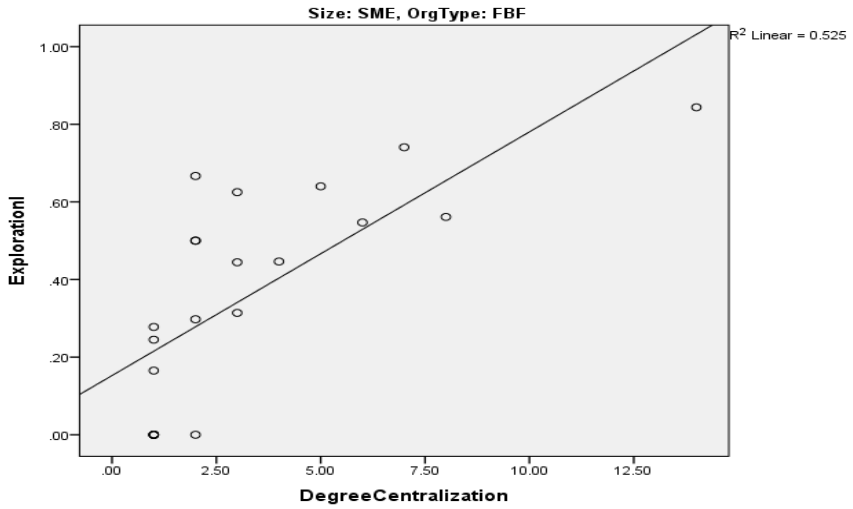


Figure 7-5 Scatter plot of process-centrality for pharmaceutical-biotechnology SMEs

7.3.2 Process and density (Hypothesis 8)

Hypothesis 8 predicts that in a patent co-authorship network, the higher level of focus on exploration collaborative process in an actor including pharmaceutical-biotechnology SME is negatively associated with ego-network density of the actor. Here again, Spearman

correlation coefficient analysis was used. The scatter plot of collaborative process and density seems to show a non-linear relationship (Figure 7-6)

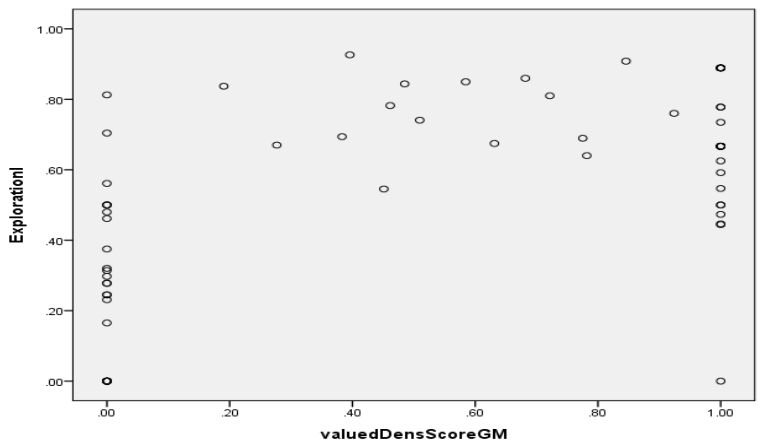


Figure 7-6 Scatter plot of process-density of ego-network of actors
Note: ExplorationI represents the continuum from pure exploitation (0) to pure exploration (1)

Given the 69 measures from the Victorian biotechnology industry, the association of process (mean = .5334, S.D =. 2942) with the valued density (mean = .5078, S.D = .4534) was tested. A Spearman correlation coefficient analysis revealed a moderate positive correlation ($\rho = .560$, $\alpha = .000$). Actors located in the k-network with a certain level of network density tended to possess more diverse partners or, in other words, actors located in a very sparse network or very dense network rarely looked for new partners. However this is a general finding for the whole Victorian biotechnology network. To analyse the situation for the pharmaceutical-biotechnology SMEs, the data was split according to actor size and actor type. First, unlike the correlation between process and centrality, size of the actor did strengthen the process-density relationship. The partial correlation to check the effect of size was more significant ($\rho = .637$, $\alpha = .000$). Likewise the results of the analysis were significant for both the whole SME sector ($\rho = .488$, $\alpha = .007$) and even more strongly for the pharmaceutical-biotechnology SMEs ($\rho = .678$, $\alpha = .001$) as reported in Table 7-9. Hence in the pharmaceutical-biotechnology SMEs there was a strong indication of a significant correlation between diversity of partners and the density of actors' ego-network. However, as shown in Figure 7-7, a non-linear relationship should be considered between these two constructs. This point is further elaborated later in Chapters 9 and 11, when the interaction of all constructs is examined simultaneously.

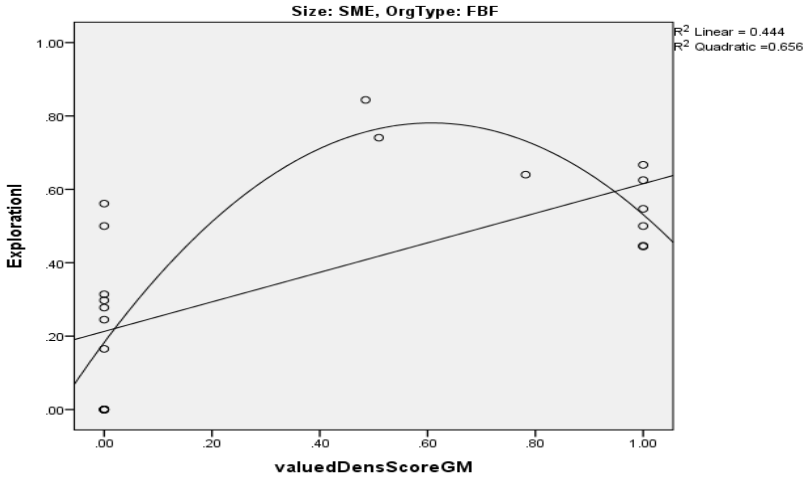


Figure 7-7 Scatter plot of process-density for pharmaceutical-biotechnology SMEs

Table 7-9 Spearman test for process-density association size and organisational type

Correlations

Size	OrgType				Exploration1	valuedDensScoreGM
Individuals	Individuals	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.433
				Sig. (2-tailed)	.	.082
				N	17	17
			valuedDensScoreGM	Correlation Coefficient	.433	1.000
				Sig. (2-tailed)	.082	.
				N	17	17
Large	PBF	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.759
				Sig. (2-tailed)	.	.080
				N	6	6
			valuedDensScoreGM	Correlation Coefficient	.759	1.000
				Sig. (2-tailed)	.080	.
				N	6	6
	H	Spearman's rho	Exploration1	Correlation Coefficient	1.000	-.600
				Sig. (2-tailed)	.	.208
				N	6	6
			valuedDensScoreGM	Correlation Coefficient	-.600	1.000
				Sig. (2-tailed)	.208	.
				N	6	6
	PRO	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.296
				Sig. (2-tailed)	.	.378
				N	11	11
			valuedDensScoreGM	Correlation Coefficient	.296	1.000
				Sig. (2-tailed)	.378	.
				N	11	11
SME	PBF	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.678**
				Sig. (2-tailed)	.	.001
				N	22	22
			valuedDensScoreGM	Correlation Coefficient	.678**	1.000
				Sig. (2-tailed)	.001	.
				N	22	22
	PRO	Spearman's rho	Exploration1	Correlation Coefficient	1.000	-.180
				Sig. (2-tailed)	.	.700
				N	7	7
			valuedDensScoreGM	Correlation Coefficient	-.180	1.000
				Sig. (2-tailed)	.700	.
				N	7	7

**. Correlation is significant at the 0.01 level (2-tailed).

7.3.3 Process and content

According to the analysis reported in Chapter 6 (Section 6.3.1), on Hypothesis 2, actors who possessed more diverse knowledge show more intention for exploration collaborative process. This was the general finding for the whole Victorian biotechnology network.

However the result of the analysis for the SME sector was not significant ($\rho = .363$, $\alpha = .053$). This was also the case for pharmaceutical-biotechnology SMEs ($\rho = .345$, $\alpha = .116 > .05$). Hence there was no indication of a significant correlation between diversity of knowledge and diversity of partners in the pharmaceutical-biotechnology SMEs. The details are provided in Chapter 6 (Section 6.3.1).

7.3.4 Summary of the findings on association of process with other constructs

Given the quantitative approach taken in Phase 2, a summary of findings in relation to the association of process with other constructs of k-networks is presented below:

1. *H7: In a patent co-authorship network, the level of collaborative process of actors including pharmaceutical-biotechnology SMEs is positively associated with central position of the actors.*

The Spearman correlation coefficient analysis revealed a very strong positive correlation ($\rho = .863$, $\alpha = .000$). This result was also supported for the SME sector ($\rho = .807$, $\alpha = .000$) and for pharmaceutical-biotechnology SMEs ($\rho =. 833$, $\alpha = .000$). This point is further elaborated later in Chapter 9 and 11 when the interaction of all constructs is examined simultaneously.

2. *H8: In a patent co-authorship network, the level of exploration collaborative process of actors including pharmaceutical-biotechnology SMEs is negatively associated with ego-network density of the actors.*

A Spearman correlation coefficient analysis revealed a moderate positive correlation ($\rho = .560$, $\alpha = .000$). Likewise, the results of the analysis were significant for both the whole SME sector ($\rho = .488$, $\alpha = .007$) and even more strongly for the pharmaceutical-biotechnology SMEs ($\rho = .678$, $\alpha = .001$), as reported in Table 7-9.

7.4 Association of process with knowledge creation

Hypothesis 9 predicts that there is no association between exploration/exploitation process with knowledge creation. To test H9, a Spearman correlation coefficient analysis was used. The findings based on this test are reported here. The scatter plot of

exploration/exploitation index (i.e. partner diversity as measure of exploration/exploitation process) and number of patents (as measure of knowledge creation) is shown in Figure 7-8.

Using the 69 measures from Victorian biotechnology industry, the association of exploration/exploitation index (mean = .5334, S.D = .2942) with knowledge creation (mean = 8.89, S.D = 13.97) was tested. A Spearman correlation coefficient analysis revealed no correlation ($\rho = .144$, $\alpha = .238$). It means the number of patents published by an actor was not associated with the diversity of the actors' partners (exploration/exploitation process). This is a general finding for the whole Victorian biotechnology network. To analyse the situation for the pharmaceutical-biotechnology SMEs, the data was split according to actor size and actor type.

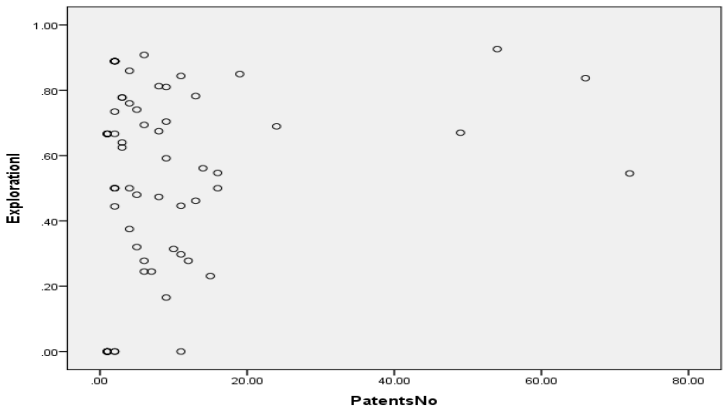


Figure 7-8 Scatter plot of content-knowledge creation

First, it was found that size of the actors can strengthen the correlation of process and knowledge creation. The partial correlation to check the effect of size showed that the ρ has increased (ρ = .235, α = .054) however this is still not sufficiently significant. The result of the analysis for the SME sector showed a moderately positive relation (ρ =. 399, α = .032). Although this was not supported for pharmaceutical-biotechnology SMEs (ρ = .366, α =. 094). There is a non-significant correlation between process and knowledge creation in the pharmaceutical-biotechnology SMEs as reported in Table 7-10. The scatter plot of process and knowledge creation for pharmaceutical-biotechnology SMEs is shown in Figure 7-9.

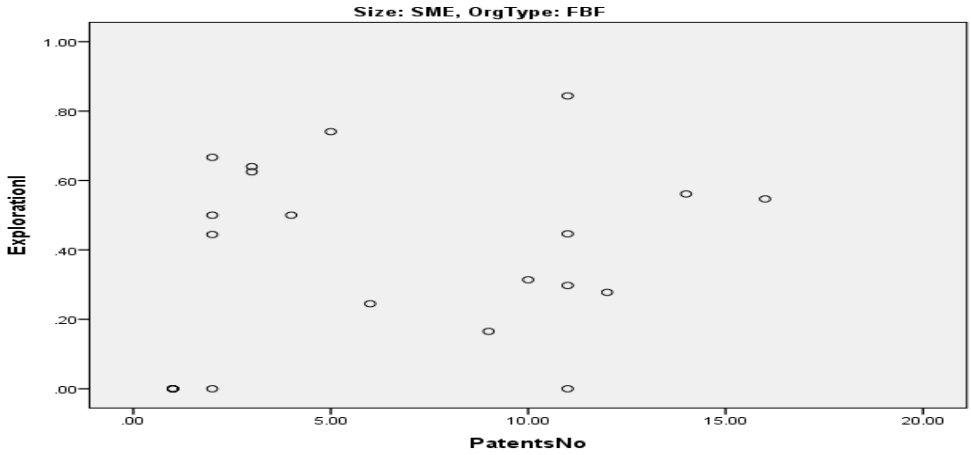


Figure 7-9 Scatter plot of process-knowledge creation for pharmaceutical-biotechnology SMEs

Table 7-10 Spearman test for process -knowledge creation association according to actors' size and type

Size	OrgType				Exploration1	PatentsNo
Individuals	Individuals	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.637**
				Sig. (2-tailed)	.	.006
				N	17	17
			PatentsNo	Correlation Coefficient	.637**	1.000
				Sig. (2-tailed)	.006	.
				N	17	17
Large	PBF	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.886*
				Sig. (2-tailed)	.	.019
				N	6	6
			PatentsNo	Correlation Coefficient	.886*	1.000
				Sig. (2-tailed)	.019	.
				N	6	6
	H	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.464
				Sig. (2-tailed)	.	.354
				N	6	6
			PatentsNo	Correlation Coefficient	.464	1.000
				Sig. (2-tailed)	.354	.
				N	6	6
	PRO	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.508
				Sig. (2-tailed)	.	.111
				N	11	11
			PatentsNo	Correlation Coefficient	.508	1.000
				Sig. (2-tailed)	.111	.
				N	11	11
SME	PBF	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.366
				Sig. (2-tailed)	.	.094
				N	22	22
			PatentsNo	Correlation Coefficient	.366	1.000
				Sig. (2-tailed)	.094	.
				N	22	22
	PRO	Spearman's rho	Exploration1	Correlation Coefficient	1.000	.595
				Sig. (2-tailed)	.	.159
				N	7	7
			PatentsNo	Correlation Coefficient	.595	1.000
				Sig. (2-tailed)	.159	.
				N	7	7

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

7.5 Summary

In this section I analysed the exploration/exploitation process of the Victorian biotechnology industry network in terms of diversity of partners. The focus was on three things: first, the role of size and type of actors on their exploration/exploitation process; second, the association of process with other characteristics of k-networks; and third the association of process with knowledge creation. The summarised findings are reported in Table 7-11.

Table 7-11 Summary of the hypotheses on process of k-network

Hypothesis	Result	Description
H6a: In a patent co-authorship network, SMEs have lower levels of exploration collaborative process compared to the larger actors.	Not rejected	Regarding SMEs, it was strongly confirmed that the level of exploration/exploitation index was lower in SMEs in comparison with large actors. It was also clear that the level of exploration/exploitation index was affected by organisational type. In PBFs the level of exploration was lower than those of Hospitals and of Individuals, while it was not significantly different from those of PROs. SMEs regardless of type had the same level of exploration.
H6b: In a patent co-authorship network, the level of knowledge diversity is not the same across actors of different types.	Not rejected	
H6c: In a patent co-authorship network, SMEs regardless of the type have the same level of exploration.	Not Rejected	
H2: In a patent co-authorship network, the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is positively associated with the exploration collaborative process.	Not rejected	As explained in Chapter 6
H7: In a patent co-authorship network, the level of exploration collaborative process of actors including pharmaceutical-biotechnology SMEs is positively associated with central position of the actors.	Not rejected	The analysis revealed a very strong positive correlation. This result was also supported for all SMEs including pharmaceutical-biotechnology SMEs.
H8: In a patent co-authorship network, the level of exploration collaborative process of actors including pharmaceutical-biotechnology SMEs is negatively associated with ego-network density of the actors.	Rejected	The analysis revealed a moderate positive correlation. Likewise, the result was supported for both the whole SME sector and even more strongly for the pharmaceutical-biotechnology SMEs. However, as indicated by the scatter plot, in deed actors located in the k-network with a certain level of ego-network density tended to possess more diverse partners or, in other words, actors located in a very sparse network or very dense network rarely looked for new partners.
H9: In a patent co-authorship network, the level of exploration collaborative process of actors including the pharmaceutical-biotechnology SMEs is not associated with the number of actors' patent.	Not rejected	Process was not associated with knowledge creation for the whole k-network, or for SMEs including the pharmaceutical-biotechnology SMEs.

Chapter 8

Structure of K-network in the Victorian Biotechnology Context

Outline of Chapter 8

Similar to Chapters 6 and 7, this chapter reports the findings of Phase 2, in relation to the structure of the k-network. In particular, it tests the hypotheses of the conceptual model (Chapter 3) regarding the structure of k-networks of actors in terms of centrality of the actors in the whole network, and the density of the actors' ego-networks (as explained in Chapter 5 Section 5.2.3).

This chapter reports tests of five hypotheses (H10, H11, H12, H13, H14). These include: the possible effect of organisational size and organisational type on centrality (H10a, H10b and H10c), and on density (H13a, H13b and H13c), the possible association of centrality with other constructs (H11) of the k-network, and finally the possible association of centrality and density with knowledge creation (H12, H14). The position of the chapter within the broader research design is illustrated in Figure 8-1.

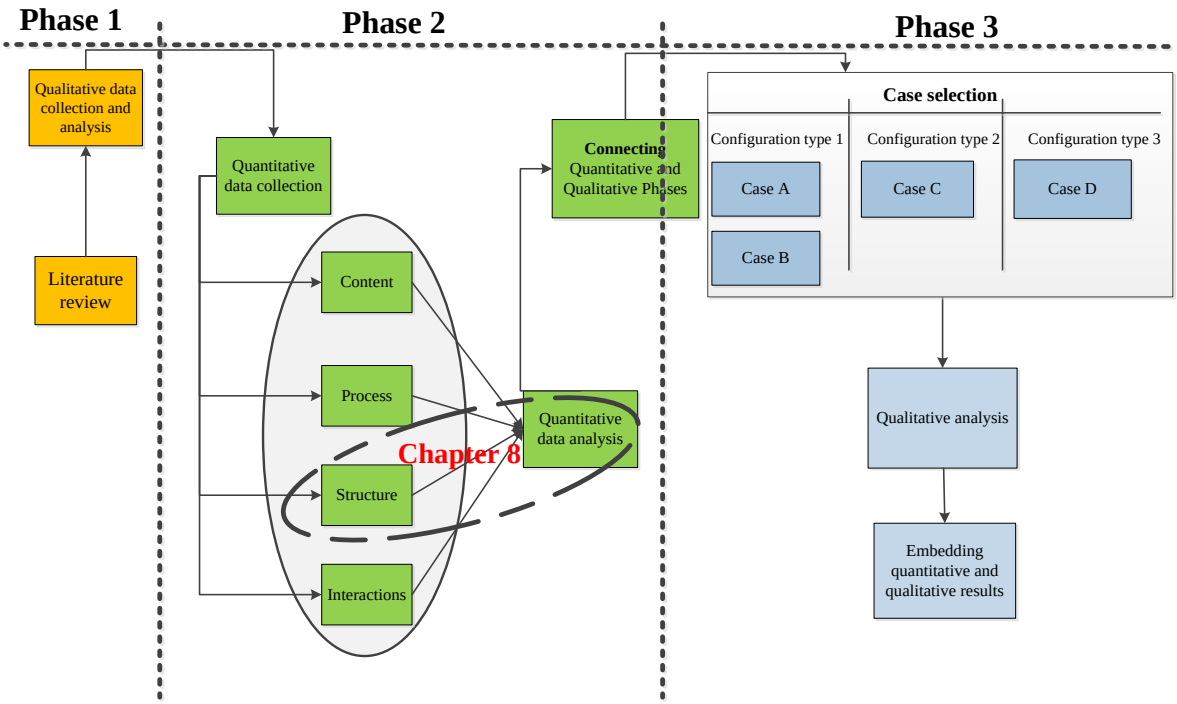


Figure 8-1 Position of Chapter 8 in the wider research design

8.1 Introduction

This chapter reports the findings from the quantitative Phase 2 on actors' position in the whole network (centrality) and the density of actors' ego-network (density). Given the conceptual model in Chapter 3 (Section 3.2.2) to study the structure of k-network in terms of centrality and density, my research tested a series of hypotheses represented in Figure 8.2. These hypotheses include the possible effect of size and organisational type on centrality (H10a, H10b and H10c), and on density (H13a, H13b and H13c) the possible association of centrality with density of the k-network (H11), and finally the possible association of centrality and density with knowledge creation (H12, H14). The associations of content and process with structure (H3, H4, H7 and H8) were reported in Chapters 6 and 7. The structure of this chapter is organised on the basis of each hypothesis, and the statistical techniques used to test the hypothesis. The validity of tests is discussed in Chapter 4 (Section 4.4.4), and the details are reported in Appendix 5.

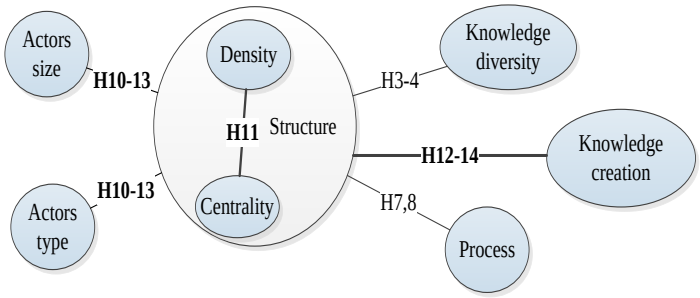


Figure 8-2 Series of hypothesis regarding structure of k-networks

It is worth noting that, because the cases selected in Phase 3 (the qualitative phase) were small-medium sized pharmaceutical-biotechnology firms (PBF-SMEs), this group was also studied at in greater depth in this quantitative analysis.

8.2 Effect of size and type on structure

Does the size and type of actors influence the actor's central position and the density of the actor's ego-network (as described in Chapter 5 (Section 5.2.3)? To answer this question, as

mentioned in Chapter 6 (Section 6.2.1), factorial ANOVA was used to test the set of hypotheses on size and type impact on centrality (H10a, H10b and H10c) and on density (H13a, H13b and H13c). The summary of findings are discussed first for role of actor size, role of actor type and then for the interaction of all of them together. This analysis is similar to that used to test the hypotheses reported in Chapters 6 and 7. However unlike the content, the concepts of centrality and density of the k-network is only defined for the collaborative actors, because isolated actors who have never collaborated with other actors, have no ego-networks.

8.2.1 Result of factorial ANOVA for centrality

As mentioned in Chapter 5 (Section 5.2.3), the concept of network centrality can be calculated in several ways including degree of centrality, betweeness, centrality closeness, and eigenvector. In this research, all these measures were calculated by UCINET6, one of the SNA software packages. However, only the results for degree of centrality are reported here. There was no significant difference from results derived from other techniques.

Degree of centrality was counted by using UCINET6 – a SNA package (Borgatti et al. 2002) – for all 69 collaborative firms. The measure here is called centrality, and the higher values of an actor's centrality represents a more central position in the network. The lowest degree of centrality is one for actors who had only one patent partnership between 2001–2010.The largest centrality was 68, for the University of Melbourne. The descriptive analysis of centrality is addressed in Appendix 5.

8.2.1.1 Role of size:

In terms of size, there are three groups of actors: large organisation, small and medium enterprises (SME), and individual inventor. The result of tests of between-subjects effects shows that there is a significant effect from size ($F = 7.142$, and $\alpha = .010$) at the 99% confidence interval. Generally, it is possible to say that actors of different sizes have different levels of centrality (Table 8-1).

Table 8-1 Role of actor size on centrality

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected model	2444.499	5	488.900	4.294	.002	.254
Intercept	5783.807	1	5783.807	50.802	.000	.446
Org type	369.069	2	184.535	1.621	.206	.049
Size	813.130	1	813.130	**7.142**	**.010**	**.102**

From the Partial Eta Squared, it is possible to see that the role of size is fairly important (10%) in explaining the variance of actors' centrality. To see the details of this analysis, the post hoc tests of least significant difference test (LSD) and Scheffe are used. Using these tests, it is possible to explore all possible pair-wise comparisons of means comprising a factor using the equivalent of multiple t-tests (Table 8-2). Regarding SMEs, it is safe to conclude that the level of centrality is lower in SMEs compared to large actors (α b= .001 < .01). However SMEs had same level of centrality compared to Individual, so the difference of the means of large organisation and individuals is not significant (α = .165).

Table 8-2 The post hoc tests to study the role of size on centrality

Pairwise Comparisons

Dependent Variable: DegreeCentralization

(I) size	(J) size	Mean Difference (I-J)	Std. Error	Sig.[d]	95% Confidence Interval for Difference[d]	
					Lower Bound	Upper Bound
Individual	Large	-7.026*[b,c]	3.473	.047	-13.967	-.086
	SME	4.878[b,c]	3.472	.165	-2.061	11.817
Large	Individual	7.026*[b,c]	3.473	.047	.086	13.967
	SME	11.904*[b,c]	3.275	.001	5.360	18.449
SME	Individual	-4.878[b,c]	3.472	.165	-11.817	2.061
	Large	-11.904*[b,c]	3.275	.001	-18.449	-5.360

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. An estimate of the modified population marginal mean (I).

c. An estimate of the modified population marginal mean (J).

d. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

One may argue that individual inventors are not compareable to organisational actors (SME or large). To explore this result I excluded all 18 individuals and ran the test again. However the result did not change that much (F = 5.899 and α = .019 < .05 and Partial Eta Squared = .112). It might also be possible to consider individual inventors as SMEs, in this case the result is the same (Fv=v7.142; αv=v.010 and Partial Eta Squared = .102).

8.2.1.2 Role of type

There were four types including pharmaceutical-biotechnology firms (PBF), hospital (H), public research organisations (PRO), and individual inventors (Individuals). The result of

tests of between-subjects effects shows that there was no effect from type (F = 1.621, and α = .206 > .05) even at the 95% confidence interval. Generally it is not possible to conclude whether any actor type (like Hospital or Individual) had a significantly different level of centrality (Table 8-3). Given the Partial Eta Squared, the relatively low importance of the role of type in explaining the variance of actors' centrality is clear.

Table 8-3 Role of actor's type on centrality

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected model	2444.499	5	488.900	4.294	.002	.254
Intercept	5783.807	1	5783.807	50.802	.000	.446
Actor's type	369.069	2	184.535	1.621	.206	.049

To explore all possible pair-wise comparisons of means, the Scheffe and LSD post hoc tests were used. The results from both tests were consistent and showed that there were several significant differences among the four types, particularly for the PBF group (Table 8-4). Regarding PBF actors, it is clear that their level of centrality was lower than that of Hospitals (α = .006 < .01) however, there was no significant difference compared to PROs and Individuals.

Table 8-4 The post hoc tests to study the role of type on centrality

Pairwise Comparisons

Dependent Variable: DegreeCentralization

(I) OrgType	(J) OrgType	Mean Difference (I-J)	Std. Error	Sig.[d]	95% Confidence Interval for Difference[d] Lower Bound	Upper Bound
FBF	H	-14.220*[b,c]	5.001	.006	-24.214	-4.226
	Individual	-2.426[b,c]	3.569	.499	-9.557	4.706
	PRO	-4.616[b,c]	3.562	.200	-11.735	2.503
H	PBF	14.220*[b,c]	5.001	.006	4.226	24.214
	Individual	11.794*[b,c]	5.067	.023	1.669	21.919
	PRO	9.604[b,c]	5.062	.062	-.513	19.720
Individual	PBF	2.426[b,c]	3.569	.499	-4.706	9.557
	H	-11.794*[b,c]	5.067	.023	-21.919	-1.669
	PRO	-2.190[b,c]	3.654	.551	-9.492	5.111
PRO	PBF	4.616[b,c]	3.562	.200	-2.503	11.735
	H	-9.604[b,c]	5.062	.062	-19.720	.513
	Individual	2.190[b,c]	3.654	.551	-5.111	9.492

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. An estimate of the modified population marginal mean (I).

c. An estimate of the modified population marginal mean (J).

d. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

8.2.1.3 Role of the interactions of size and type

The result of tests of between-subjects effects shows that there is no significant effect for the interaction of size and type (α = .341 > .01). Generally, it is not possible to say whether

the combination of any of these control variables has any significant effect on the centrality level of actors (Table 8-5).

Table 8-5 Role of the interaction of actor size and actor type on centrality

Tests of Between-Subjects Effects

Dependent Variable: DegreeCentralization

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2444.499[a]	5	488.900	4.294	.002	.254
Intercept	5783.807	1	5783.807	50.802	.000	.446
OrgType	369.069	2	184.535	1.621	.206	.049
size	813.130	1	813.130	7.142	.010	.102
OrgType * size	104.590	1	104.590	.919	.341	.014
Error	7172.486	63	113.849			
Total	15188.000	69				
Corrected Total	9616.986	68				

a. R Squared = .254 (Adjusted R Squared = .195)

To see the details of that analysis, it is useful to check the plots of these factors, as illustrated in Figure 8-3. It is possible to see that the level of centrality is always higher for large actors, however the difference between large organisations, Individuals and SME actors are not statistically significant as reported in Table 8-6 . According to Figure 8-4, it seems that SMEs regardless of the type have almost the same level of centrality. Moreover the difference between level of centrality for large organisations vs. small-medium PROs (SME-PROs) is bigger than that of PBFs. There is no SME hospital in this network so any more analysis regarding this type of actor is not possible.

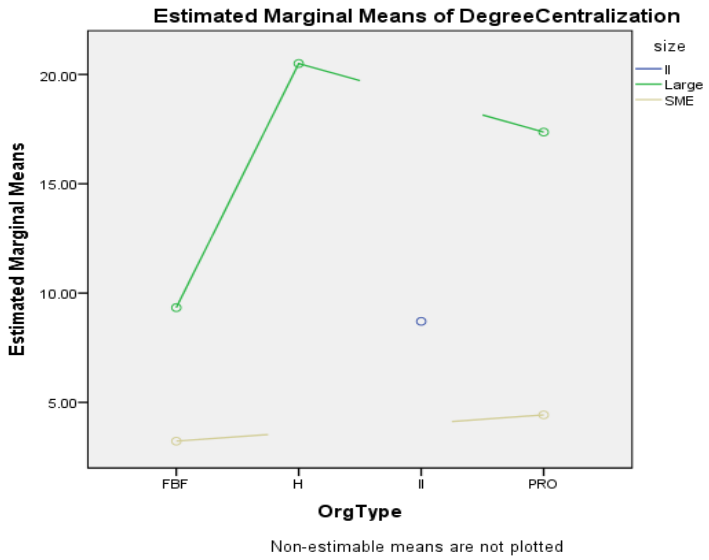


Figure 8-3 Centrality within four types of actors distinguished by size of the actors

Table 8-6 The post hoc tests to study the role of the interaction of actor size, and actor type on centrality

Pairwise Comparisons

Dependent Variable: DegreeCentralization

size	(I) OrgType	(J) OrgType	Mean Difference (I-J)	Std. Error	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
Individual	PBF	H	.[a,b]	.	.	.	.
		II	.[a]	.	.	.	.
		PRO	.[a,b]	.	.	.	.
	H	FBF	.[a,b]	.	.	.	.
		II	.[a]	.	.	.	.
		PRO	.[a,b]	.	.	.	.
	Individual	FBF	.[b]	.	.	.	.
		H	.[b]	.	.	.	.
		PRO	.[b]	.	.	.	.
	PRO	FBF	.[a,b]	.	.	.	.
		H	.[a,b]	.	.	.	.
		II	.[a]	.	.	.	.
Large	PBF	H	-11.167	6.160	.075	-23.477	1.144
		II	.[b]	.	.	.	.
		PRO	-8.030	5.415	.143	-18.852	2.791
	H	FBF	11.167	6.160	.075	-1.144	23.477
		II	.[b]	.	.	.	.
		PRO	3.136	5.415	.565	-7.685	13.958
	Individual	FBF	.[a]	.	.	.	.
		H	.[a]	.	.	.	.
		PRO	.[a]	.	.	.	.
	PRO	FBF	8.030	5.415	.143	-2.791	18.852
		H	-3.136	5.415	.565	-13.958	7.685
		II	.[b]	.	.	.	.
SME	PBF	H	.[b]	.	.	.	.
		II	.[b]	.	.	.	.
		PRO	-1.201	4.630	.796	-10.454	8.051
	H	FBF	.[a]	.	.	.	.
		II	.[a,b]	.	.	.	.
		PRO	.[a]	.	.	.	.
	Individual	FBF	.[a]	.	.	.	.
		H	.[a,b]	.	.	.	.
		PRO	.[a]	.	.	.	.
	PRO	FBF	1.201	4.630	.796	-8.051	10.454
		H	.[b]	.	.	.	.
		II	.[b]	.	.	.	.

Based on estimated marginal means

a. The level combination of factors in (I) is not observed.

b. The level combination of factors in (J) is not observed.

c. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

8.2.2 Result of factorial ANOVA for density

As mentioned in Chapter 5 (Section 5.2.3), the geometric mean was used in this research to calculate density in a valued network or clustering in weighted networks (Opsahl and Panzarasa 2009). Density was calculated for each of the 69 collaborative actors. The higher values of an actor density represent more closed partnerships in the ego-network of that actor. In the same way a value of one represents an actor who was strongly focused on a constant set of partners. The lowest degree of density is zero for actors who had no closed patent partnership between 2001 and 2010.The largest figure was one for several actors. The descriptive analysis of density is shown in Appendix 5.

8.2.2.1 Role of size

There are three groups of size including large organisation, SMEs, and individual inventors. The results of tests of between-subjects effects shows that there is no significant effect from size (F = .018, and α = .893) at the 99% confidence interval. It is not possible to argue that actors of different size have different levels of density (Table 8-7). Moreover, from the Partial Eta Squared it is also clear that the role of size is not able to explain the variance in actors' density.

Table 8-7 Role of actor's size on density

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected model	9587.953	5	1917.591	8.229	.000	.395
Intercept	73203.036	1	73203.036	314.1	.000	.833
Size	4.257	1	4.257	.018	.893	.000

To further explore the data, the post hoc tests of LSD and Scheffe were used again. Using these tests, it is possible to explore all the pair-wise comparisons of means comprising a factor using the equivalent of multiple t-tests (Table 8-8). Here it can be seen that the level of density was lower in SMEs compared to individual inventors (α = .000 < .01). However SMEs had the same level of density compared to large actors. Moreover, the difference of the means of large and individuals was significant (α = .000). It means individual inventors have the most dense ego-networks compared to actors of other sizes.

Table 8-8 The post hoc tests to study the role of size on density

Dependent Variable: ValueDensity_RAN
LSD

(I) Size	(J) Size	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Individual	Large	23.45652*	4.882669	.000	13.69929	33.21376
	SME	26.60345*	4.663061	.000	17.28506	35.92183
Large	Individual	-23.45652*	4.882669	.000	-33.21376	-13.69929
	SME	3.14693	4.262402	.463	-5.37080	11.66466
SME	Individual	-26.60345*	4.663061	.000	-35.92183	-17.28506
	Large	-3.14693	4.262402	.463	-11.66466	5.37080

Based on observed means.
The error term is Mean Square(Error) = 233.040.
*. The mean difference is significant at the .05 level.

8.2.2.2 Role of type

Given the four types of actor, the results of tests of between-subjects effects shows that there is not a significant effect from organisational type (F = 2.811, and α = .068 > .05)

even at the 95% confidence interval. Generally, it is not possible to conclude whether any actor type (like Hospital or Individuals has a significant different level of centrality (Table 8-9). Moreover from the Partial Eta Squared we can see the role of type is important to explain the variance of actors' density (8%).

Table 8-9 Role of actor's type on density

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected model	9587.953	5	1917.591	8.229	.000	.395
Intercept	73203.036	1	73203.036	314.122	.000	.833
Size	4.257	1	4.257	.018	.893	.000
Org type	1309.972	2	654.986	2.811	.068	.082

To explore the details of this analysis, the post hoc tests of LSD and Scheffe were used to explore all possible pair-wise comparisons of means (Table 8-10). The results from both were consistent, and show that there are several significant differences among four types including the PBF group. Regarding PBF actors, it is safe to conclude that their level of density was lower than that of Individuals ($\alpha = .000 < .01$) and slightly lower than Hospitals ($\alpha = .047 < .01$). However, there were no significant differences compared to public PROs. Individuals and Hospitals show higher level of density compared to other organisational types.

Table 8-10 The post hoc tests to study the role of type on density

Multiple Comparisons

Dependent Variable: ValueDensity_RAN
LSD

(I) OrgType	(J) OrgType	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
PBF	H	-13.89881*	6.867528	.047	-27.62247	-.17515
	Individual	-25.48214*	4.693733	.000	-34.86182	-16.10247
	PRO	3.85119	4.611894	.407	-5.36494	13.06732
H	PBF	13.89881*	6.867528	.047	.17515	27.62247
	Individual	-11.58333	7.249023	.115	-26.06935	2.90268
	PRO	17.75000*	7.196302	.016	3.36934	32.13066
Il	PBF	25.48214*	4.693733	.000	16.10247	34.86182
	H	11.58333	7.249023	.115	-2.90268	26.06935
	PRO	29.33333*	5.162843	.000	19.01621	39.65045
PRO	PBF	-3.85119	4.611894	.407	-13.06732	5.36494
	H	-17.75000*	7.196302	.016	-32.13066	-3.36934
	Individual	-29.33333*	5.162843	.000	-39.65045	-19.01621

Based on observed means.
The error term is Mean Square(Error) = 233.040.
*. The mean difference is significant at the .05 level.

8.2.2.3 Role of the interactions of size and type

The result of tests of between-subjects effects shows that there is no significant effect for the interaction of size and type (α = .776 > .01). It is not possible to say whether the combination of any of these control variables has any significant effect on the density of actors (Table 8-11).

To see the details of that analysis, it is useful to check the plots of these factors, as illustrated in Figure 8-3. It is possible to see that the level of density is the same for all SMEs regardless of the their organisational types.

Table 8-11 Role of the interaction of actor size and actor type on density

Tests of Between-Subjects Effects

Dependent Variable: ValueDensity_RAN

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	9587.953[a]	5	1917.591	8.229	.000	.395
Intercept	73203.036	1	73203.036	314.122	.000	.833
Size	4.257	1	4.257	.018	.893	.000
OrgType	1309.972	2	654.986	2.811	.068	.082
Size * OrgType	18.966	1	18.966	.081	.776	.001
Error	14681.547	63	233.040			
Total	108794.500	69				
Corrected Total	24269.500	68				

a. R Squared = .395 (Adjusted R Squared = .347)

Moreover, it seems that both PBFs and PROs have the same level of density. To test H13c, although the level of density for pharmaceutical-biotechnology SMEs was higher than their larger counterparts, it was lower than Individuals, as shown in Figure 8-4, and the differences between large, individual and SME actors were not statistically significant, as also reported in Table 8-12.

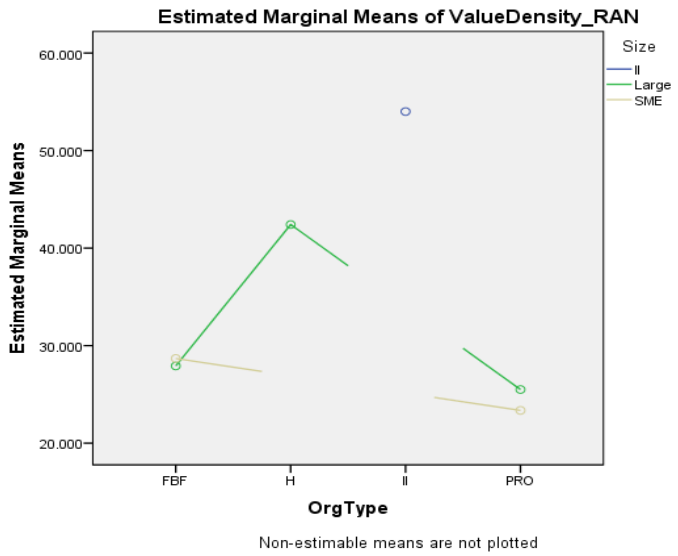


Figure 8-4 Density within four types of actors distinguished by size of the actors

Table 8-12 The post hoc tests to study the role of the interaction of actors' size, type on density

Pairwise Comparisons

Dependent Variable: ValueDensity_RAN

OrgType	(I) Size	(J) Size	Mean Difference (I-J)	Std. Error	Sig.[c]	95% Confidence Interval for Difference[c] Lower Bound	Upper Bound
PBF	Individual	Large	.[a]	.	.	.	.
		SME	.[a]	.	.	.	.
	Large	II	.[b]	.	.	.	.
		SME	-.765	7.031	.914	-14.815	13.285
	SME	II	.[b]	.	.	.	.
		Large	.765	7.031	.914	-13.285	14.815
H	Individual	Large	.[a]	.	.	.	.
		SME	.[a,b]	.	.	.	.
	Large	II	.[b]	.	.	.	.
		SME	.[b]	.	.	.	.
	SME	II	.[a,b]	.	.	.	.
		Large	.[a]	.	.	.	.
Individual	Individual	Large	.[b]	.	.	.	.
		SME	.[b]	.	.	.	.
	Large	II	.[a]	.	.	.	.
		SME	.[a,b]	.	.	.	.
	SME	II	.[a]	.	.	.	.
		Large	.[a,b]	.	.	.	.
PRO	Individual	Large	.[a]	.	.	.	.
		SME	.[a]	.	.	.	.
	Large	II	.[b]	.	.	.	.
		SME	2.143	7.381	.773	-12.607	16.892
	SME	II	.[b]	.	.	.	.
		Large	-2.143	7.381	.773	-16.892	12.607

Based on estimated marginal means

a. The level combination of factors in (I) is not observed.

b. The level combination of factors in (J) is not observed.

c. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

8.2.3 Summary of the findings for role of actor size and actor type on centrality and density

Given the quantitative approach taken in Phase 2, here is the list of findings in relation to the role of size and type on the process of the k-network:

1. *H10a: In a patent co-authorship network, SMEs have a lower level of centrality compared to their larger counterparts.*

It is safe to conclude that the level of centrality was lower in SMEs compared to large actors ($\alpha = .001 < .01$).

2. *H10b: In a patent co-authorship network, the level of centrality is higher in non-commercial actors compared to commercial actors (i.e. pharmaceutical companies).*

PBFs have a lower level of centrality than that of Hospitals ($\alpha = .006 < .01$) however, there is no significant difference compared to PROs.

3. *H10c: In a patent co-authorship network, pharmaceutical-biotechnology SMEs have the lowest level of centrality compared to their larger counterparts.*

This hypothesis was rejected. Although the level of centrality was always lower for SME actors, as shown in Figure 8-2, the differences between large, individuals and SME actors were not statistically significant as reported in Table 8-6. In this regard also this research found:

- SMEs have the same level of centrality regardless of their type ($\alpha = .796 > .01$)
- PBFs regardless of their size have the same level of centrality ($\alpha = .219 > .01$), however large PROs have a more central position ($\alpha = .015$ a little bit more than .01).

4. *H13a: In a patent co-authorship network, SMEs have no more dense ego-network compared to large actors.*

The level of density was lower in SMEs compared to individual inventors ($\alpha = .000 < .01$). However SMEs had the same level of density compared to large actors. Moreover,

the difference of the means of large organisations and Individuals was significant (α = .000). Individuals had the most dense ego-network compared to actors of other sizes.

5. *H13b: In a patent co-authorship network, the level of ego-network density is not the same across actors with different types.*

This hypothesis was rejected. PBFs had a lower level of density than that of Individuals (α = .000 < .01) and slightly lower than hospitals (α = .047 < .01). However, there was no significant difference compared to PROs. Individuals and Hospitals showed a higher level of density compared to other organisational types.

6. *H13c: In a patent co-authorship network, pharmaceutical-biotechnology SMEs have no more dense ego-networks compared to large pharmaceutical-biotechnology actors, and less dense ego-network than those of individual inventors.*

Although the level of density for pharmaceutical-biotechnology SMEs was higher than their larger counterparts but lower than Individuals, as shown in Figure 8-3, the difference between large organisations, individual and SME actors was not statistically significant, as reported in Table 8-12. In this regard this research also found that:

- The level of density was the same for all SMEs regardless of their organisational types. Moreover, PBFs and PROs have the same level of density.
- Large actors, regardless of their organisational type, had almost the same level of density. However Hospitals tend to work in a slightly more dense network compared to large PROs (α = .033 > .01).
- PBFs had the same level of density regardless of their size (α =. 914 > .01). This was the case for the PROs as well (α = .773 > .01). More details of these statistical analyses are reported in Appendix 5 (Section on Interaction).

8.3 Association of centrality with density of the k-network

This section explores Hypothesis 11, which predicts the possible inter-relationships between centrality of actors in a k-network with other constructs of the k-network. All these possible associations however, were tested except for centrality and density. In Chapter 6

(Sections 6.3.2 and 6.3.3) the inter-relationship between content-centrality and content-density are analysed. The inter-relationships between process-centrality and process-density are also analysed in Chapter 7 (Sections 7.3.1 and 7.3.2). Here the possible relationship between centrality and density is examined. Again, there is no reason to assume linearity of the possible relation between centrality and other constructs (i.e. density), so the Spearman correlation coefficient analysis was used. Appendix 5 explains in more detail why this technique was selected and why the technique is rigorous in this context. The findings based on this test are reported here.

8.3.1 Centrality and density

Based on data collected from the Victorian biotechnology industry, the association of centrality of actor among the whole k-network with the valued density (described in Chapter 5 Section 5.2.3) of the actor's ego-network is examined. This relationship is formulated in Hypothesis 11 (H11). As H11 predicts, in a patent co-authorship network, there is a positive association between centrality and density; however for pharmaceutical-biotechnology SMEs this association is not strong. The scatter plot of these two constructs is illustrated in Figure 8-5.

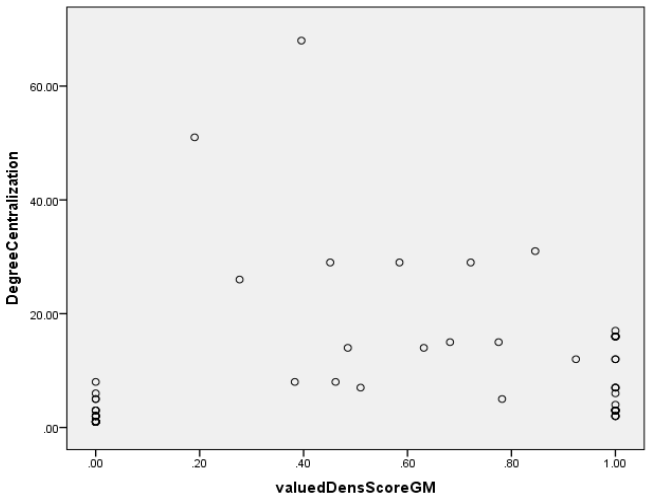


Figure 8-5 Scatter plot of density-centrality

Using the 69 measures from the Victorian biotechnology industry, the association of degree centrality of actors (mean = 8.985, S.D = 11.982) with the valued density of actors' ego-networks (mean = .5078, S.D = .4534) was tested. A Spearman correlation coefficient

analysis revealed moderately positive correlation ($\rho = .492$, $\alpha = .000$). Actors who were located in a more central position tended to possess more closed ego-networks. This means that in the Victorian biotechnology industry, central actors tend to keep their partnerships closed, though a more central position may allow actors a higher chance of bridging to a new set of partners. This is a general finding for the whole Victorian biotechnology network. To analyse the situation for the 22 pharmaceutical-biotechnology SMEs, the data set was split according to size and organisational type.

First, the size of the actors did not strengthen the centrality-density relationship. To check the effect of size, the partial correlation was run and showed a less positive correlation ($\rho = .335$, $\alpha = .005$). Moreover, the results of the analysis for the whole SME sector was more significant ($\rho = .480$, $\alpha = .008$). For pharmaceutical-biotechnology SMEs, this relation was also significant ($\rho = .579$, $\alpha = .005$). In the pharmaceutical-biotechnology SMEs there was a significant correlation between ego-network density of a pharmaceutical-biotechnology SME and the position of that SME in the whole industry k-networks, as reported in Table 8-13. However, as shown in the scatter plot, it seems that there could be a non-linear relationship (Figure 8-6). This point is elaborated later in Chapters 9 and 11.

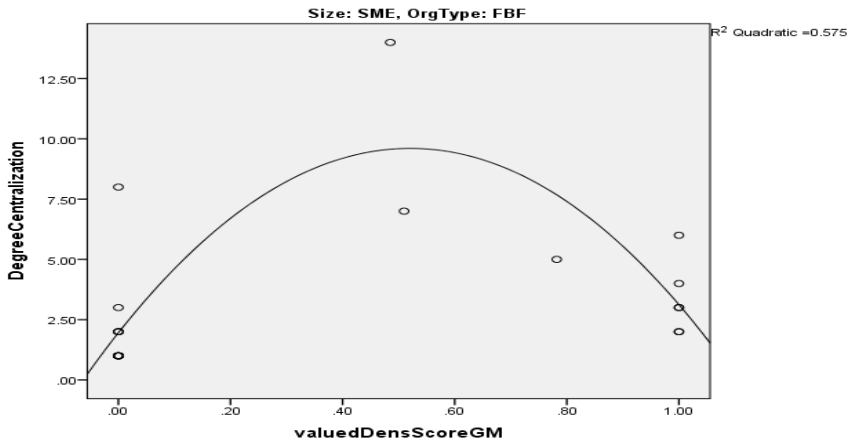


Figure 8-6 Scatter plot of density-centrality for pharmaceutical-biotechnology SMEs

Table 8-13 Spearman test for density-centrality association size and organisational type

Size	OrgType				DegreeCentralization	valuedDensScoreGM
Individual	Individual	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	.427
				Sig. (2-tailed)	.	.087
				N	17	17
			valuedDensScoreGM	Correlation Coefficient	.427	1.000
				Sig. (2-tailed)	.087	.
				N	17	17
Large	PBF	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	.742
				Sig. (2-tailed)	.	.091
				N	6	6
			valuedDensScoreGM	Correlation Coefficient	.742	1.000
				Sig. (2-tailed)	.091	.
				N	6	6
	H	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	-.551
				Sig. (2-tailed)	.	.257
				N	6	6
			valuedDensScoreGM	Correlation Coefficient	-.551	1.000
				Sig. (2-tailed)	.257	.
				N	6	6
	PRO	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	.733*
				Sig. (2-tailed)	.	.010
				N	11	11
			valuedDensScoreGM	Correlation Coefficient	.733*	1.000
				Sig. (2-tailed)	.010	.
				N	11	11
SME	PBF	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	.579**
				Sig. (2-tailed)	.	.005
				N	22	22
			valuedDensScoreGM	Correlation Coefficient	.579**	1.000
				Sig. (2-tailed)	.005	.
				N	22	22
	PRO	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	.233
				Sig. (2-tailed)	.	.615
				N	7	7
			valuedDensScoreGM	Correlation Coefficient	.233	1.000
				Sig. (2-tailed)	.615	.
				N	7	7

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

8.3.2 Centrality and process

According to the analysis reported in Chapter 6 (Section 6.3.2), actors who possessed a more central position showed a greater propensity for exploring new partners. This was a general finding for the whole Victorian biotechnology network. Likewise, the result of the analysis for the SME sector was strongly significant ($\rho = .807$, $\alpha = .000$), as was also the case for pharmaceutical-biotechnology SMEs ($\rho = .833$, $\alpha = .000$). It means there is a strong sign to see a significant positive correlation between exploration collaborative process of a pharmaceutical-biotechnology SME and the central position of that SME (more details are provided in Chapter 7 Section 7.3.2).

8.3.3 Centrality and content

According to the analysis reported in Chapter 6 (Section 6.3.3), actors who possess a more central position showed a slightly greater propensity to explore new knowledge areas. This was the general finding for the whole Victorian biotechnology network. However the result of the analysis for the SME sector was not significant ($\rho = .363$, $\alpha = .053 > .05$), and neither was that for pharmaceutical-biotechnology SMEs ($\rho = .345$, $\alpha = .116 > .05$). There was no significant positive correlation between knowledge diversity of a pharmaceutical-biotechnology SME and the position of that SME (more details are provided in Chapter 6, Section 6.3.3).

8.3.4 Summary of the findings on association of centrality and density

Given the quantitative approach taken in Phase 2, here is a summary of findings in relation to the association of centrality and density:

H11: In a patent co-authorship network, there is a positive association between centrality and density; however for pharmaceutical-biotechnology SMEs this association is not strong.

Given the analysis reported above, there was a moderately positive correlation between centrality and density for all actors in the Victorian biotechnology industry. For pharmaceutical-biotechnology SMEs, this relation was also significant. In the pharmaceutical-biotechnology SMEs there was a significant correlation between ego-network density of a pharmaceutical-biotechnology SME and the position of that SME in the whole industry k-network, as reported in Table 8-13. However, as shown in the scatter plot, it seems that there could be a non-linear relationship (Figure 8-5). This point is elaborated later in Chapter 9.

8.4 Association of centrality and density with knowledge creation

Based on the 69 measures from Victorian biotechnology industry, the association of actors' degree of centrality and density of the actor's ego-network with knowledge creation (i.e. the number of the published patents) is examined in this section. According to Hypothesis 12, it was expected to have a positive association between central position of an actor and

the knowledge creation of the actor. Hypothesis 14 also predicted a negative relationship between the ego-network density of an actor and the knowledge creation of the actor. To test these possible relations, Spearman correlation coefficient analysis was used. Chapter 4 (Section 4.4.4), explains why this technique was selected and why the technique is rigorous and valid in this context.

8.4.1 Association of centrality and knowledge creation

This possible association was predicted in Hypothesis 12. The scatter plot of centrality and knowledge creation is shown in Figure 8-7.

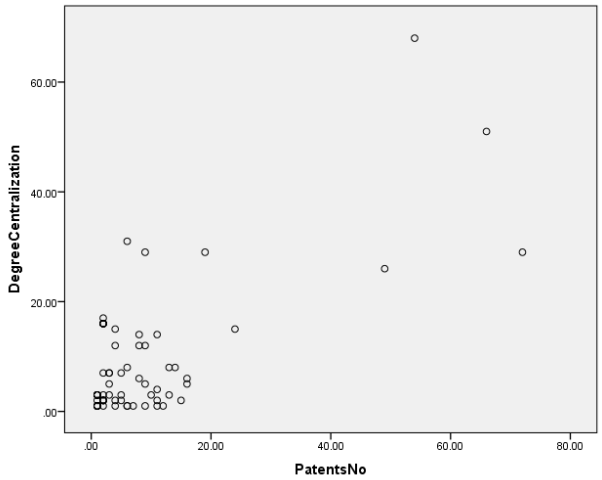


Figure 8-7 Scatter plot of centrality-knowledge creation

In the Victorian biotechnology industry, the association of actors' centrality (mean = 8.985, S.D = 11.982) with knowledge creation (mean = 8.89, S.D = 13.97) was tested. A Spearman correlation coefficient analysis revealed a moderately positive correlation ($\rho = .368$, $\alpha = .002$). This means that the number of patents published by actors was to some extent associated with the position of the actors in the whole k-network. However, this was a general finding for the whole Victorian biotechnology network. To analyse the situation for the pharmaceutical-biotechnology SMEs, the data was split according to size and organisational type. First, it is clearly obvious that size of actor dramatically improved the correlation of centrality and knowledge creation. To check the effect of size, again the partial correlation was used and the result showed that the ρ had increased almost two times ($\rho = .679$, $\alpha = .000$). However the result of the analysis for the SME sector showed

a less strong relation ($\rho = .412$, $\alpha = .026$). This is the case for pharmaceutical-biotechnology SMEs as well ($\rho = .436$, $\alpha = .042$). These results indicate a significant correlation between centrality and knowledge creation in the pharmaceutical-biotechnology SMEs (Table 8-14, Figure 8-8)

Table 8-14 Spearman test for centrality-knowledge creation association according to actor size and actor type

Correlations

Size	OrgType				DegreeCentralization	PatentsNo
Individual	Individual	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	.628**
				Sig. (2-tailed)	.	.007
				N	17	17
			PatentsNo	Correlation Coefficient	.628**	1.000
				Sig. (2-tailed)	.007	.
				N	17	17
Large	PBF	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	.941**
				Sig. (2-tailed)	.	.005
				N	6	6
			PatentsNo	Correlation Coefficient	.941**	1.000
				Sig. (2-tailed)	.005	.
				N	6	6
	H	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	.794
				Sig. (2-tailed)	.	.059
				N	6	6
			PatentsNo	Correlation Coefficient	.794	1.000
				Sig. (2-tailed)	.059	.
				N	6	6
	PRO	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	.821**
				Sig. (2-tailed)	.	.002
				N	11	11
			PatentsNo	Correlation Coefficient	.821**	1.000
				Sig. (2-tailed)	.002	.
				N	11	11
SME	PBF	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	.436*
				Sig. (2-tailed)	.	.042
				N	22	22
			PatentsNo	Correlation Coefficient	.436*	1.000
				Sig. (2-tailed)	.042	.
				N	22	22
	PRO	Spearman's rho	DegreeCentralization	Correlation Coefficient	1.000	.449
				Sig. (2-tailed)	.	.312
				N	7	7
			PatentsNo	Correlation Coefficient	.449	1.000
				Sig. (2-tailed)	.312	.
				N	7	7

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

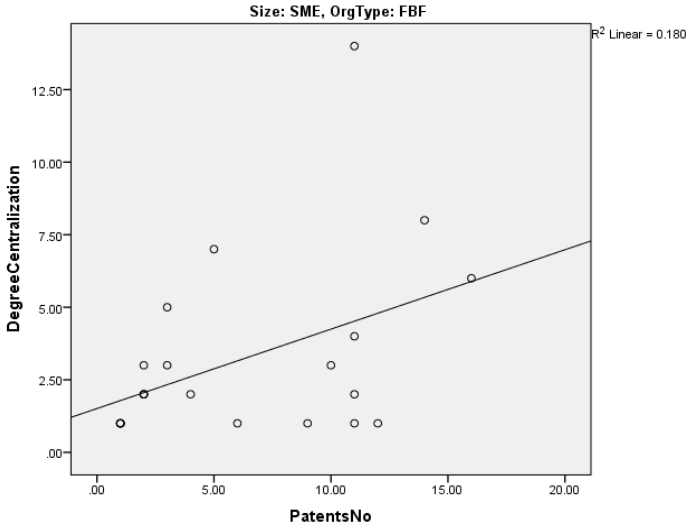


Figure 8-8 Scatter plot of centrality-knowledge creation for pharmaceutical-biotechnology SMEs

8.4.2 Association of density and knowledge creation

Hypothesis 14, as explained in Chapter 3, predicts a negative association between the density of an actor's ego-network and the knowledge creation of the actor. In Figure 8-9, the scatter plot of density and knowledge creation is shown.

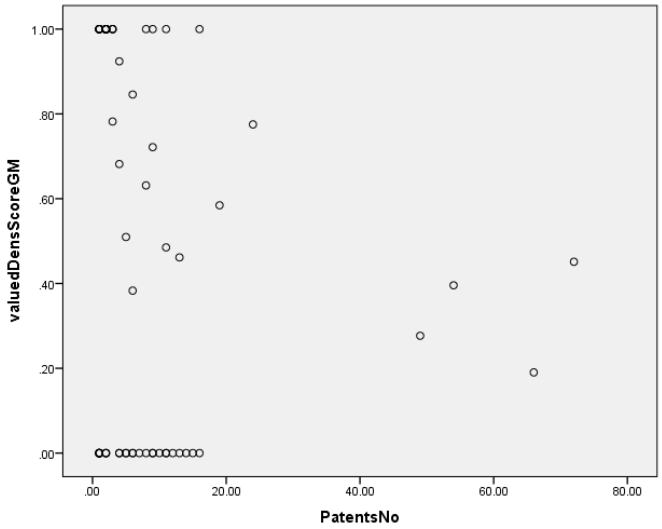


Figure 8-9 Scatter plot of density-knowledge creation

The association of ego-network density of actors (mean = .5078, S.D =.4534) with knowledge creation (mean = 8.89, S.D = 13.97) was tested using the 69 measures from

Victorian biotechnology industry. A Spearman correlation coefficient analysis revealed a moderately negative correlation ($\rho = -.306$, $\alpha = .011$). The number of patents published by actors was to some extent associated with the density of actors' ego-networks in the whole k-network. However this was a general finding for the whole Victorian biotechnology network. To analyse the situation for the pharmaceutical-biotechnology SMEs, I split data according to actor size and organisational type. First, it is clearly obvious that in adding actor size, the correlation dropped from the significance. A partial correlation is used to check the effect of size like the previous similar tests for the other constructs ($\rho = -.012$, $\alpha = .921$). However, the result of the analysis for the SME sector showed no significant relation ($\rho = -.124$, $\alpha = .523$), as was the case for pharmaceutical-biotechnology SMEs as well ($\rho = .028$, $\alpha = .901$). There was no significant correlation between valued density and knowledge creation in the pharmaceutical-biotechnology SMEs (Table 8-15, Figure 8-10).

Table 8-15 Spearman test for density-knowledge creation association according to actor size and actor type

Correlations

Size	OrgType				PatentsNo	valuedDensScoreGM
Individua	Individual	Spearman's rho	PatentsNo	Correlation Coefficient	1.000	.281
				Sig. (2-tailed)	.	.275
				N	17	17
			valuedDensScoreGM	Correlation Coefficient	.281	1.000
				Sig. (2-tailed)	.275	.
				N	17	17
Large	PBF	Spearman's rho	PatentsNo	Correlation Coefficient	1.000	.698
				Sig. (2-tailed)	.	.123
				N	6	6
			valuedDensScoreGM	Correlation Coefficient	.698	1.000
				Sig. (2-tailed)	.123	.
				N	6	6
	H	Spearman's rho	PatentsNo	Correlation Coefficient	1.000	-.754
				Sig. (2-tailed)	.	.084
				N	6	6
			valuedDensScoreGM	Correlation Coefficient	-.754	1.000
				Sig. (2-tailed)	.084	.
				N	6	6
	PRO	Spearman's rho	PatentsNo	Correlation Coefficient	1.000	.533
				Sig. (2-tailed)	.	.091
				N	11	11
			valuedDensScoreGM	Correlation Coefficient	.533	1.000
				Sig. (2-tailed)	.091	.
				N	11	11
SME	PBF	Spearman's rho	PatentsNo	Correlation Coefficient	1.000	.028
				Sig. (2-tailed)	.	.901
				N	22	22
			valuedDensScoreGM	Correlation Coefficient	.028	1.000
				Sig. (2-tailed)	.901	.
				N	22	22
	PRO	Spearman's rho	PatentsNo	Correlation Coefficient	1.000	-.535
				Sig. (2-tailed)	.	.216
				N	7	7
			valuedDensScoreGM	Correlation Coefficient	-.535	1.000
				Sig. (2-tailed)	.216	.
				N	7	7

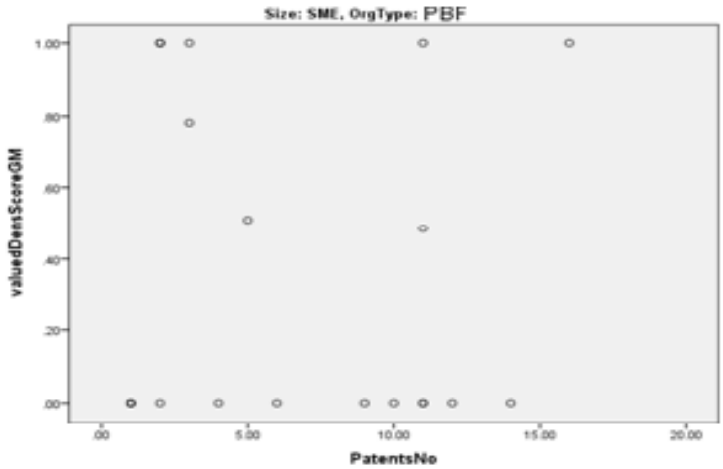


Figure 8-10 Scatter plot of density-knowledge creation for pharmaceutical-biotechnology SMEs

8.5 Summary

In this chapter, I analysed the structure of the Victorian biotechnology-industry network in terms of the position of actors in the whole k-network (centrality) and the valued density of actors' ego-network (density). This chapter reported on three things: first, the role of actor size and actor type; second, the association of structure with other characteristics of k-networks; and third the association of structure with the knowledge creation. The summarised findings are reported in Table 8-16.

Table 8-16 Summary of the hypotheses on structure of k-network

Hypothesis	Result	Description
H10a: In a patent co-authorship network, SMEs have lower levels of centrality compared to their larger counterparts.	Not rejected	The level of centrality is lower in SMEs compared to large actors. Pharmaceutical-biotechnology firms, had a lower level of centrality than that of Hospitals however, there was no significant difference compared to PROs
H10b: In a patent co-authorship network, the level of centrality is higher in non-commercial actors compared to commercial actors (i.e. pharmaceutical companies).	Not rejected	
H10c: In a patent co-authorship network, pharmaceutical-biotechnology SMEs have lower level of centrality compared to their larger counterparts.	Rejected	Although the level of centrality was always lower for SME actors as shown in Figure 8-4, the difference between large, Individuals and SME actors were not statistically significant
H11: In a patent co-authorship network, there is a positive association between centrality and density; however for pharmaceutical-biotechnology SMEs, this association is not strong.	Not rejected	The analysis revealed a moderately positive correlation between centrality and density for all the actors in the Victorian biotechnology industry including pharmaceutical-biotechnology SMEs
H12: In a patent co-authorship network, the level of centrality of actors including pharmaceutical-biotechnology SMEs is positively associated with SMEs innovativeness.	Not rejected	The number of patents published by actors is to some extent associated with the position of the actors in the whole k-network. This was the case for pharmaceutical-biotechnology SMEs as well.
H13a: In a patent co-authorship network, SMEs have no more dense ego-networks compared to large actors.	Not rejected	The level of density was lower in SMEs compared to individual inventors. However SMEs had the same level of density in comparison to large actors.
H13b: In a patent co-authorship network, the level of ego-network density is not the same across actors of different types.	Not rejected	PBFs, had a lower level of density than that of Individuals and slightly lower than Hospitals. However, there was no significant difference compared to PROs. Individuals and Hospitals showed higher levels of density compared to other organisational types.
H13c: In a patent co-authorship network, pharmaceutical-biotechnology SMEs have the same level of ego-networks density compared to large pharmaceutical-biotechnology actors and individual inventors.	Not rejected	Although the level of density for pharmaceutical-biotechnology SMEs was higher than their larger counterparts but lower than Individuals, as shown in Figure 8-5, the differences between large organisations, Individuals and SME actors were not statistically significant.
H14: In a patent co-authorship network, the level of ego-network density of actors is negatively associated with the number of actors' patents; however for pharmaceutical-biotechnology SMEs this association is not strong.	Not rejected	The analysis revealed a moderately negative correlation. The number of patents published by actors was to some extent associated with the density of actors' ego-network in the whole k-network. However, the results of the analysis showed no significant relation for the pharmaceutical-biotechnology SMEs.

Chapter 9

Interaction of Content-Process-Structure of K-network on Knowledge Creation within the Victorian Biotechnology Context

Outline of Chapter 9

After reviewing the constructs of content, process, and structure in previous chapters (Chapter 6–8), this chapter reports the last findings of Phase 2 regarding the interaction of these constructs of the k-network, and how the interaction influences knowledge creation. In particular, it tests Hypothesis 15 (H15), which was formulated as part of the conceptual model in Chapter 3 (Section 3.2). The chapter reports how the combination of binomial regression analysis and interaction analysis were used, to test H15. In this hypothesis, all possible interactions of the constructs (18 models) were tested and possible effects of actor size and actor type on the interaction were examined as well. The results highlight three important interactions. The position of the chapter within the broader research design is illustrated in Figure 9-1.

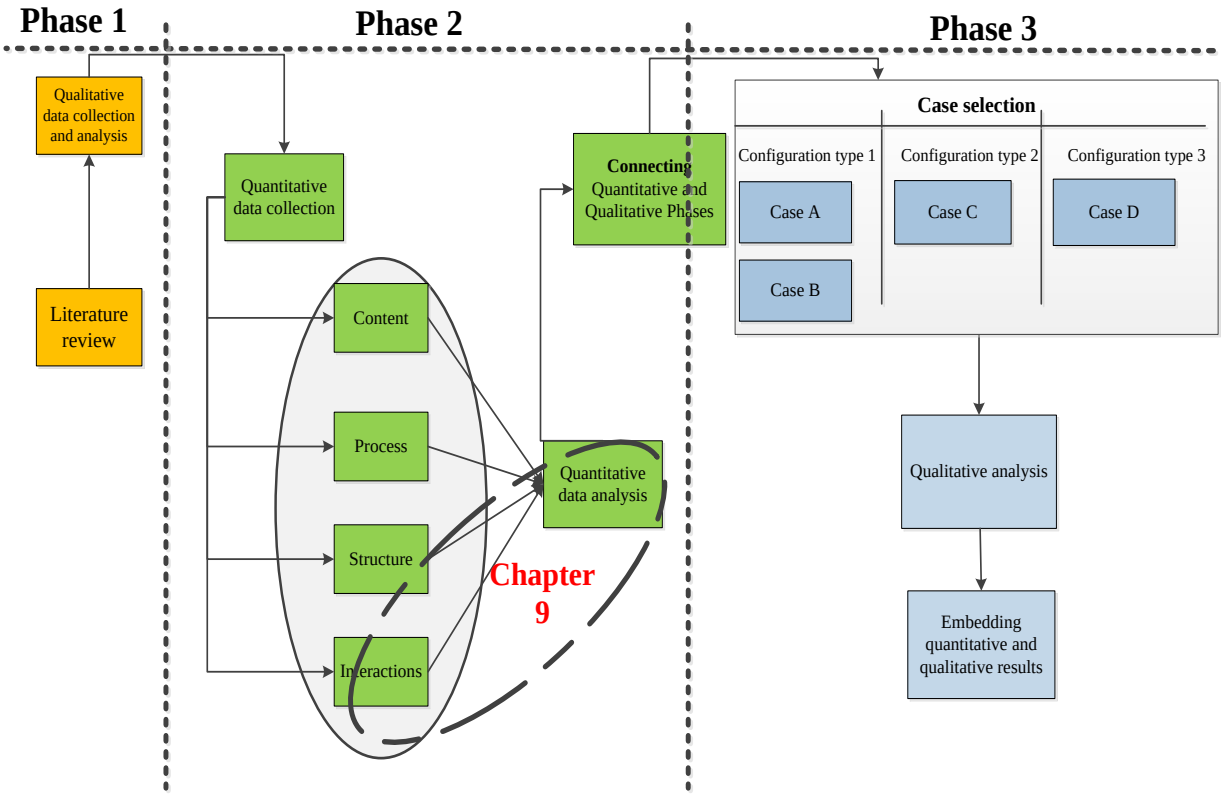


Figure 9-1 Position of Chapter 9 in the wider research design

9.1 Introduction

From what has been found so far, this research reported that each of the constructs of content, process, and centrality and density of structure, affects knowledge creation within the Victorian biotechnology industry. It was found also that these constructs are not fully independent from each other. Moreover, in the real world, the effects of content, process, and structure apply simultaneously and hence there are interaction effects between them that can impact on knowledge creation among actors. The interaction of all constructs was formulated in Hypothesis 15 as reported in Chapter 3 (Section 3.2.3).

To test this hypothesis, the combination of binomial regression analysis and interaction analysis was used, as discussed in Chapter 4 (Section 4.4.2). The results showed three interesting interactions, which have been used to introduce a novel classification of k-network configuration. This classification provided a basis for the selection of cases in Phase 3.

9.2 Moderated multiple regression

Moderated multiple regression (MMR) is frequently employed to analyse interaction effects between continuous predictor (independent) variables (West and Aiken 1991; Irwin and McClelland 2001). Here the question is how the interaction of content, process, structure does affect knowledge creation. In statistical terms, knowledge creation (i.e. number of published patents) is the dependent variable and to test

Hypothesis 15 (H15), this research examined how the covariates or the independent variables interact with knowledge creation in the Victorian biotechnology context (Figure 9-2). The independent variables are knowledge diversity as content, the exploration/exploitation index as structural exploration/exploitation process, and degree centrality and ego-network density as structure of actors' k-networks. To answer this question, the MMR included the binominal multiple regression analysis followed by the interaction analysis (West and Aiken 1991).

There are several methods for analysing multiple regressions like linear regression. However, this research used a negative binomial regression analysis. The details on why this technique was employed and why it is rigorous and valid to use the technique in this context are reported here.

9.2.1 Validity of the analysis

To understand the role of interplay among all the k-network constructs including actor size and actor type with knowledge creation, this research used a negative binomial as an extension of the Poisson multivariate regression analysis by SPSS 20. Since the dependent variable is a counted variable (number of patents), linear regression is not appropriate in modelling such data mainly because the assumptions of homoscedasticity or normally distributed errors are violated[16] as supported by the Koenker test (Koenker and Bassett Jr 1982) for heteroscedasticity (Chi-Square =14.361, Significance level of Chi-square .0062 <.05). Therefore the linear regression model is not recommended so the model is tested by using negative binomial regression analysis. Poisson regression also was not used since Poisson distribution assumes that the mean and variance of the event count are equal. However, in my data set the variance of patents often exceeds the mean. Moreover since I used a single data source to measure both dependent and independent variables, there would be a risk of common-method bias (CMB). However, CMB was not deemed a problem for this analysis (Podsakoff et al. 2003), as the test of Harman's single-factor shows (Variance = .480 < .5). Another assumption in conducting a multi regression analysis is about non-multicollinearity. To check this, here the common test of Tolerance or Variance Inflation Factors (VIF) was used for each variable. In the VIF test, values of between 1.39 and 3.34 were obtained as reported in Appendix 6. According to the common rule, VIF should be less than 10. Also in the moderated multiple regressions, the procedure of mean centring is commonly recommended to mitigate the potential threat of multicollinearity; however the effectiveness of this method is debated in the literature (Shieh 2011; Dalal and Zickar 2012).

[16] The heteroscedasticity was also reflected in the histogram of residuals and the scatter plot standardized residuals vs. predicted value, since there is a funnel pattern in plot i.e. for the higher predicted values there are more fragmented variance (residuals). These figures are illustrated in Appendix 6.

In this analysis, the method of data centring was tested for interaction of centrality and knowledge diversity, but did not produce any significant different results. To be consistent with the literature (Rodan and Galunic 2004), for this analysis I used 0.05 significance level. Finally to check for interactions of construct I used normalised variables in order to avoid the problematic β weight. The detailed discussion can be found in (Irwin and McClelland 2001).

9.2.2 Interaction Models

Several models were tested to check for the possible interaction of content, process and structure (both centrality and density). The summary of all the tests are reported in Table 9.2.

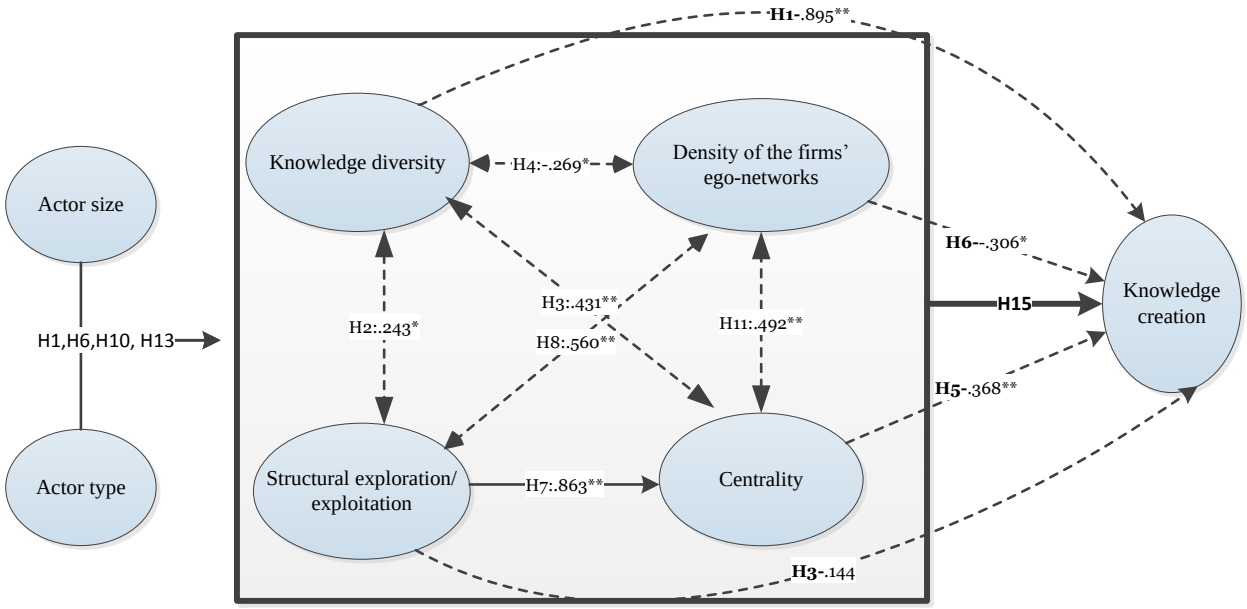


Figure 9-2 Hypothesis 15 (H15) in the whole conceptual model
** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed).

This interaction analysis includes 17 models since I have four variables of centrality, density, knowledge density, and exploration collaborative process. Therefore the possible combinations of interactions among each two variables were six (i.e. (4*(4-1))/2). However to check the two-variable interaction first I checked multivariate regression analysis of two variables, then I added the interaction term (i.e. the product of two variables) to each

model. Therefore 12 models were required to check the interaction among each two models (Model 1 to Model 12). Then based on the significant results, I added five more models to check the interaction among three variables and finally among all four variables (Figure 9-2). However, there were 4*2 possible interactions required for the three-variable interaction models and 1*2 for four-variable interaction. Therefore, a total of 22 possible models was needed. However from all the Model 1 to Model 12, two-variable interactions, there were three significant models, including content-centrality, exploration-density, and exploration-centrality. Therefore I only reported four out of eight possible models (Model 13 to Model 16) since there were only some models that were significant in the two-variable interaction models. Finally I tested the interactions of all four variables (Model 17 to Model 18).

Table 9-1 provides the descriptive statistics and the correlations between the variables for the 69 cooperative actors. Table 9-2 represents the results of the binomial regression analysis to explain the knowledge creation of the actors in the Victorian biotechnology industry. In the rest of the chapter, I report on the follow up interaction analysis for the significant results.

9.3 Results of binomial regression analysis

The descriptive statistics and the correlations between the variables for the 69 cooperative biotechnology actors are provided in Table 9-1. The results of the binomial regression analysis to explain knowledge creation of the actors in the Victorian biotechnology industry are also reported in Table 9-2. Table 9-2 does not show the results of tests for the size and type simply because of the space limitation and because neither size nor type is significant in these models. However, the details are reported in Appendix 6.

Table 9-1 Descriptive analysis of all variables and interactions

Variable	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Patent number	8.90	13.98	1													
2. Degree centrality normal	8.99	11.89	.368**	1												
3. Valued-density	.51	0.45	-.306*	.492**	1											
4. Knowledge diversity	0.52	0.30	.895**	.431**	-.269*	1										
5. Exploration/exploitation index	0.53	0.29	.144	.863**	.560**	.243*	1									
6. Valued-density *centrality	0.18	0.64	-.043	-.369**	-.605**	-.002	-.346**	1								
7. Knowledge diversity *Exploration/exploitation	0.33	1.12	.017	.087	-.213	-.019	.003	.095	1							
8. Knowledge diversity *Centrality	6.23	10.61	.625**	.899**	.214	.691**	.713**	-.143	.156	1						
9. Knowledge diversity * Valued-density	-0.18	0.99	-.079	-.009	-.087	-.124	-.093	.426**	.635**	.149	1					
10. Valued-density* Exploration/exploitation	.60	0.83	-.451**	-.360**	-.194	-.395**	-.277*	.669**	-.141	-.338**	.292*	1				
11. Centrality* Exploration/exploitation	0.56	1.01	.059	.010	-.354**	.101	-.155	.558**	.427**	.152	.403**	.455**	1			
12. Centrality * Valued-density * exploration/exploitation	-.21	.73	.059	.628**	.557**	.148	.641**	-.180	.019	.540**	.000	-.356**	-.170	1		
13. Centrality* Knowledge diversity * Exploration/exploitation	.16	1. 45	.461**	.316**	.067	.518**	.277*	-.226	-.459**	.313**	-.484**	-.212	-.046	-.044	1	
14. Centrality* Knowledge diversity * Exploration/exploitation * Valued density	.11	.95	-.441**	-.183	-.012	-.515**	-.090	.182	.387**	-.324**	.474**	.238*	-.094	-.105	-.316**	1

Valid N (listwise) 69 ** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed).

Table 9-2 Binominal regression models

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14	Model 15	Model 16	Model 17	Model 18
Degree norm-centrality	.025* 0.011)	-0.02 (0.2)							.059** (.012)	.054** (.014)	.64** (.014)	.139** (.034)	.058** (.015)	.064** (.0162)	.038** (.014)	.043* (.018)	.037* (.014)	.036** (.015)
Valued-density			-.410 (.003)	-.411 (.335)			-1. 52** (.3640)	-1.55 (.412)	-.988** (.3088)	-1.16** (.349)			-.998† (361)	-1.10* (.384)			-.295 (414)	-.303 (.416)
Knowledge diversity	2.86** (0.532)	3.78** (.73)	3.43** (.470)	3.43** (.475)	3.61** (.512)	3.74** (.522)									2.96** (.547)	3.015** (559)	2.800** (.592)	2.75** (.653)
Exploration/exploitation index					-.228 (.567)	-.216 (.553)	2.32** (.580)	1.112 (.705)			-1.018 (.654)	-2.892* (.993)	.042 (.769)	-.363 (.900)	-1.17† (.643)	-1.17† (.643	-.820 (8131)	-.810 (.815)
Centrality*Valued density										-.334 (.290)								
Knowledge diversity * Exploration/exploitation						.196 (.143)												
Knowledge diversity *centrality		0.508† (0.282)																
Knowledge diversity * Valued-Density				-.005 (.157)														
Valed Density* Exploration/Exploitation								-.79** (.212)										
Centrality*Exploration/ Exploitation												-.889* (.317)						
Centrality * Valued-density *Exploration/exploitation														.284 (.308)				
Centrality* Knowledge diversity*Exploration/ exploitation																-.068 (158)		
Centrality* Knowledge diversity*Exploration/exploit ation *Valued density																		-.306 (.200)
Likelihood Ratio Chi-Square	62.484	65.723	58.679	58.680	57.337	59.248	23.729	38.386	43.401	44.749	35.784	45.771	43.40	44.229	65.832	66.014	66.335	66.367
Goodness of Fit-Bayesian Information Criterion (BIC)	397.35	398.34	401.155	405.388	402.497	404.820	436.104	425.682	416.433	419.319	424..05	418.297	420.66 4	424.073	398.236	402.298	401.96	406.16
Model Degree of freedom	2	3	2	3	2	3	2	3	2	3	2	3	3	4	3	4	3	5
Prob.> Chi-Square	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

Note. ** significant at ρ=0.01 * significant at ρ= 0.05 † significant at ρ= 0.1 Standard errors in parentheses

9.4 Interaction analysis

As shown in Table 9-2, there were three significant interactions identified – in Model 2, Model 8, and Model 12. These interactions support H15, that the combination of content, process, and structure of actors' k-networks influence the actors' knowledge creation. For further analysis of these results, the interaction analysis (West and Aiken 1991) was used, which provided more insights about the interrelationship between content, process and structure to explain H15.

9.4.1 Content and centrality

First to understand the role of diversity of knowledge and centrality, in Model 1, the impact of these two variables on knowledge creation was tested. Size and type were also used as control variables; however the results showed that neither actor size nor actor type was significant in this model (Table 9-3). As shown in Model 1, knowledge diversity and central position were significant. However, in Model 2 when I included the interaction of both centrality and knowledge diversity, centrality falls from significance. However the interaction is barely significant.

Table 9-3 Impact of knowledge diversity and centrality on knowledge creation with regard to actor size and actor type

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-.362	.3492	-1.046	.322	1.076	1	.300
Knowledge diversity	3.783	.7325	2.347	5.218	26.674	1	.000
DegreeCentralization	-.022	.0276	-.076	.032	.615	1	.433
DegreeCentrality_Knowledge diversity	.508	.2822	-.045	1.061	3.244	1	.072
(Scale)	1[a]						
(Negative binomial)	1[a]						

Dependent Variable: PatentsNo
Model: (Intercept), KHetero, DegreeCentralization, DegreeCentrality_KHetro_Normalized
a. Fixed at the displayed value.

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	Sig.
(Intercept)	1.076	1	.300
Knowledge diversity	26.674	1	.000
DegreeCentralization	.615	1	.433
DegreeCentrality_Knowledge diversity	3.244	1	.072

Dependent Variable: PatentsNo
Model: (Intercept), KHetero, DegreeCentralization, DegreeCentrality_KHetro_Normalized

Following this multiple regression analysis, to get more insight about possible interactions of content and centrality on knowledge creation, interaction analysis was used (West and Aiken 1991). According to West and Aiken (1991), to see the role of

interaction, all 69 actors were categorised based on knowledge diversity level into three groups of low, medium and high.

As shown in Figure 9-3, it is clear that the centrality of actors in the k-network is not associated with knowledge creation (i.e. number of patents) if the actors possess low knowledge diversity (i.e. the horizontal line $R^2 = 0$).

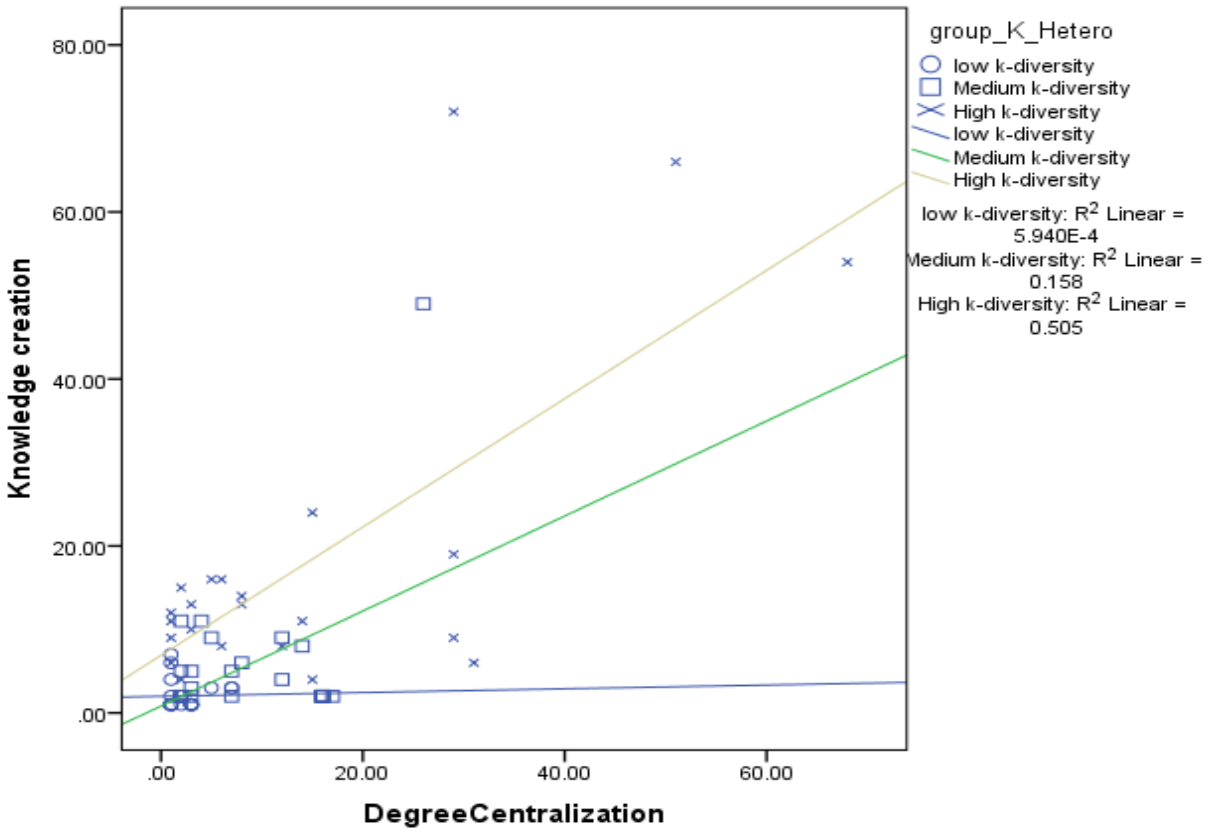


Figure 9-3: The correlation between patent number (knowledge creation) and centralisation based on the three groups of knowledge diversity

For the actors with medium level knowledge diversity, the association between knowledge creation and centrality increased (i.e. the middle line R^2 = .158). This analysis shows that for the group with medium level of knowledge diversity, almost 40% (R = 0.397) of their knowledge creation behaviour is associated with their centrality. However for the actors with high knowledge diversity, (i.e. the upper line R^2 = .505) this reached 71% (R = 0.710).

Then, to retest these results about centrality and knowledge diversity, I also categorised all 69 actors based on centrality (i.e. low, medium and high central actors). In the scatter plot of knowledge diversity and knowledge creation for the three groups with low, medium and high centrality (Figure 9-4), the results show that knowledge diversity

regardless of degree of centrality always showed significant correlation with knowledge creation (R^2 for low, medium and high centrality groups are as follows 53%, 57%, and 47%).

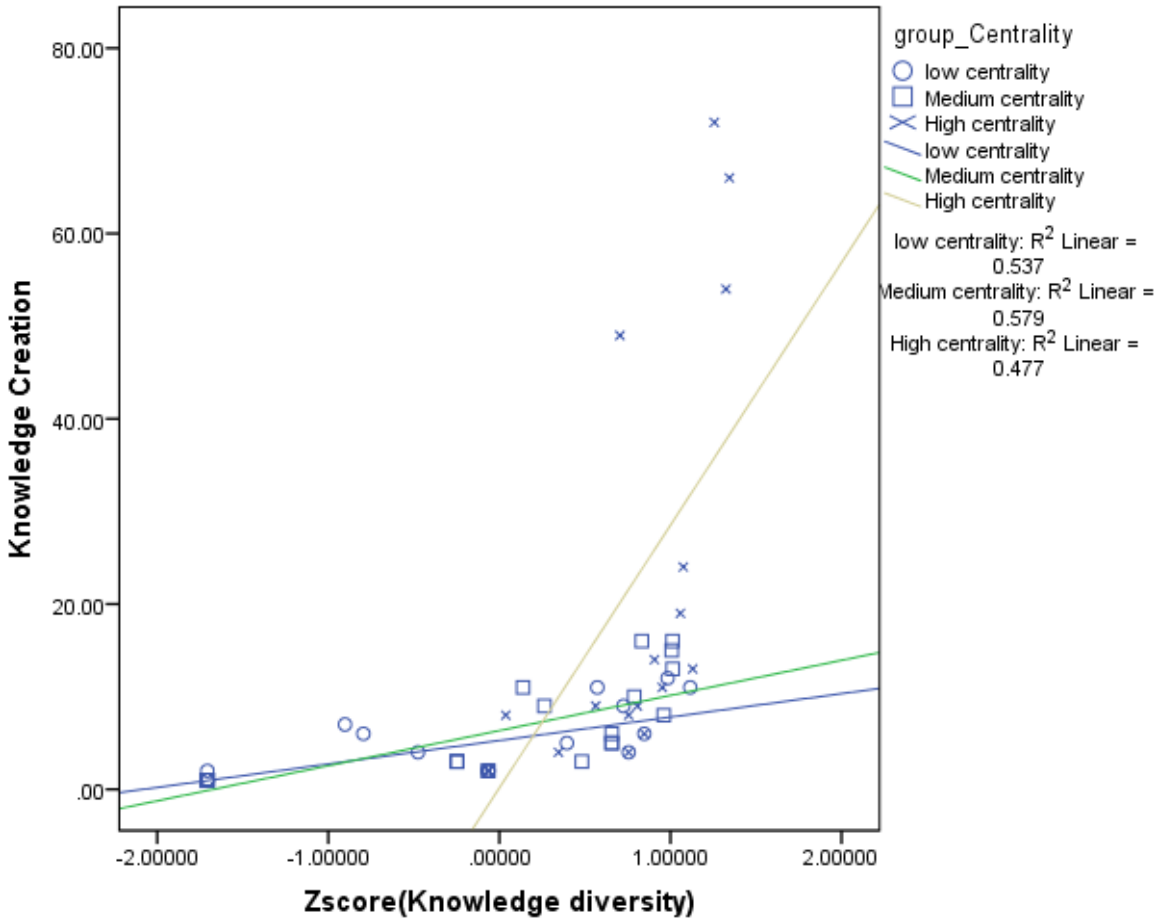


Figure 9-4 The correlation between patent number (knowledge creation) and knowledge diversity based on the three groups of centralisation

This is supported by the results of multi-regression analysis as well. In summary this moderated multiple regressions analysis suggests that 1) having a central position shows less contribution to the knowledge creation of actors compared with possessing diverse knowledge, and 2) these two complement each other to support knowledge creation. In other words, if an actor possesses some level of diverse knowledge, then gaining a more central position might lead to a higher level of knowledge creation.

9.4.2 Density and process

Beyond the bilateral association of actors' ego-network density and knowledge creation (H14), as shown in Figure 9-2, the interaction of density and process was also associated with knowledge creation (as supported by Model 8 in Table 9-2). To understand the role of structure, Model 7 which includes sparseness (which is 1-density), was tested. Size and type were also used as control variables; however the result showed that neither actor size nor actor type was significant in this model (Table 9-4).

In this model exploration/exploitation index showed positive but not significant effects on knowledge creation (α = .115); however density showed significant negative effects (α = .000). However the combination of these two associated negatively with knowledge creation (β = -.797, α = .000). According to this multiple regression analysis, it is clear that the interaction of density and exploration is significantly associated with knowledge creation; however the exploration/exploitation process on its own has no impact.

Table 9-4 Impact of exploration/exploitation and density on knowledge creation with regard to actor size and actor type

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	4.968	.6396	3.714	6.221	60.331	1	.000
Exploration/Exploitation index	-2.206	.6928	-3.563	-.848	10.135	1	.001
Density	-2.634	.5444	-3.701	-1.567	23.410	1	.000
Exploration/Exploitation_Density_normal	-.396	.2495	-.885	.093	2.520	1	.112
(Scale)	1[a]						
(Negative binomial)	1[a]						

Dependent Variable: PatentsNo
Model: (Intercept), Exploration/Exploitation index, Density, Exploration_Density_normal
a. Fixed at the displayed value.

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	Sig.
(Intercept)	60.331	1	.000
Exploration/Exploitation index	10.135	1	.001
Density	23.410	1	.000
Exploration/Exploitation_Density_normal	2.520	1	.112

Dependent Variable: PatentsNo
Model: (Intercept), Exploration/Exploitation index, Density, Exploration_Density_normal

To gain further insight about possible interactions of collaborative process and density on knowledge creation, here also all 69 actors were categorised based on density into three groups of low, medium and high density (West and Aiken 1991). As shown in Figure 9-5, it is clear that the association of exploration/exploitation with knowledge creation is mixed: being both positive and negative. This is why the effect of this variable in the model above is not significant.

More precisely, for actors with a low density ego-network, exploration results in more patents (R = .40). Even for actors with medium density ego-networks, there is a positive association between exploration collaborative process and knowledge creation in terms of patents. However when actors are located in a high-density network, increasing exploration resulted in lower knowledge creation (R = -.40).

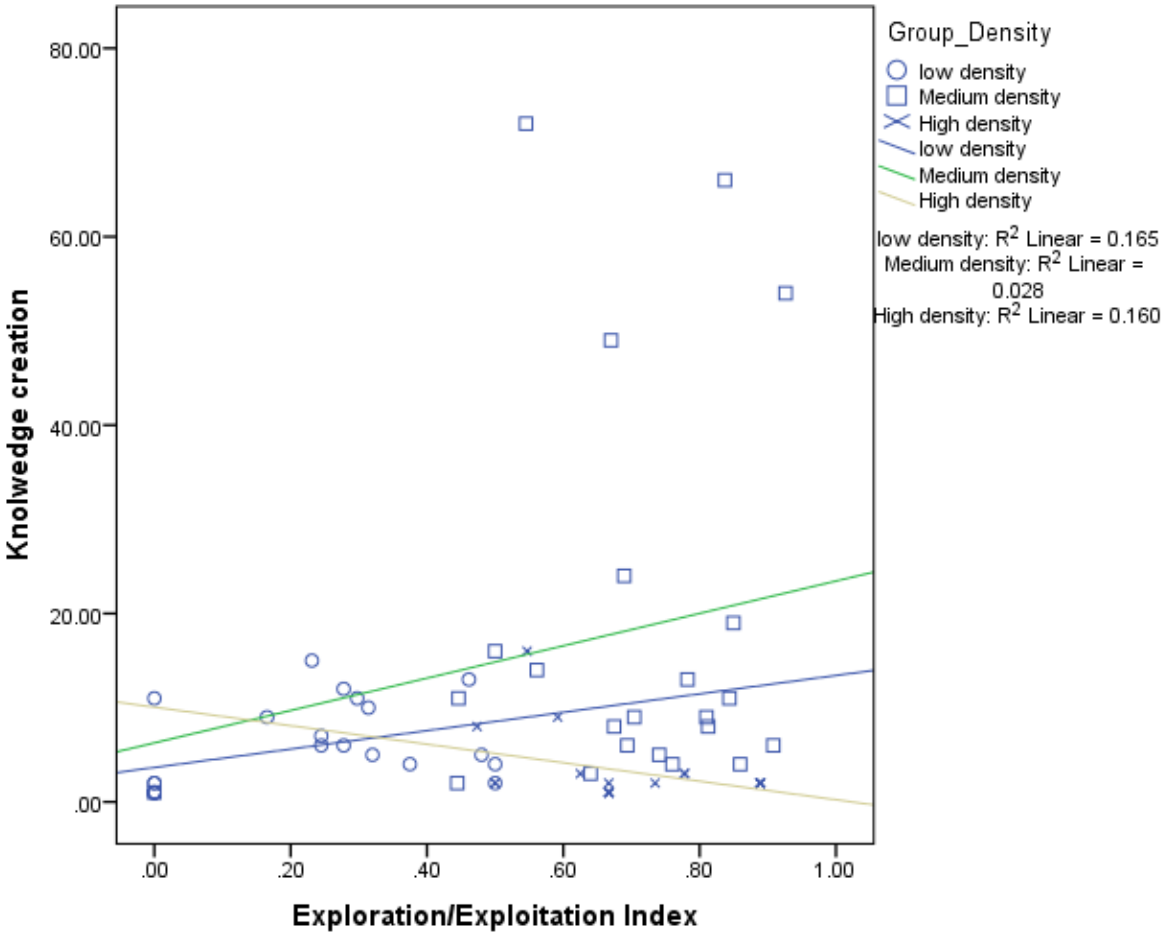


Figure 9-5 The correlation between patent number (knowledge creation) and exploration/exploitation process based on the three groups of density

According to the scatter plot of density and knowledge creation for three groups of low (actors with exploitation process), medium (actors with balanced exploration/exploitation collaborative process) and high (actors with exploration collaborative process), the results also show that density regardless of collaborative process of actors always had a significant negative correlation with knowledge creation (Figure 9-6). However, the impact for actors with exploitation process was very weak (R for low, medium and high exploration groups are as follows .09, -.30, and -0.52).

This is supported by the multi-regression analysis result as well since density remains significant even after the moderation factor of exploration/exploitation was added (Table 9-2).

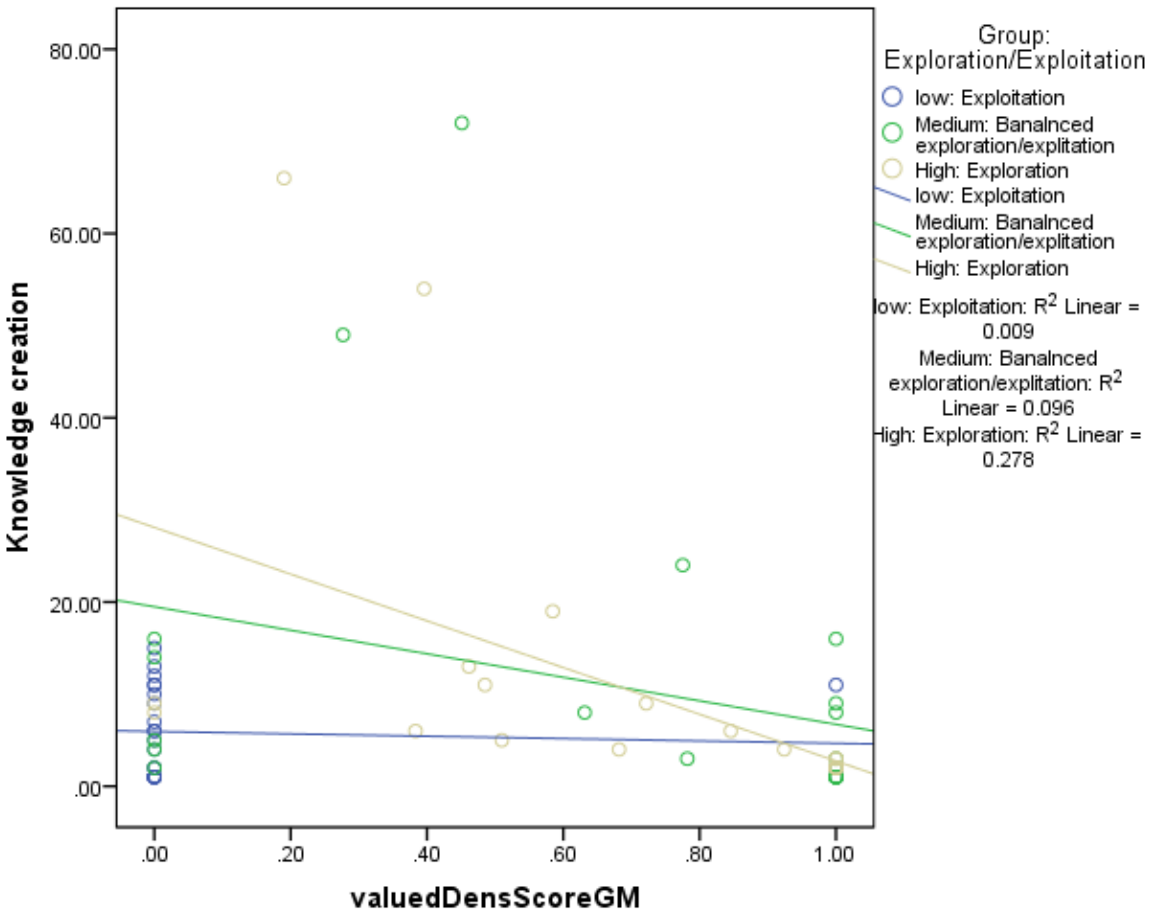


Figure 9-6 The correlation between patent number (knowledge creation) and density based on the three groups of exploration/exploitation process

A Spearman correlation coefficient analysis between density and exploration revealed a moderate positive correlation (ρ = .560, α = .000). This means that actors located in k-networks with a certain level of ego-network density tended to focus on exploration collaborative process. In other words, considering interaction analysis, it is clear that focusing on exploration for actors with low dense network may facilitate more knowledge creation, however probably it would not be the case for the actors in dense network. In summary, the results show that focusing on exploration may lead to higher patents only for actors with low density networks. This association is still positive until the actors reach the medium level of density (mean of geo-metric valued density =

.526). Then, in contrast for the actors with a high dense ego-network, pursuing exploration may result in lower patents.

9.4.3 Process and centrality

Another significant interaction was among process and centrality, as is shown in Model 11 (Table 9-2). According to the binominal multivariate analysis followed by the interaction analysis, it is clear that beyond the bilateral association of centrality and knowledge creation (H5), the interaction of centrality and exploration/exploitation process was associated with knowledge creation. In summary, focusing on exploration may lead to higher knowledge creation only for actors with peripheral position in the k-network. In contrast for the actors with more central position pursuing exploration may result in lower knowledge creation. The details of these results, are reported here.

First in Model 11, size and type were also used as control variables; however the result showed that neither actor size nor actor type was significant in this model (Table 9-5). Exploration/exploitation process had no significant effects on patents (α = .120); however centrality showed a very weak positive influence (β = .064, α = .000). Nevertheless in Model 12 when the interaction factor was added, all of them became significant. The exploration/exploitation process has a negative impact, therefore the combination of these two constrcuts associated negatively with knowledge creation (β = -.889, α = .005) and the model improved as the Goodness of Fit-Bayesian Information Criterion (BIC) decreased (Tables 9-2), however not very significantly.

Table 9-5 Impact of knowledge diversity and centrality on knowledge creation with regard to actor size and actor type

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.872	.3250	1.235	2.509	33.192	1	.000
DegreeCentralization	.064	.0144	.036	.092	19.624	1	.000
Exploration/exploitation index	-1.018	.6546	-2.301	.265	2.419	1	.120
(Scale)	1[a]						
(Negative binomial)	1[a]						

Dependent Variable: PatentsNo
Model: (Intercept), DegreeCentralization, Exploration/exploitation index

a. Fixed at the displayed value.

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	Sig.
(Intercept)	33.192	1	.000
DegreeCentralization	19.624	1	.000
Exploration/exploitation index	2.419	1	.120

Dependent Variable: PatentsNo
Model: (Intercept), DegreeCentralization, Exploration/exploitation index

To test the interaction analysis, all actors were categorised based on the exploration/exploitation index into three groups of low (i.e. actors with exploitation process), medium (i.e. actors with balanced exploration/exploitation process) and high (i.e. actors with exploration collaborative process). According to the scatter plot of centrality and knowledge creation for these three groups, the results showed that centrality regardless of collaborative process of actors always had significant positive correlation with knowledge creation (Figure 9-7).

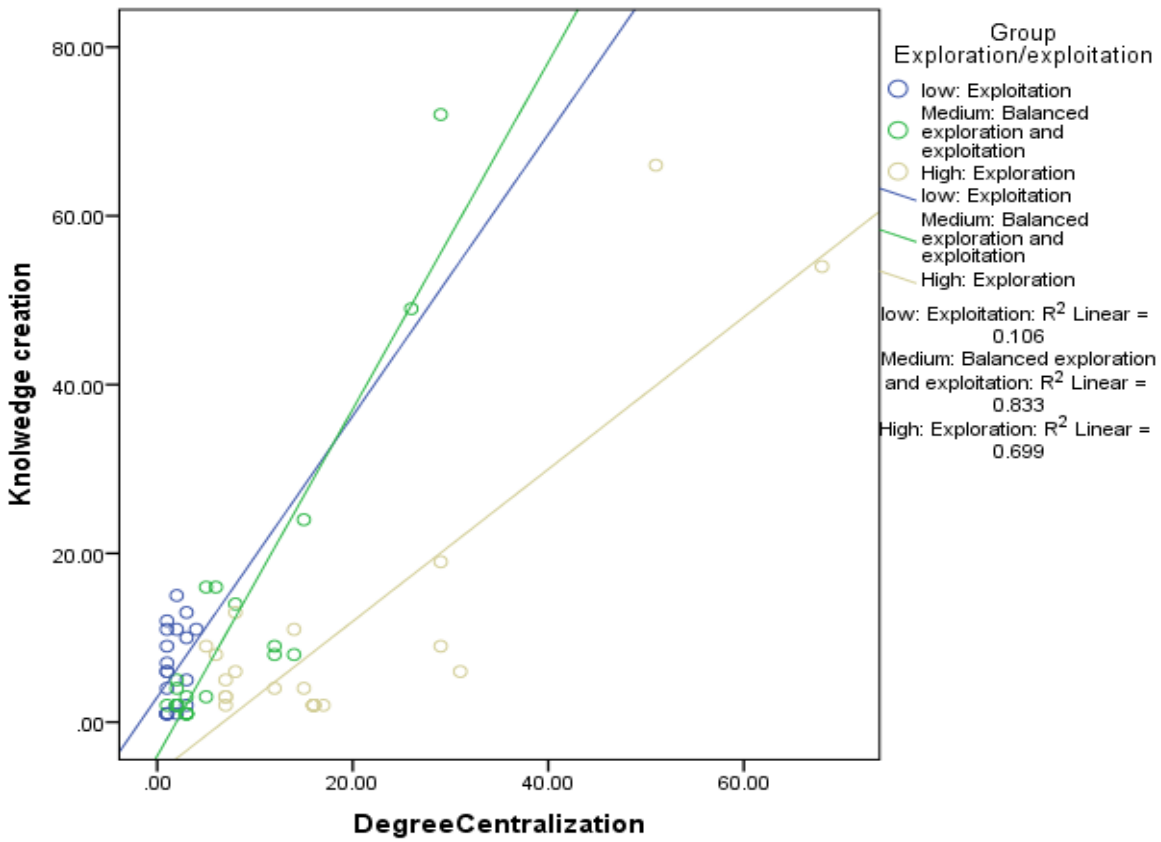


Figure 9-7 The correlation between patent number (knowledge creation) and centrality based on the three groups of exploration/exploitation process

However the impact for actors with low diverse partners (exploitation collaborative process) was not very strong (R = 0.32) compared to actors with medium (R = 0.91) and high exploration (R = 0.83) groups. This was supported by the multi-regression analysis as well since density remained significant even after adding the moderation factor of exploration. Also exploration had a mixed positive and negative association with knowledge creation. This is why the effect of this variable in Model 11 is not significant. More precisely, for peripheral actors (low central), focusing on exploration

collaborative process resulted in more knowledge creation (R = .14). However for firms with a medium central position, there was a negative association between collaborative process and knowledge creation (R = -.54). Likewise when very central actors focused on higher exploration process, this resulted in a lower number of patents (R = -.26). Focusing on exploration may lead to higher knowledge creation only for actors with a peripheral position in the k-network. In contrast, for actors with a more central position, pursuing exploration may result in lower knowledge creation (Figure 9-8).

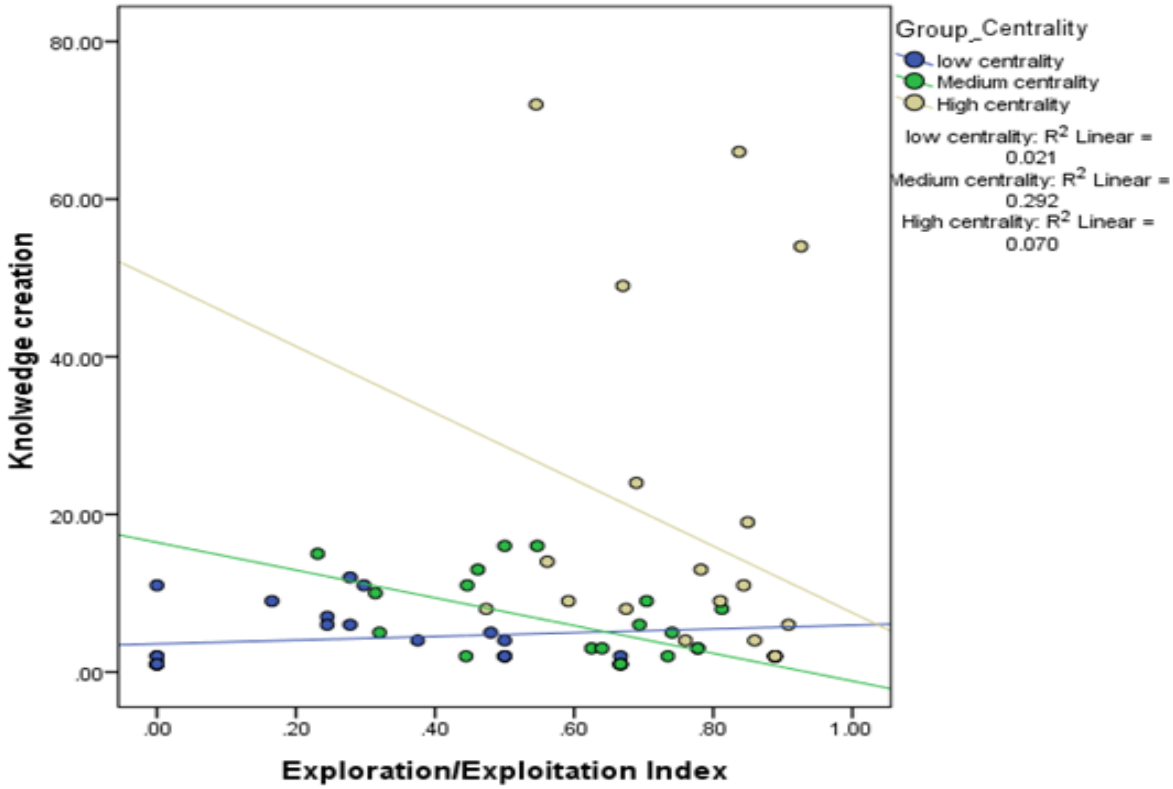


Figure 9-8 The correlation between patent number (knowledge creation) and exploration/exploitation process based on the three groups of centralisation: Summary of the results

A Spearman correlation coefficient analysis between centrality and exploration/exploitation process revealed a very strong positive correlation (ρ = .863, α = .000). Actors who possessed a more central position in the k-network were more inclined to explore new partners. Adding this to the interaction analysis, we can see that actors with a high central position cannot expect to increase their knowledge creation by contracting with new partners. It means for these actors it would be better if they keep their relations with current partners. In summary, focusing on exploration may lead to higher knowledge creation only for actors with a peripheral position in the k-network.

In contrast for the actors with more central position pursuing exploration may result in lower knowledge creation.

9.5 Summary

Hypothesis 15 (H15) predicted that in a patent co-authorship network, the level of knowledge creation of actors (including SMEs) is influenced by the interactions of knowledge diversity, collaborative process, centrality and density of their network. Using binominal regression analysis followed by the interaction analysis, H15 was tested and confirmed. More specifically, three significant interactions were found. It is also important to mention that using the role actor size and actor type to explain knoweldge creation are far less important compared to the interaction of content, process and structure. While the interaction of content, process and structure were examined, size and type became insignificant; although the role of size and type had been confirmed independently as reported in the previous chapters (Chapter 6, 7 and 8). Hence, these findings do not rely significantly on size and type of the actors, therefore it is possible to assume that the results can be applied to all actors including SMEs (as reported in next chapter) as well. The results can be summarised into three sections.

Interaction 1. As reported before, there is no consensus on the role of centrality that an actor has with its partners on knowledge creation. Having a central position shows less contribution to the actors' knowledge creation compared with possessing diverse knowledge. Moreover, in some circumistances these two complement each other. In other words, if an actor possesses some level of diverse knowledge, then gaining a more central position might lead to a higher level of knowledge creation. This finding is aligned with Wadhwa and Kotha (2006), and provides more explanation about the complementary role of content and centrality in supporting knowledge creation.

Interaction 2. There are two competing views about the role of ego-network structures, namely closed networks vs. sparse networks. In this research, sparseness or low density of ego-networks showed a positive correlation with knowledge creation. This study showed that focusing on exploration may lead to higher knowledge creation only for actors with a low density network. This association was still positive until the actors reached a medium level of density (mean of geo-metric valued density = .526). In contrast, for the actors with a high density ego-network,

pursuing exploration may result in lower knoweldge creation. The collaborative process also shed more light on the mixed results of the structural hole theory as reported in the literature (Beckman and Haunschild 2002; Phelps 2010; Demirkan and Demirkan 2012). According to this theory, a sparse network with many structural holes is a suitable network for brokering (Burt 2004) and bridging with new partners (exploration process).

Interaction 3. The third significant interaction was among process and centrality. This interaction in summary, posits that actors with high central position cannot expect to increase their knowledge creation by emphasising exploration through contracting with new partners. For these actors it would be better if they keep their relations with their current partners. In summary, focusing on exploration may lead to higher knowledge creation only for actors with a peripheral position in the k-network. This interaction seems to be explained by cost of partnership as further explained in Chapters 10 and 11.

Chapter 10

Knowledge Networks in the Context of Selected Cases in the Victorian Biotechnology Industry

Outline of Chapter 10

Following the results of Phase 2 reported in Chapters 5–9, this chapter reports the findings of Phase 3, the qualitative case studies. The aim of this phase was to show how selected cases describe their patent co-authorship network and explain their attitude toward their k-networks.

In this chapter the nominated four cases are introduced purposefully and the way that they were selected is explained. Then each of the four cases is described in detail in relation to the content, process, and structure of its k-network. The case studies were designed to gain more insight about three possible configurations that actors can possess in the whole Victorian biotechnology network.

The results of this analysis show how the findings reported in Chapters 5–9 were confirmed through cases. Other constructs also emerged, which can enrich the conceptual model that was developed in Chapter 3 and tested in Chapters 5–9. The position of the chapter within the broader research design is illustrated in Figure 10-1.

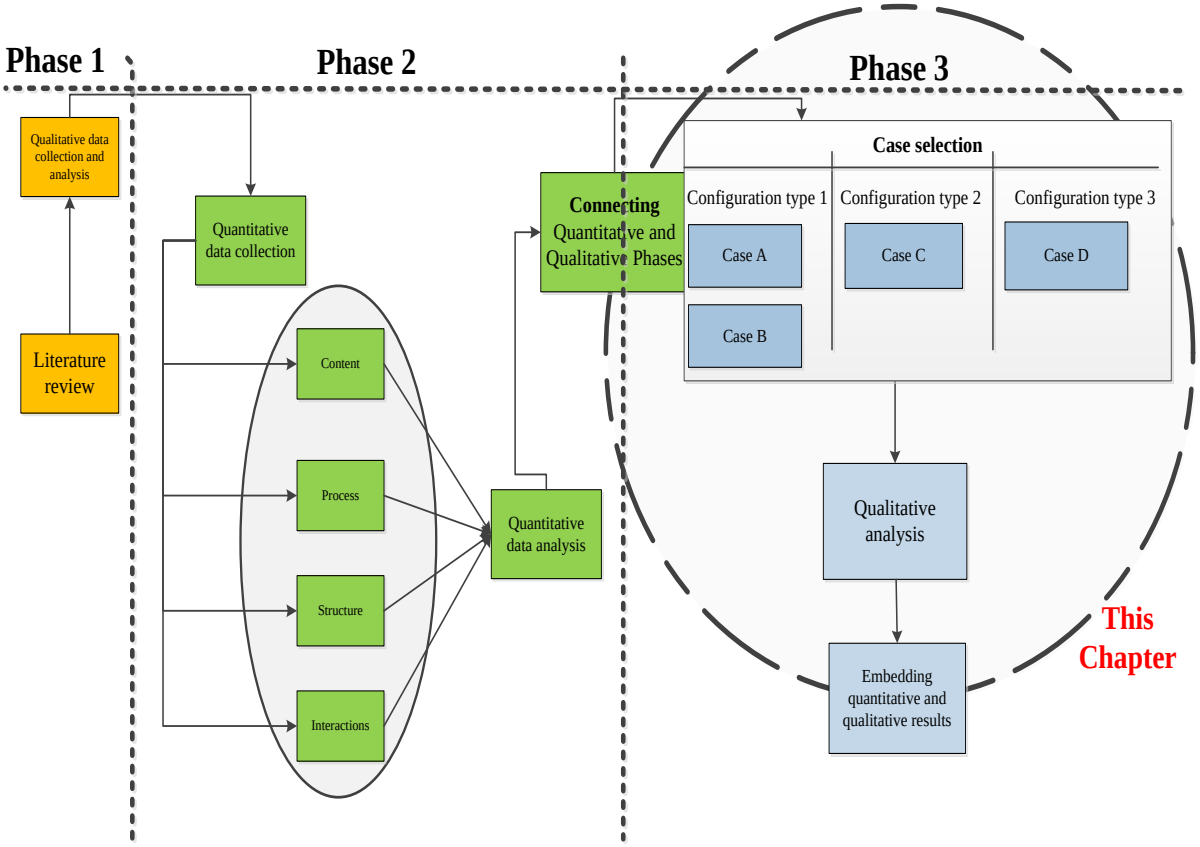


Figure 10-1 Position of chapter 10 within the wider research design

10.1 Introduction

As discussed in the research design Chapter 4 (Section 4.5.2), the purpose of having a qualitative phase after the quantitative one, was the combination of corroboration and confirmation of the results of the quantitative phase.

According to the findings reported in Chapter 9, three possible k-network configurations were identified that contribute to knowledge creation. Case companies were selected to cover these possible configurations. It was hoped to have two companies of each configuration, however, given the availability of cases, I managed to study two cases for only one of the configurations. To select these cases, only private pharmaceutical-biotechnology firms (PBF) that were considered with a focus on small and medium enterprises (SMEs). This was because of two reasons:

1. As also shown in other similar research studies (e.g. Powell et al. 1996; Owen-Smith and Powell 2004), the majority of the participants of the whole industry network in this research were SMEs. The high motivation for SMEs to participate in k-networks and acquire needed knowledge is discussed in the

literature (e.g. Wong and Aspinwall 2004; Shaw 2006), however, few studies in the literature have addressed this sector through qualitative inquiry.

2. To reduce the complexity of research, following Yin's recommendation (2003), only PBF-SMEs were selected purposefully to avoid mixing the results with public SMEs or large size public and private actors like universities or big pharmaceutical companies like the CSL Group.

10.2 Nominated cases

According to SNA results combined with binominal regression analysis, followed by the interaction analysis discussed in Chapter 9, three interactions were explored (Section 9-5). These interactions were used to identify the possible impact of content, process and structure on actors' knowledge creation. As discussed there, these possible impacts were:

- **Positive**: i.e. the combination of content, process, and structure favours the firm's knowledge creation.
- **Mixed**: i.e. some part of the combination of content, process, and structure favours the firm's innovativeness while some other parts hinder the firm's endeavour towards knowledge creation.
- **Neutral** i.e. the combination of content, process, and structure have no particular influence to favour or to hinder the firm's knowledge creation.

Theoretically there are 16 possible configurations of these elements, as enumerated in Table 10-1. On the basis of their impact on knowledge creation, these configurations can be classified into three types. In this section, I used these three possible impacts to select SMEs for in-depth case studies. As shown in the table, all the pharmaceutical-biotechnology SMEs (the cohort of the study) were mapped to these three possible configurations. In the final two columns, the total number of actors and their demographics in terms of size and type are reported. Five out of 16 possible configurations were not matched with any actors in the Victorian biotechnology industry network.

Table 10-1 Mapping network actors into the possible configurations based on the four k-network constructs

Possible Configurations	Centrality	Density	Process	Content	Interactions			Impact on k-creation	PBF-SMEs	Participant actors
					I	II	III			
1	High	High	High	High	+	-	-	Mixed	0	8 Actors – 5 H, 2 PBF, 1 PRO
2	High	High	High	Low	+	-	-	Mixed	0	9 Actors – 9 Individuals
3	High	High	Low	High	+	0	0	Positive	1-SME	2 Actors – 1 SME-PBF, 1 PRO
4	High	High	Low	Low	0	0	0	Neutral	0	0
5	High	Low	High	High	+	+	-	Mixed	1-SME	10 Actors – 1 SME-PRO, 4 large PRO, 5 PFB
6	High	Low	High	Low	+	+	-	Mixed	0	0
7	High	Low	Low	High	+	0	0	Positive	0	1 SME-PRO
8	High	Low	Low	Low	0	0	0	Neutral	0	0
9	Low	High	High	High	+	-	+	Mixed	2-SMEs	2 Actors – 2 SME-PBF
10	Low	High	High	Low	0	-	+	Mixed	2-SMEs	9 Actors – 6 Individuals, 2 SME-PBF, 1 large H
11	Low	High	Low	High	+	0	0	Positive	1-SME	1 SME-PBF
12	Low	High	Low	Low	0	0	0	Neutral	2-SMEs	4 Actors – 2 PBF-SME, 1 PRO-SME, 1 Individual
13	Low	Low	High	High	+	+	+	Positive	0	0
14	Low	Low	High	Low	0	0	0	Neutral	0	0
15	Low	Low	Low	High	+	0	0	Positive	6-SMEs	11Actors – 6 SME-PBF, 1 Large PBF, 4 PRO
16	Low	Low	Low	Low	0	0	0	Neutral	6-SMEs	12 Actors – 6 SME-PBF, 2 large PBF, 1 Individual, 3 PRO
Total								21PBF- SMEs		69 Participants

10.2.1 Favouring configurations

There were 13 actors which could be mapped into five possible favouring configurations with positive impact on knowledge creation. Among all the seven configurations, four of them had no actors. Regarding pharmaceutical-biotechnology SMEs (PBF-SMEs), there were only eight firms that could be nominated for further study. Among these SMEs, I managed to study two of them. The details about all positive configurations are shown in Table 10-1 (Firms representing configurations three and 11 were selected as cases: SME-A and SME-B) respectively.

10.2.2 Mixed configurations

There were 40 actors which could be mapped into six possible configurations with mixed (both positive and negative) impact on innovation. Among all the six configurations, one of them had no actors. Regarding the pharmaceutical-biotechnology SMEs (PBF-SMEs), there were only five firms that could be nominated for further study. Among these SMEs, I managed to study one of them. The detail about all mixed configurations is shown in Table 10-1 (A firm representing configuration five was selected as a case: SME-C).

10.2.3 Neutral configurations

There were 16 actors which could be mapped into three possible neutral configurations with no particular impact on knowledge creation. Regarding the pharmaceutical-biotechnology SMEs (PBF-SMEs), there were only eight firms that could be nominated for further study. Among these SMEs, I managed to study one of them. The detail about all neutral configurations is shown in Table 10-1 (A firm representing configuration 12 was selected as a case: SME-D).

10.3 Description of the cases

As it discussed in the previous section (10.2), there were five possible configurations in the Victorian biotechnology network. Following the method explained in Chapter 4 (Section 4.3), I contacted and recruited participants in each of these configurations to develop a deeper understanding of selected cases and their k-networks. Each case was been studied through: 1) in-depth interviews with managers/inventors and their partner companies in the network; 2) visiting their sites; 3) reviewing their documents like presentation files and annual reports; and 4) collecting patent data from patent documents provided by AusPat (as explored in Chapter 4, Section 4.4.2). Here the case study findings are reported.

10.3.1. SME-A as an example of firms with the favouring configuration

10.3.1.1. Background

SME-A was founded in 1997 and since then has been publicly listed on the Australian Stock Exchange (ASX) as a biotechnology company working on treatments for chronic and life-threatening conditions based on a transformational gene technology.

Before 2000, SME-A was involved in a drawn-out but ultimately successful patent litigation defending the firm's platform technology patents. This action resulted in their patents being re-examined and re-issued in all jurisdictions by 2012.

The main business focus of this SME included drug discovery and development, infectious diseases, oncology, pain, and regenerative cells and stem cells. SME-A was one of the pioneers of "X" technology, a technology that has broad application for medical conditions. The discovery of "X" was awarded the Nobel Prize, indicating the extraordinary importance of this biological mechanism. This SME held the predominant patent position in the use of "Y" technology, which was one of two major approaches to technology "X" for human therapeutic and research applications.

10.3.1.2. Size of the company

This company was headquartered in Melbourne and had an office in the US from 2001 to 2005. During this time, the number of employees was between 6–8 employees with three senior level (C-level) managers. However after 2005, the management team decided to shut down the US office to concentrate more on the Asian and European markets (based on information given by the chief financial manager). A summary of company size and revenue is given in Table 10-2.

Table 10-2 Size and annual revenue of the company from 2001–10

Year	Number of employees	Approx. annual revenue in $
2010	Re-structuring 3 employees	180,000
2009		300,000
2008		760,000
2007		500,000
2006		1,000,000
2005	Owning a US company (office) with 6–8 employees.	900,000
2004		760,000
2003		730,000
2002		-

Based on their annual reports, SME-A also had additional part-time employees in financial and administrative positions.

10.3.1.3. Products and services and role in the industry value chain

According to the diagram shown in Figure 10-2 (Allen Consulting Group 2010), the main activities of this company were focused on the research and development phase: basic R&D, discovery and early stage of development. This information was taken from

the interview with the chief scientist of the company, who has also worked on all the patents that the company owned.

> *"We are a virtual company working with a number of Clinical Research Organizations (CROs) probably 4 or 5 and a couple of research labs, 2 or 3. We have strong patents in the gene silencing technologies that have a lot of uses, we have a very fundamental position in this technology. We are kind of typical for this business, although every business is different."*

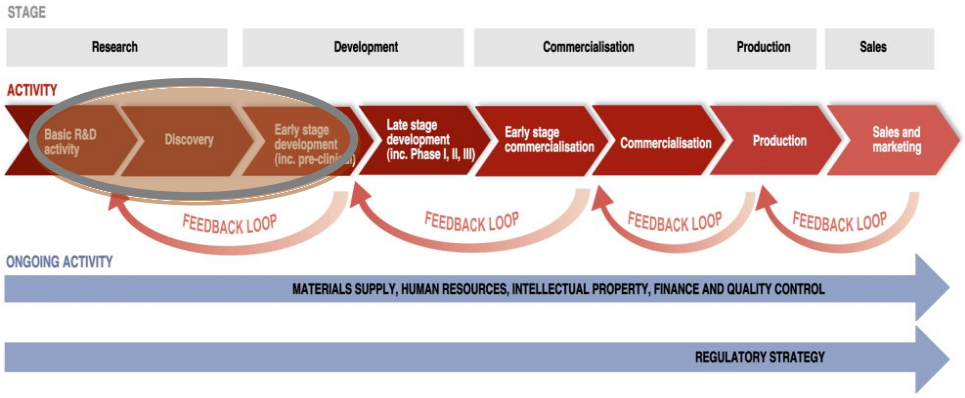


Figure 10-2 Position of SME-A, within the biotechnology industry value chain (supply chain) Adapted from Allen Consulting Group (2010).

10.3.1.4. Structure of the patent-based collaborations

The patent-based collaboration of SME-A mainly involved getting help with expertise and facilities from Clinical Research Organisations (CROs). This company also needed other types of partnership to take the discovery to the next stages, which were clinical testing, development and commercialisation, production and sales. This kind of partnership however, may not be represented in their patent co-authorship network. The several patents that were filed in AusPat, had the main partner as the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The other partner was a PRO located in Queensland where the chief scientist (i.e. the interviewee) was based. This distance from headquarters (Melbourne) was not an issue for SME-A. However, there was a long series of litigation processes running between SME-A and its partners. For this reason, the interviewee was not very keen on explaining the relationships between SME-A and its partners. The interviewee (the chief scientist of the company) participated in many patents of the company mentioned:

> *These collaborations are based on fundamental patents. Our partnership was through [Clinical Research Organisations] CROs*

and research labs. This is the way that we had collaborated with them, we have bought people. There are literally hundreds of CROs worldwide to offer resources for chemical drug development.

The ego-network of this SME-A (BF13) and its partners (i.e. P3 and P83) are represented in Figure 10-3.

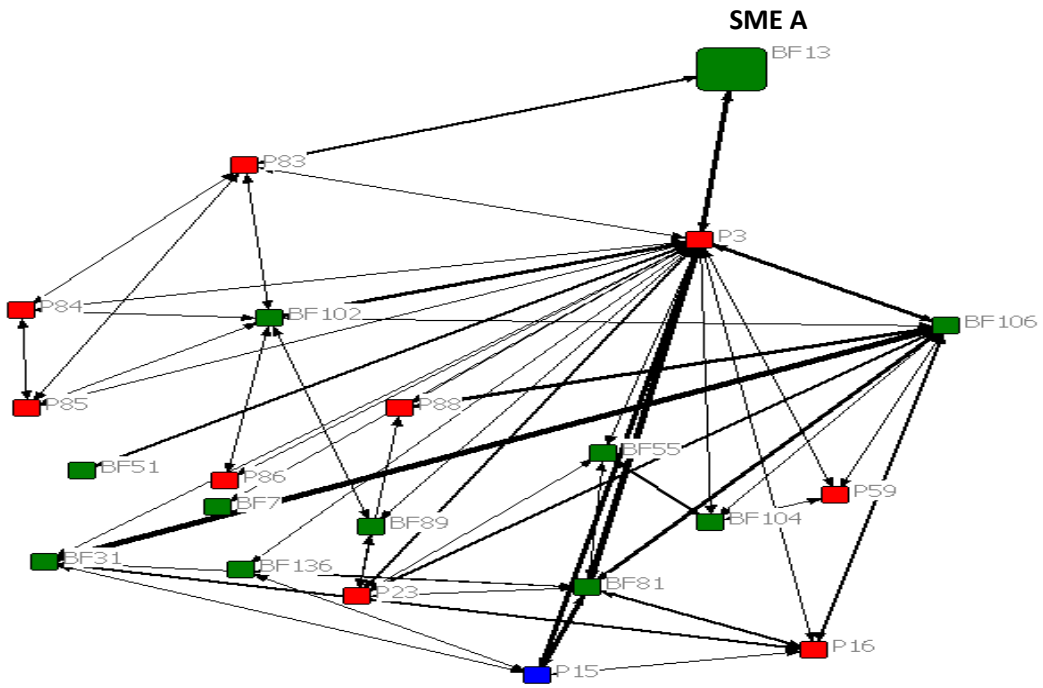


Figure 10-3 Ego-network of SME-A

According to their patent documents, SME-A was located in a high centrality and high density network. Regarding centrality degree, this SME was higher than average both in terms of degree centrality (local centrality, 6) and closeness centrality (global centrality, 1.364), while the median for these measures were 3 and 1.366 accordingly[17]. Given the degree centrality this SME has a very high centrality degree. However, across the whole network this measure was not actually very high. Also in terms of density in its ego-network, this SME had a high dense ego-network, since all the partners also had collaborations with each other as well.

10.3.1.5. Content of the patent co-authorship network

The technological knowledge of this SME included eight IPCs. Compared to the median of the whole network (include all large size universities and big biotechnology-

[17] The closeness centrality is a reverse measure so bigger numbers represent further distance to the centre of the network

pharmaceutical firms), the level of knowledge diversity in this SME was high (8 IPCs – knowledge diversity =0.77 > 0.53).

SME-A believed that having diverse knowledge and expertise helped it to create more knowledge. To explain the process of how this SME acquired such heterogeneous knowledge and the tools that they used, the chief scientist of the SME-A mentioned:

> *There is much information that we could acquire through meetings. First the idea about the technology and the relevant documents also the information about the background and about research plan and quote and that sort of stuff.*

Tacitness of knowledge is a characteristic of knowledge that has been discussed in the knowledge creation and sharing literature (Li et al. 2010). In this regard, I asked about this attribute. When it comes to knowledge creation in terms of patents, the necessary parts of all this tacit knowledge had to be documented and codified. SME-A also considered tacit knowledge as important know-how that its scientists were using to create new knowledge for new drugs. However, this process was not a big challenge or critical part of knowledge creation mainly because of the nature of the knowledge. The main area of knowledge here was technological knowledge. However, beyond the technological knowledge, other areas like identifying partners were considered a challenge for this SME.

> *We need virtual organisations with particular expertise. The real issue is to understand the network structure of CROs which is sophisticated and not very well structured.*

10.3.1.6. Collaborative process of the patent co-authorship network

The level of the diversity of their patent partners (the exploration/exploitation index) was moderate (51% <= Average: 53%) in comparison with other firms in the industry. Between 2001 and 2010, this SME not only looked for two partners but also worked independently on several projects. To explain this balanced exploration/exploitation approach, the chief scientist of the SME-A mentioned that they try to explore new partners because patent projects are complex and each has different functions, so they keep collaborations with various companies, and universities like [A]. As discussed with interviewee and supported by the exploration/exploitation index which was calculated based on the case patent documents for this firm, this case seemed to pursue a balanced exploration and exploitation approach. However, as the interviewee reiterated

several times, there was a strong intention towards exploring new products. Hence the focus of the case company seemed to be more on exploration. To explain about the ways in which SME-A actively acquired, created, shared and harnessed information during its partnerships, the firm mainly relied on meetings supported by documents communicated via email and Skype.

10.3.1.7. The interaction of content, process and structure of the k-network in SME-A

How do the inter-relationships of the content, process and structure of the k-network of SME-A, contribute to their collaborative knowledge creation? To answer this question, all data sources of SME-A were analysed and the resultant summary of all the themes is shown in Table 10-3. These themes include the initial codes which were identified based on the research framework (Table 10-3) and that were also represented in the interview protocol. Emergent themes representing the contextual factors of the selected case are also listed in this table. Moreover the sources of the themes are shown in the table as well.

Table 10-3 Summary of all the themes in SME-A
Note: Sources of each theme are represented by *

Constructs in SME-A	Themes	Data sources			
		Interview protocol or emergent	Interviews	Patent documents	Annual reports/formal documents/ websites
Background	Activities	Interview protocol	*		*
	Size	Interview protocol	*		*
Content	Diversity	Interview protocol	*	*	
	Tacit knowledge	Interview protocol	*		
	Non-technological knowledge	Interview protocol	*		*
	Knowledge capacity	Emergent	*		
	Business strategy	Emergent	*		
	Timeliness	Emergent	*		
	Quality of knowledge	Emergent	*		
Process	Partners diversity	Interview protocol	*	*	
	Exploration process	Interview protocol	*		
	Technology and method	Interview protocol	*		
Structure	Purpose	Interview protocol	*		*
	Challenges	Interview protocol	*		
	Centrality	Interview protocol		*	
	Density	Interview protocol		*	

Given the data sources mentioned in Table 10-3, the knowledge creation of SME-A in terms of patenting via its k-network can be explained by several constructs. In addition to the constructs discussed in the research framework (which were tested and confirmed in Phase 2) SME-A introduced not only knowledge diversity, partner diversity and the structure, as important constructs but also highlighted other constructs that may explain the k-network of the firm.

Emergent themes

In addition to the constructs discussed in the interview protocol, several new themes emerged in this case study.

Timeliness: Having timely access to knowledge and protecting it via patenting. SME-A believed that diverse knowledge works for them to create more knowledge since their diverse knowledge came based on a fundamental idea in a timely manner (very early in 2000).

> *I think now we have a strong position because of these patents. Since these patents are very fundamental and very early in our field...then we developed upon them.*

It was believed that being a first-mover in the market in terms of access to new knowledge and using patents to protect their position helped SME-A to create more knowledge, and to be more innovative.

Knowledge capacity: The capability of SME-A to create new knowledge seems to be another important factor to explain its knowledge creation. SMEs are widely recognised as companies with limited resources in terms of expertise and financially (Hanna and Walsh 2002). For instance SME-A believed that to get the required capacity to handle the complex projects they have to collaborate with other companies, mainly to access to their partners' knowledge.

Business strategy: Access to diverse knowledge can help knowledge creation mainly if SMEs pursue an aggressive knowledge strategy. For instance, this was mentioned by an interviewee in SME-A:

> *We always try to be first in the market and provide innovative technologies, we are looking into potential and innovative products for example in the […] pain therapeutic area for cancer patients, it*

> *was a very innovative strategy to see a very important unmet nee,…so I think we are a very leading innovative company in gene therapy.*

Business strategy seems another important factor to explain knowledge creation at SME-A.

Quality of knowledge: Quality of knowledge, according to Chiu, Hsu and Wang (2006) is linked with characteristics like relevancy, easy to understand and reliability. This construct is also considered as a main factor for sharing and exchanging knowledge with partners (Wasko and Faraj 2005).

In this case, the interviewee mentioned the importance of access to relevant and reliable expertise when he talked about the challenges of partnership.

> *The real issue is that the network structure of CROs is sophisticated and not very well structured. To have access to relevant and realisable expertise, you need to know the structure of these virtual organisations particularly with their diverse expertise.*

10.3.1.8. Summary of SME-A's approach to creating knowledge via its k-network

This case has a favouring type of configuration. In SME-A, content-centrality interaction influences knowledge creation as represented in Figure 10-4. More precisely the higher diverse knowledge co-exists with the central position of the case. This interaction has a positive effect on knowledge creation as discussed in Chapter 9. This interaction is also confirmed in this case mainly based on the patent documents and interviewee perceptions. Moreover, there are two key points should be considered here: 1) Although quantitative findings supported the interaction of content and structure, this case study, also showed that SME-A perceived exploration/exploitation process as an important factor. Hence, this case supported the triadic interactions among content-process and structure; however the role of content-structure interaction seems more significant. 2) The positive association of the favouring configuration and knowledge creation is influenced based on several factors that emerged based on the empirical data of the case study. These factors are timeliness, business strategy and knowledge capacity. The result of this analysis is illustrated in Figure 10-4.

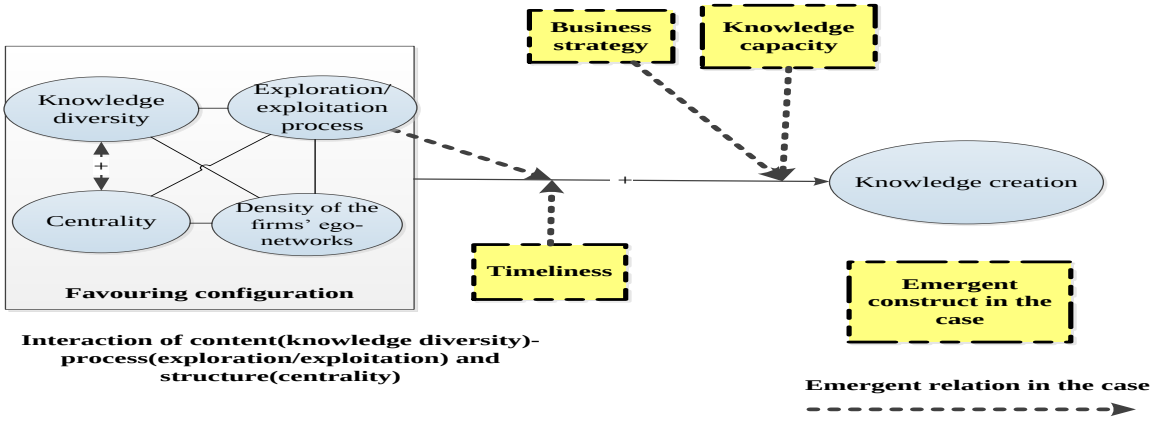


Figure 10-4 Confirmation of the initial model with the emergent constructs in SME-A

10.3.2. SME-B as an example of firms with the favouring configuration

10.3.2.1. Background

SME-B is an Australian publicly listed company that has developed and commercialised multiplexed molecular diagnostic tests, based upon its proprietary BBX technology. BBX is a platform for the kind of medium density multiplexed tests (5–150 substances) of most use to pathology labs. SME-B's products compete in the global market for molecular diagnostic tests – currently valued at around US$2.6 billion, and expected to double in the next five years – and are used by commercial pathology providers.

10.3.2.2. Size of the company

This company manufactures its products at a custom-built facility in Melbourne, Australia. A summary of its size and revenue is provided in Table 10-4.

Table 10-4 Size and the annual revenue of the company between 2001–10

Year	Number of employees	Approx. annual revenue in $
2010	12	645,218,000
2009	9	146,751,000
2008	7	50,925,000
2007	5	58,929,000

10.3.2.3. Products and services and role in the industry value chain

According to the diagram shown in Figure 10-5 (Allen Consulting Group 2010), SME-B covered a range of activates in both the research and development phase: basic R&D, discovery and early stage of development. They also asked worked with several partners

for the late stage of development. This information was taken from the interview with the executive director and also chief scientist of the company who had also worked on all the patents that the company owned.

> *We have been involved with some basic R&D, almost all we do is focused on application for diagnostics. We are not studying any diseases, we study the detection of the diseases so almost we apply some research but we do a little bit basic research more on physical chemistry, something like that, just to understand how to better make these diagnostics, we do clinical tests, we have basic R&D but mostly about developing tools for better detection*

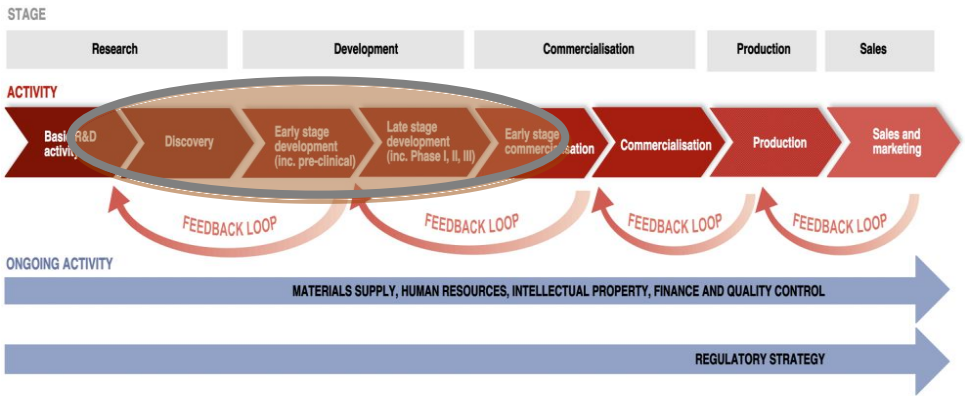


Figure 10-5 Position of SME-B, within the biotechnology industry value chain (supply chain)

Adopted from Allen Consulting Group (2010).

10.3.2.4. Structure of the patent co-authorship network

Based on the interview with the executive director and also chief scientist of the company, the main purpose of collaboration for SME-B was gaining complementary knowledge required for producing technologies in relation to detecting diseases.

> *I had a problem and [my partner] provided knowledge to solve it since [he] had the first observation on micro resonators so we both were in the same area…So we both are co-owners of this patent.*

He explained that the part of the reason for collaboration is getting new knowledge in the particular phenomenon (of micro resonator) and the fusion of this knowledge with SME-B's idea led to a new patent. However, these partners are not going to help the SME to commercialise the patents.

The patent-based collaboration of SME-B mainly refers to getting knowledge of an individual inventor (BF144 in Figure 10-6) and a large size university (BF106 in Figure

10-6) both of which are located in Victoria. SME-B also needed other types of partnership to take the discovery to the next stages, which are clinical test, development and commercialisation, production and sales. This kind of partnership however, may not be represented in their patent co-authorship network. The ego-network of this SME-B (BF36) and its partners (i.e. BF106 and BF114) are represented in Figure 10-6.

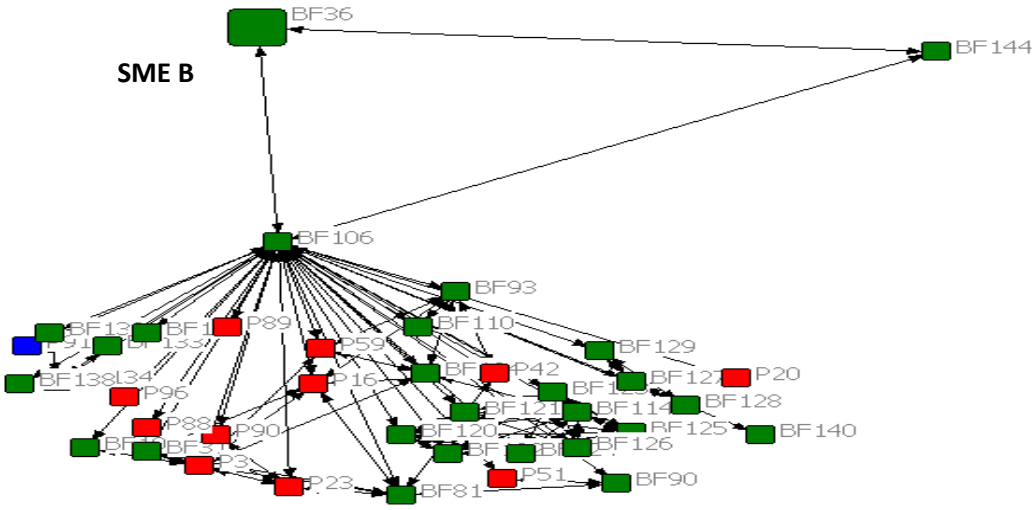


Figure 10-6 Ego-network of SME-B

According to their patent documents, SME-B was located in a low centrality and high density network. In regard to centrality degree, this SME had a lower than average score both in terms degree centrality (local centrality, 2) and closeness centrality (global centrality, 1.368)[18], while the mean and median for these measures were 8.9 and 3; and 1.272 and 1.366 respectively. This SME has a very low centrality degree, however, the closeness centrality which shows the position of the SME in in the whole network, was about the average. This was mainly because of having several contacts with BF106 which is a large university and a key player in the whole network. Indeed, the relationship is with a small group of researchers (two people) in that university and their names appeared in the patent documents. Also in terms of density in its ego-network, this SME had a high density ego-network, since all the partners also had collaboration with each other as well. During the interview, I also noticed the very close relationship between this SME and BF144 – the individual inventor and a seminal researcher who

[18] The closeness centrality is a reverse measure so bigger numbers represent further distance to the centre of the network

also worked in a university. Regarding the frequencies of interactions during the patent project, the interviewee mentioned their close relationships:

> *[He] was a friend of a friend, a contact from a family friend…so I have found him by my contacts, and we get together maybe twice or three times a year…and also with other biomedical companies since these partnership with other biomedical companies should help us both.*

10.3.2.5. Content of the patent co-authorship network

The technological knowledge of this SME, included five IPCs. Given the average of the whole network (including all large size universities and big biotechnology-pharmaceutical firms), this SME had an upper medium level of knowledge diversity (five IPCs – knowledge diversity = 0.56).

SME-B believed that having diverse knowledge regarding the technology BBX helped them to create more patents. However their knowledge was not very diverse.

> *We basically do molecular genetics in microbiology…so we don't have much outside that, and we never had the luxury of being able to hire people from outside of the molecular genetics microbiology to work on some other aspects of either diagnostics or some other relevant market… we are not enormously diverse but regarding BBX, fairly we know the technology very well and we explored various applications of BBX.*

To explain the reason for that level of diversity, the chief director of SME-B pointed at two factors: the size and the budget of the company. Also he explained that they would like to enter air filtering systems or other interesting subjects, but so far this has not been their model, as he is not sure whether it is good or bad for the company.

In regards to tacit knowledge, SME-B, like SME-A mainly did not considered tacit knowledge as a big challenge or critical part of the knowledge creation mainly because the knowledge required to be shared was mainly articulated in documents in term of numbers, algorithms, and test procedures. However beyond the technological knowledge, the non-technological knowledge like getting knowledge about the market was considered as another aspect of knowledge sharing with partners.

10.3.2.6. Collaborative process of the patent co-authorship network

The level of the diversity of their patent partners (the exploration/exploitation index) is low (31.4 % <= Average: 53%) in comparison with other firms in the industry. From 2001–10, this SME was mainly locked into an arrangement with its two partners for several projects. Regarding the collaborative process, the chief director of SME-B explained that the company pursued both approaches but confirmed that their focus was on exploitation:

> *The way that we generally work is that we co-found projects with partners and we come with our own knowledge and intellectual capital and they come with what they want us to help them to make a new product, we develop a plan on how we can do that, we do the design, we do the experiments and we get that product off the ground. So we try to reuse our intellectual properties and knowledge to make new products. That's how it works up to now.*

Meanwhile, they were looking for new partners but all partnerships do not necessary result in patents. Most of them were sought for further stages of the value chain like commercialisation and sales. Regarding the objectives of knowledge management, the policies and the ways in which SME-B acquired, created, shared and harnessed information through partnership, the chief director of the SME-B mentioned that while they do have procedures for design, there are no formal policies on managing their knowledge. Whenever they have a new problem to approach the solution of that problem, they follow the procedure, primarily via their own staff. There are few staff and all are quite familiar with each other's expertise, as they had been working together for years. No-one has left the company since it started. Occasionally they need to hire a bookkeeper or software developer.

10.3.2.7. The interaction of content, process and structure of the k-network in SME-B

How do the inter-relationships of the content, process and structure of the k-network of SME-B, contribute to their collaborative knowledge creation? To answer this question, all data sources of SME-B were analysed. A summary of all the themes is provided in Table 10-5. These themes include the initial themes identified based on the research framework and that are also represented in the interview protocol. Emergent themes representing the contextual factors of the selected case are also listed in this table. Sources of the themes are also shown

Drawing on the data sources identified in Table 10-5, the knowledge creation of SME-B in terms of patenting via its k-network can be explained by several constructs. In addition to the constructs discussed in the research framework (which were tested and confirmed in Phase 2,) SME-B not only introduced knowledge diversity, partner diversity and the structure, as important constructs but also highlighted other constructs that may explain the k-network of the firm.

Table 10-5 Summary of all the themes in SME-B

Note: Sources of each theme are represented by *

Constructs in SME-A	Themes	Data sources			
		Interview protocol or emergent	Interviews	Patent documents	Annual reports/formal documents/ websites
Background	Activities	Interview protocol	*		*
	Size	Interview protocol	*		*
Content	Diversity	Interview protocol	*	*	
	Tacit knowledge	Interview protocol	*		
	Non-technological knowledge	Interview protocol	*		*
	Knowledge capacity	Emergent	*		
	Business strategy	Emergent	*		
Process	Partners diversity	Interview protocol	*	*	
	Exploration process	Interview protocol	*		
	Technology and method	Interview protocol	*		
Structure	Purpose	Interview protocol	*		*
	Challenges	Interview protocol	*		
	Centrality	Interview protocol		*	
	Density	Interview protocol		*	

Emergent themes

Several new themes emerged in this case study, in addition to the constructs discussed in the interview protocol.

Knowledge capacity: To extend the scope of their business and create more diverse knowledge SME-B requires more capability for handling knowledge. The executive director and also chief scientist of SME-B believed that:

> *We never had the luxury of being able to hire people from outside of the molecular genetics microbiology to work on some other aspects*

> *of either diagnostics or some other relevant market. This is because of the size of our company and also because of money. We would like to find partners to reach beyond our existing areas.*

Exploration/exploitation process: The intention toward a balanced exploration/exploitation process was seen in this company. The quote mentioned in the previous construct (i.e. knowledge capacity) can also imply that working with different partners on new areas of knowledge has been considered as a source for knowledge diversity and knowledge creation. The capability to get funding and ability to manage new projects seems another construct that influences how this SME uses its knowledge base to create new knowledge.

Business strategy: This SME seemed to pursue an 'analyser' type of strategy**.** According to the four types of strategy identified by Miles, Snow, Meyer and Coleman (1978), analysers like SME-B are looking for new opportunities in the market, while they keep their relations with their existing customers. The interview with the chief director of SME-B mentioned the intention to identify new ventures and new markets several times. This is also supported by analysing the web page of the company which encourages partnerships in new markets like the US and Europe.

Moderately diverse knowledge seems to be the result of that approach, which helps knowledge creation mainly if SMEs pursue an analyser type of strategy. For instance the chief director of SME-B noted:

> *I think this [exploitation process] is a fairly decent model since we don't have to raise all the money and we have the customers right away, so we not looking for something entirely new…we applied the technologies that we already have.*

Partner organisational type: The other interesting point mentioned is the organisational type of partners that was considered as a factor for choosing partners and exploration of knowledge. In the main, this SME was not looking for partnerships with academics and universities particularly with Australians, mainly because poor experiences in the past. The chief director of SME-B believed that this kind of partnership is rather opportunistic and is not easily handled.

> *There are lots of challenges when you are dealing with a university. First my experience with academics is that…. it is really hard to get realistic deals with major universities since it is a long and*

complicated process and takes lots of money. This is the case in Australia, I don't know why that is exactly but I have seen other places e.g. in US. it comes out easily compared to Australia. The linkages between the universities and the industry partners are antagonistic since they [academics] tend to over- value what they know.

10.3.2.8. Summary of SME-B's approach to creating knowledge via its k-network

This case has a favouring type of configuration. In SME-B, the content-centrality interaction influences the knowledge creation, as represented in Figure 10-7. More precisely, the moderate knowledge diversity co-exists with the low central position of the case. This interaction had a small[19] positive effect on knowledge creation, as discussed in Chapter 9. This interaction is also confirmed in this case, mainly based on the patent documents and interviewee perceptions. Like SME-A, the study of this case provides two major findings. First this case study supported the triadic interactions among content-process and structure in SME-B, however the role of content-structure interaction seems more significant as found by the quantitative phase (see interaction 1 in Chapter 9, Section 9.5). Second, the positive association of the favouring configuration and knowledge creation is influenced by business strategy and knowledge capacity. Moreover, type of partner was highlighted as an important factor influencing on exploration/exploitation process. The result of this analysis is illustrated in Figure 10-7.

[19] In comparison with SME-A this SME showed a lower number of patents (16 vs.11 patents) and also the intention for being innovative is represented and confirmed in interviews. This is discussed in the comparative analysis of cases (Section 10.4).

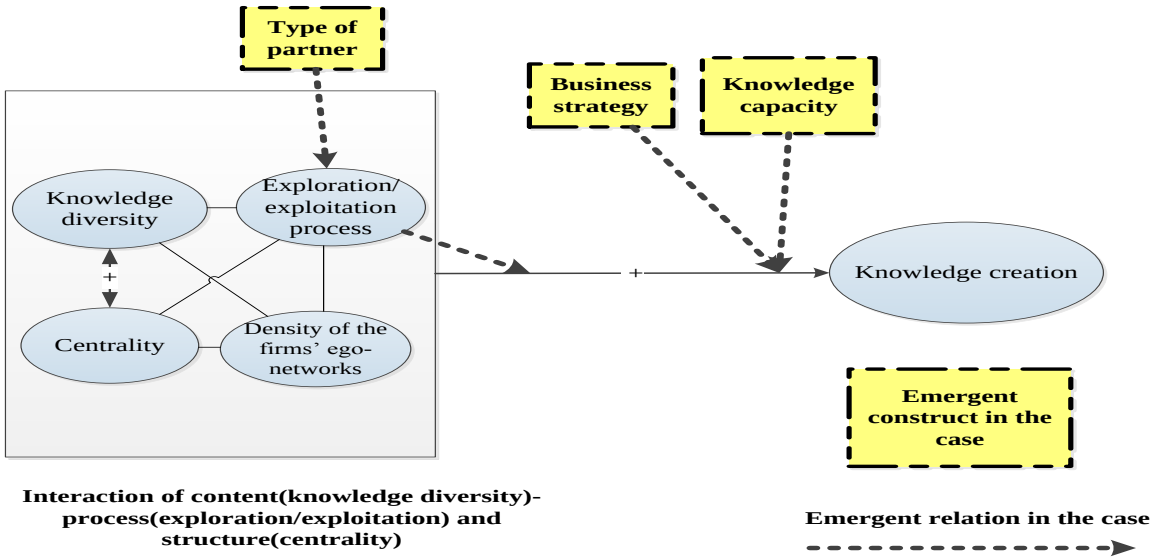


Figure 10-7 Confirmation of the initial model with the emergent constructs in SME-B

10.3.3. SME-C as an example of firms with the mixed-impact configuration

10.3.3.1. Background

SME-C was a publicly owned research-focused, biotechnology company. The company was principally engaged in research and development of immunology related technologies with applications to cancers, infectious diseases and vaccine development. They had several collaborations to accomplish their initiatives on developing flu vaccines, stem cell therapy, respiratory virus vaccine, therapies for cancer vaccine enhancement and autoimmune disorders. For instance, SME-C had established research collaborations with a stem cell laboratory of a large size university, the Australian Stem Cell Centre (ASCC) and a private laboratory corporation. This SME was headquartered in Melbourne, Victoria, Australia. As mentioned by the CEO of this SME, after 2010, they stopped trading publicly:

> *We have taken it off from the stock market. It does still exist as a private company….It still functions but not publicly trading…So our company had a combination of good RA or good biotech companies…We were sort of typical, I suppose, because we generated the technology within the university and we did something which was completely bizarre. To give you a bit of background on the technology we were working in the immune system so the company had research and it had clinical…We are researching how we could improve the compound. We are not like one that was backed up with clinical studies. These two are going in parallel.*

Clinical studies we've had funded by the company itself but also by big grants in the US and a big pharmaceutical company we formed a partnership with a pharmaceutical company based in Chicago.

10.3.3.2. Size of the company

SME-C had a CEO and four senior managers and 10 employees in their laboratory. In that period they also had a close partnership with a bigger company, and sometimes employed them temporarily. The close partner of SME-B (BF8 in Figure 10-9) would have had probably about 60 employees in 2002–2003, including all the management and administrative stuff and technical staff.

10.3.3.3. Products and services and role in the industry value chain

According to the diagram shown in Figure 10-8 (Allen Consulting Group 2010), SME-C covered a range of activities in both the research and development phase, basic R&D, discovery and early stage of development. They also asked worked with several partners for the late stage of development. This information was taken from the interview with the CEO and chief scientist of the company who had also worked on all the patents that the company owned (Figure 10-8).

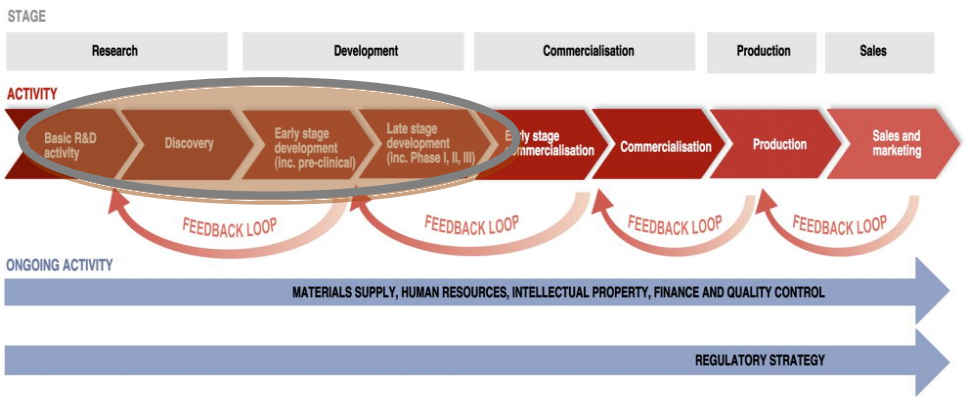


Figure 10-8 Position of SME-C, within the biotechnology industry value chain (supply chain) Adopted from Allen Consulting Group (2010).

10.3.3.4. Structure of the patent co-authorship network

The patent based collaboration of SME-C mainly refers to getting help to continue their research. Consistent with the patent documents I found in AusPat, the main partners of SME-C were a large university and a private company, both of which were located in Victoria during 2001–2010. SME-C needed other types of partnership to take the discovery to the next stages, which are clinical test, development and

commercialisation, production and sales. For instance they had collaborations with many clinics and hospitals in US to conduct their clinical tests. This kind of partnership however, may not be represented in a patent document. Based on the interview with the CEO and chief scientist of the company they have explained their reason for their partnership:

> *It's very rare to be able to survive in a biotech company without continuing research because the next guys come along. Once you get beyond the initial discovery, you want to go into the clinic. [SME-C] funded the first clinical trial; we did in Australia and in the world that was here in Melbourne. That probably costs I guess a couple of millions but to take that trial to the US we needed to get NIH[20]s funding we needed to have a biotech partner so with the combination of Melbourne and Chicago research and clinical studies we already have some clinical studies before we were known as [SME-C'].*

Based on the interview with the CEO and chief scientist of SME-C, there were two types of collaboration identified, however only the first type is represented and discussed in this study.

> *We are research institutes so our primary goal of collaboration is to bringing technologies, the agency, methodologies which can make our story much stronger...to put them all together not one plus one equals two, one plus one equals four…You have two forms of collaboration one is the discovery and the other one is the delivery. It depends on what area you are in but in the area of clinical treatment we have very strong collaboration with clinicians because they are the other ones who deliver. I can't create everything but if there is someone who can cooperate so we would have very strong partnership with clinics. Also we have to work with the regulators (TGA), [which is] our policeman.*

This SME was located in a high centrality and high density network. In relation to centrality degree, this SME had a higher average both in terms degree centrality (local centrality, 8) and closeness centrality (global centrality, 1.365), while the mean and median for these measures were 8.9 and 3; and 1.272 and 1.366 respectively. SME-C had a high centrality degree and an average closeness centrality in the whole network[21]. Also in terms of density in its ego-network, this SME had a very sparse ego-network,

[20] National Institutes of Health (NIH) is an agency of the US Department of Health and Human Services.

[21] The closeness centrality is a reverse measure so bigger numbers represent greater distance to the centre of the network

since none of the partners had collaboration with each other. The ego-networks of this SME (BF112) and its partners (i.e. BF8 and BF93) are represented in Figure 10-9.

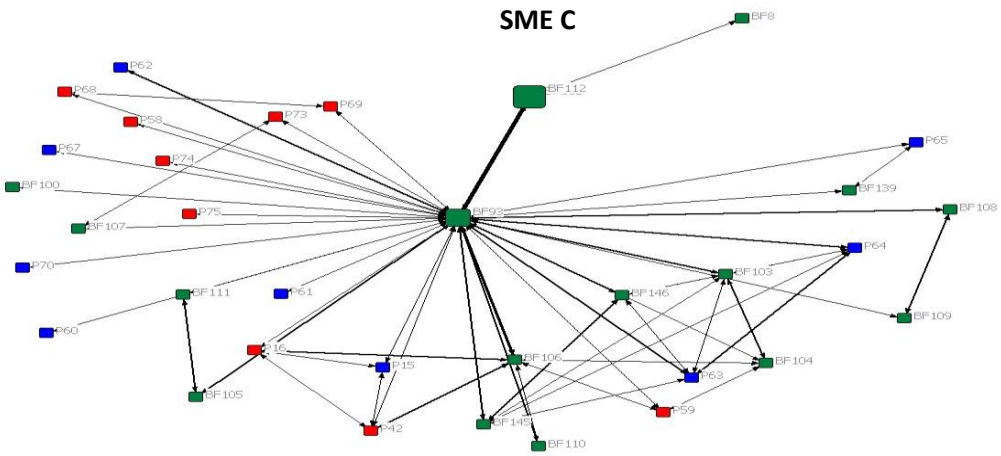


Figure 10-9 the ego-network of SME-C

10.3.3.5. Content of the patent-based collaborations

The technological knowledge of this SME included eight technological area of knowledge (IPCs). Given the average of the whole network (including all large size universities and big biotechnology-pharmaceutical firms), this SME had a higher level of knowledge diversity (8 IPCs and knowledge diversity = 0.79). To explain how SME-C acquired such heterogeneous knowledge and the tools that they use, the CEO and chief scientist of SME-C noted:

> *Yes we have a diverse area of knowledge protected by patents…but I think it is a mistake! We spend several millions in there to owning the patent. Our attitude was to owning the patents. The history of this is that I had an idea and at Christmas dinner, my brother said to me that this is a great idea, you should have a patent around it, and I knew nothing about patents, I was a scientist so in January I started to file these patents…at that time we had a poor vision in [SME-C] about it. We thought we should have a portfolio of patents so extended divisions and subdivisions in several countries. All these patents cost us dollars and time to register to file for PCT and to get reviewed in America and all around the world.*

As mentioned above, SME-C recently changed their policy and instead of exploring new areas of knowledge, they decided to stay focused on their existing knowledge and the application and exploiting of a few of these patents.

The other characteristic of content which was discussed based on the interview protocol was the non-technological knowledge through partnerships. The CEO and chief scientist of SME-C mentioned the non-technological areas that they needed and also commented on the university [BF93] as a partner for helping in non-technological areas:

> *Always we have to deal with non-technological knowledge as well, because we have to integrate our product to the marketplace. The role of the board is important; they have to keep the relations with the partners by thinking about the whole market not just their wishes for their wallets…..We got a fabulous board, this is one the key strength of [SME-C]…the partners for non-technological knowledge were colleagues with skills in accountancy, patent and law expertise, venture capitalist, public relations including people in the university [BF93 in Figure 10-9] but mainly from elsewhere.*

10.3.3.6. Collaborative process of the patent-based collaborations

The level of the diversity of their patent partners (the exploration/exploitation index) was moderate to high (56% Average: 53%) in comparison with other firms in the market. Between 2001 and 2010, this SME had not only looked for two partners but also it worked independently for several projects. The CEO and chief scientist of SME-C explained:

> *Yes our approach was exploring very diverse areas but was wrong. Now, scientifically, however we are working with all around the world but commercially, partnerships are restricted to few strategic partnerships.*

To understand how SME-C manages information or knowledge which is shared among people in their collaborations, they mentioned the distinction between private and public knowledge and size of the participant companies.

> *The way it works in 90% of the cases is that you have an open public knowledge discussion with your potential partner. It could happen in a conference; could happen over a coffee or beer and someone says "oh… that sounds interesting". So the initial contact is open. But everyone is holding back their cards…Then you sign a Confidentiality Disclosure Agreements (CDA)…comes in step 2. Step 1 is some common ground here…In our space…we need to understand each other's technologies so we have signed confidentiality with them so the way we propose is introduction. You know, someone saying you should go to talk to Adel because he has been working on and this guy might have something on there. Let's go to the next step. I will show you mine if you will show yours but*

> *let's go through the confidentiality. So up into the discussion, first, confidentiality second. Mining into the data is the third step and then invariably, if a partnership is being formed, then you have two avenues: one is joint venture agreement or co-licensing agreement or sub-licensing agreement and that depends on the product. But the sharing of information is not in the confidentiality or CDA.*

In terms of the method and techniques that they have usedto share their knowledge during the partnership, the SME-C interviewee mentioned:

> *No nothing clever…So in our space it can be technology, they can come into the labs and see some tricks that we do and other people don't do.*

To keep track of the findings of scientists, they also used regular private and group meetings. From the research perspective every Monday they have a laboratory meeting where researchers present their work, but during the week the SME-C interviewee (CEO) has meeting with all the individuals one-on-one or in small groups. They also discuss the emerging data with their partners in America by using PowerPoint presentations, written documentation, and unpublished data but there is no public disclosure.

10.3.3.7. The interaction of content, process and structure of the k-network in SME-C

How do the inter-relationships of the content, process and structure of k-network of SME-C, contribute to their collaborative knowledge creation? To answer this question, all data sources of SME-C were analysed and the summary is reported in Table 10-6.

Table 10-6 Summary of all the themes in SME-C
Note: Sources of each theme are represented by *

Constructs in SME-C	Themes	Data sources			
		Interview protocol or emergent	Interviews	Patent documents	Annual reports/formal documents/ websites
Background	Activities	Interview protocol	*		*
	Size	Interview protocol	*		*
Content	Diversity	Interview protocol	*	*	
	Tacit knowledge	Interview protocol	*		
	Non-technological knowledge	Interview protocol	*		*
	Knowledge capacity	Emergent	*		
	Business strategy	Emergent	*		
	Timeliness	Emergent	*		
	Quality of	Emergent	*		

Constructs in SME-C	Themes	Data sources			
		Interview protocol or emergent	Interviews	Patent documents	Annual reports/formal documents/ websites
	knowledge				
	Public vs. private	Emergent	*		
Process	Partners diversity	Interview protocol	*	*	
	Exploration process	Interview protocol	*		
	Public vs. private	Interview protocol	*		
	Technology and method	Interview protocol	*		
Structure	Purpose	Interview protocol	*		*
	Challenges	Interview protocol	*		
	Centrality	Interview protocol		*	
	Density	Interview protocol		*	

These themes include the initial themes which were identified based on the research framework and interview protocol (Table 10-6) and that were also represented in the interview protocol. Emergent themes representing the contextual factors of the selected case are also listed in this table. The sources of the themes are also shown.

SME-C possessed a mixed-impact configuration which deals with three interactions. Given the data sources mentioned in Table 10-6, the knowledge creation of SME-C in terms of patenting via its k-network can be explained by several constructs. In addition to the constructs discussed in the research framework (which were tested and confirmed in Phase 2), SME-C not only introduced knowledge diversity, partner diversity and the structure as important constructs but also highlighted other constructs that may explain the k-network of the firm:

This interaction shows how SME-C uses its central position to access more diverse knowledge. This was tested and emerged from the quantitative analysis showing a positive association of diverse content and central position with knowledge creation. It means that, given the relatively high central position of SME-C in the whole network of the industry, access to diverse knowledge area helped the company to produce more knowledge. To explain this association further there are some additional constructs that emerged through the case analysis.

Knowledge capacity: To extend the scope of the business and create more diverse knowledge, SME-C required more capability for handling knowledge. The CEO of SME-C believed that this capacity was required for their partnership projects. He

explained that they have collaborations to understand better how stem cells work and from a research perspective to explore how they work clinically.

> *In this business we have competitive research with them [i.e. partners] so we need to understand each other's technologies thoroughly.*

Easier access to diverse knowledge is facilitated by central position but is also critical to understand this knowledge thoroughly.

Timeliness: Being in the centre of the network has been considered as a factor for faster and more timely access to required knowledge (Powell et al. 1996). Knowing someone who has relevant knowledge does not necessarily result in a contact facilitating knowledge creation. Having timely access to the knowledge provider seems vital for creating knowledge as well (Cross et al. 2002). The CEO of SME-C also believed that diverse knowledge, when provided in a timely manner works, for them to create more knowledge. This is why they tried their contacts who could provide faster access to the required knowledge.

> *...For research you collaborate to improve the quality and get to end results faster. It's quicker for me to send someone to Boston for six months to do a research project than trying to set it up here.*

Quality of knowledge: This factor was identified in SME-A. In this case also, the quality of expertise was mentioned by the interviewee as a reason for having partnerships. The quality of knowledge was believed as a factor that encouraged synergy: *"one plus one equals four".*

Business strategy: SME-C seemed to pursue an innovator or prospector type of strategy**.** According to the four types of strategy identified by Miles et al. (1978), prospectors like SME-C are looking for new opportunities in the market, either by collaboration with two key partners or just by themselves. In the interview with the CEO and chief scientist of SME-C, he mentioned their intention for identifying new ventures and new markets several times. This is also supported by analysing the company's website which mentions encouraging partnerships in new markets like the US and Europe. The intention toward an exploration approach was seen in this company between 2001 and 2010. High diversity of knowledge seems to be result of that

approach, which helps knowledge creation particularly if the SME pursues an innovator type of strategy.

This interaction which was tested and emerged from the quantitative analysis showed a positive association of exploration collaborative process and sparse network with knowledge creation. It means that the sparse ego-network of SME-C and approach of this case toward exploration has helped company to produce more knowledge. SME-C had two partners and worked with them closely, but in a sparse network to create more knowledge. To explain the reason why this company worked in a sparse network, they believed that in addition to their main partner (a large university), for a new project they needed a particulalr laboratory which was not available to the existing partner. Also, they were not very happy with the main partner so there was not enough motivation to involve the university as well. According to the patent documents, these three companies (SME-C and its two partners) worked closely in several projects. To explain this association there were some constructs that emerged through the case analysis.

Partner organisational type: Like SME-B, SME-C was not satisfied with working with the universities. Hence for SME-C, the organisational type of partners was considered as an important factor for choosing partners and exploration of knowledge. To explain the reason why this company worked in a sparse network, they believed that universities including their main partner (a large university) was not sufficiently strategic, so they did not want to repeat another project with them.

> *The people in the university [BF93] who are supposed to help business people, I don't think they are right people, they tend to be academic not business people… I'd rather to go to people with a MBA degree, who could be a better help, although they were not in university except for their courses in MBA, but they understand how the business works, how the stock market works*

Public vs. private knowledge: Type of knowledge, public vs. private, was important for knowledge creation in this case. Private knowledge in terms of technologies and expertise are expected to be protected by legal contracts like confidentiality disclosure agreements (CDAs). However, public knowledge is communicated more freely. Although patent projects start with exchanging public knowledge, without fully understanding the private knowledge it is not possible to create new knowledge in terms

of a new patent. The size of the partner, however could be a factor in deciding not to sign a CDA.

> *Many big companies as you would know won't sign a CDA because they are too big…We worked with [J&C – a pseudonym] and they are saying we can't sign [a CDA], there are 10,000 people in this company, how do I know of a guy who does not work on your staff. But if you have got a specific project even with a big company like that then you can get a CDA in place. But CDAs tends to be more in lower level companies.*

Knowledge capacity: To explore new partners and extend their partnerships SME-C seemed to require more capability for handling knowledge as well. The CEO of SME-C believed that this capacity was required for their partnership projects. As discussed before, there is complicated private knowledge that needs to be understood. One method for improving their capacity is to send people to study and research with research institutes that might be a possible future partner of the company. For instance, the interviewee mentioned a person who was sent to Chicago for a possible future partnership.

Knowledge exploration process: Exploring new areas of knowledge can happen though partnerships or by the firm itself. In this case, the importance of being explorative and acquiring new knowledge was emphasised. The CEO believed that establishing a biotechnology company has two aspects: first the technology which comes from research institutes and second the continuous research which should always be to underpin the technology.

> *It's very rare to be able to survive as a biotech company without continuing research because the next guys come along. Once you get beyond the initial discovery, you want to go into the clinic.*

However, this diverse area of knowledge was also considered as an "arrogant and naive approach" by the company. He believed that it would be better if they focused on two of patents, mainly because patent process is lengthy and expensive. This is the *"smart approach"* to know the breadth of application of a patent before working on the other patents.

> *We have diverse areas of patents, but I think it is a mistake; we spend several millions in there to owning the patent…All these patents cost us dollars and time to register to file for PCT and to get*

> *reviewed in America and all around the round. It turned out to be millions of dollars that we spent on patents. It was a total waste! We had a massive portfolio but at the end we dropped [nearly] all of them, we kept two and developed them.*

The third significant interaction in this case was among process and centrality. According to the interaction analysis in Phase 2 (Chapter 9), focusing on exploration may lead to higher knowledge creation only for actors with peripheral position in the k-network. By contrast for actors with a more central position, pursuing exploration may result in lower knoweldge creation.

This interaction in SME-C affected knowledge creation negativily. There was evidence to support the finding that having exploration via diverse partners was punished by their investors and shareholders. They believed that this approach may be associated with higher risks and costs.

> *If you have too many partners, [or change your partners frequently] that might not be acceptable for investors, After 2005, we had got letters from our investors they told us that 'you're genius guys but having various partnerships is so complex and risky…now we are going to stop giving you any money' so we had to stop investing on new technologies.*

In their patent projects, although SME-C had only two partners in their patent co-authorship network, they had various partnerships with two partners, but also completed several patents independently. This approach compared to the average of the industry could be an indication of the exploration process (the exploration/exploitation index was moderate to high: 56% Average: 53%).

This mixed (positive and negative) impact can be interpreted by a cost-benefit analysis of partnerships. The main benefits of partnerships discussed by SME-C were access to high quality knowledge in a timely manner. However when this company possessed a high central position it should be easier for the company to access required knowledge through its contacts. However several partnerships, even with multiple existing contacts, requires money and time for arrangements and new agreements, particularly in this business, where private knowledge (in terms of technologies and expertise) is protected by legal contracts like CDAs The possible costs associated with even repeat partnerships, can be more than the benefit of the partnership. This may result in lower knowledge creation.

As explained before, close collaborations and partnerships which are required for a knowledge creation project that can result in patents, may require exchanging knowledge that is considered private knowledge. This type of knowledge is often protected by complicated contracts like CDAs particularly when the participants are small size companies (Figure 10-10). The more SME-C explores new partners, the more money and time should be spent on contracting and dealing with the risk of disclosure of their knowledge. Even working with repeat partners requires negotiation and contracting processes that have to deal with disclosure risk. This is why investors and shareholders may face a more complicated trend which would hinder their future investments on new projects. This effect could be one of the factors that stop investors. However, more general reasons like the economic trend in late 2005 could explain the fact that SME-C had to exit the stock market and stop trading publicly. Hence, it is not possible to have a strong conclusion that this negative influence was due to the co-existence of central position of the company with its partner exploration approach.

10.3.3.8. Summary of the SME-C's approach to create knowledge via its k-network

This case had a mixed impact configuration. Based on the analysis represented in Chapter 9, the mixed-impact configuration includes more than one interaction among all the three possible interactions. More precisely for SME-C, all the three possible interactions seem to influence knowledge creation. These three interactions include the content-centrality interaction, centrality-exploration interaction, and density-exploration interaction as represented in Figure 10-10.

High knowledge diversity co-exists with a central network position of the case. This interaction has a strong[22] positive effect on knowledge creation, as discussed in Chapter 9. This interaction was also confirmed in this case, mainly based on the patent documents and perceptions of perceptions of its CEO and chief scientist. The positive association of interaction 1 and interaction 2 influenced knowledge creation based on several factors that emerged based on the empirical data of the case analysis. The negative effect of interaction 3, was also supported by the data. However there are other possibilities that can explain the negative effect like the decline in the global economy after 2005 as reported by the OECD (Blundell-Wignall, Atkinson and Lee 2008). The

[22] In comparison with SME-A this SME created about the same number of patents (16 vs.14 patents) and the intention for being innovative is also represented and confirmed in perceptions of the CEO and chief scientist of the SME-C. This will be discussed later in the comparative analysis of cases (Section 10.4).

three interactions and emergent factors are illustrated in Figure 10. Emergent factors in this case are timeliness, quality of knowledge, business strategy and knowledge capacity for interaction 1 and type and size of partner and public vs. private knowledge as influencing factors for interactions 2 and 3.

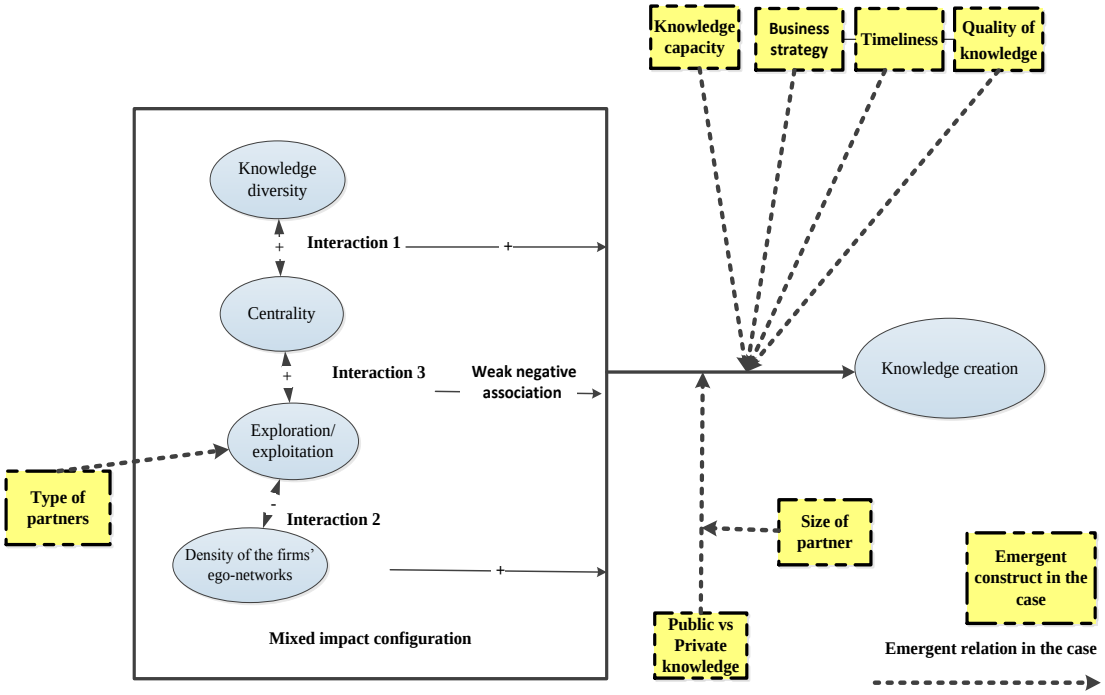


Figure 10-10 Confirmation of the initial model with the emergent constructs in SME-C

10.3.4. SME-D as an example of firms with the neutral impact configuration

10.3.4.1. Background

SME-D was a small molecule drug discovery company that aimed to translate innovative cancer biology research into lead and preclinical stage drug candidates. Since 2004, this company was funded under the Australian federal government's cooperative research centres (CRC) scheme – an initiative administered by the former Department of Industry, Innovation, Science, Research and Tertiary Education. The CRC program supports end-user driven research collaborations to address major challenges facing Australia like cancer. CRCs pursue solutions to these challenges that are innovative, of high impact, and capable of being effectively deployed by the end-users (CRC 2012).

10.3.4.2. Size of the company

From 2001 to 2010, this company had five core staff, including three management team members working with about 50 scientists as a R&D team, who were based at several universities and other public research institutes and on a project basis. The chief business officer of the company explained[23]:

> *We are sort of a virtual organisation. Our headquarter staff and core management team includes five of us. But we actually found about 50 people in [BF93 University] and [XPMC research centre], [IEWH public research centre], [VXU public medical research centre]. They are our employees in some way.; In fact they are our scientists. And they work at their environment at [previously mentioned organisations]. So they don't work in our labs, but are working on other peoples' labs, but we found them as they work on our projects. These 50 people are core scientists for about five years and our projects come and go. We have project A, project B, and then we start project C but these people remain the same.*

10.3.4.3. Products and services and role in the industry value chain (supply chain)

The main activities of this company have focused on research and development of molecule drug discovery in cancer biology research. This mainly refers to discovery, and early stages of development according the diagram below, as explained in the interview with the chief business officer of the company.

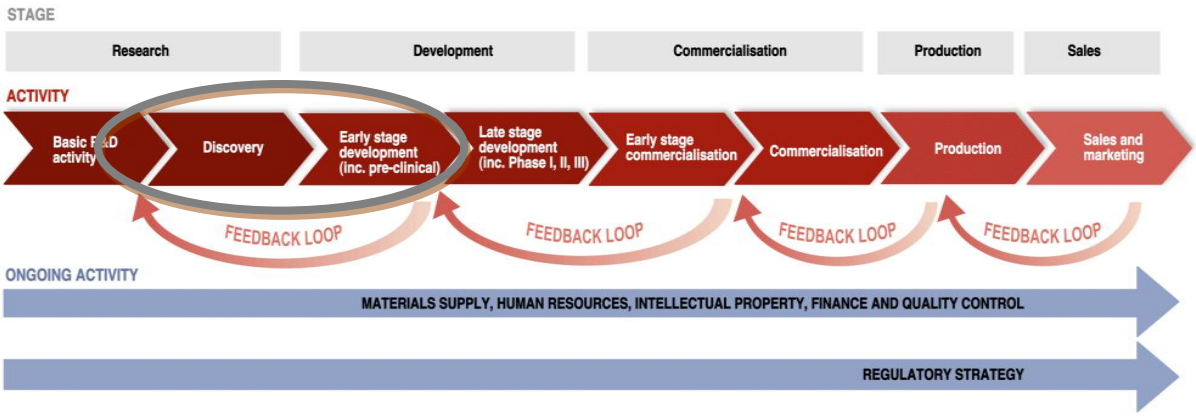


Figure 10-11 Position of SME-D, within the biotechnology industry value chain (supply chain)

Adopted from Allen Consulting Group 2010

[23] All names mentioned in the text are pseudonym

This is also reflected in one of the company documents (Figure 10-12). As shown in the Figure 10-12, SME-D targeted the gap between basic R&D normally engaged in by universities and public research centres and clinical development in the public sector.

Figure 10-12 Targeted section for SME-D to create value

In the interview with a partner of SME-D (BF93 in Figure 10-12), the director of a research centre in the university (BF93) described the nature of his institute:

> *We are post target validation and more about drug candidate development. Most of our activities are preclinical…so have a lot of collaborations with pharma and biotech companies like [SME-D]…we had the projects for down [basic R&D in Figure 10-11] but we fairly much focus in the translational development. There are a lot of different labs and faculties that are involved with biotech and interested into translational research like science faculty, medical faculty, faculty of pharmacy. Our institute is a joint venture between medicine and faculty of pharmacy. ...Here we have 200 staff and scientists.*

10.3.4.4. Structure of the patent co-authorship network

The patent based collaboration of this company mainly referred to getting help with basic science research (Figure10-11). The interviewee who was the chief business officer of the company mentioned:

> *We are not doing the basic R&D activity, that's what our partners like [BF93] and [XPMC] do.*

According to the two patents that were filed in AusPat, both of the patent partners are located in Victoria. For finding new discoveries, this company needed other types of partnership to take the discovery to the next stages, which are clinical tests, development and commercialisation, production and sales. This kind of partnership however, may not be represented in a patent document. Based on the interview with the

SME-D chief business officer, the main reasons for their partnerships are getting knowledge and technologies to discover and develop drugs. To define the purpose of collaboration, a similar question was asked from the director of the research centre in the university BF93, as the main partner of SME-D:

> *There were different groups that have worked on [Topic Z], and the idea was that by bringing all these groups together under a CRC, it would accelerate research and development in that field… CRC will fund with money coming from both federal government as well as money coming from cash and in-kind of CRC[24]. ... overarching that there are agreement, the participants agreements which outlines how different organisations and core members and core participants of CRC will conduct themselves that includes any areas such as commercialisation, intellectual property handling. So for any CRC funded project, the IP generated from that project is owned by CRC. So the CRC is responsible for the IP. All participants benefit from the commercial exploitation of that IP, so there is a backing beneficial return back to participants. It's a little bit different to a Pharma or Biotech company, and that's the model which the CRC works. So the aim of collaboration is funding goes to the participant that has capacity and skillsets in the program that the CRC thinks has high value and high impact. And our obligations to the CRC are we have to provide in-kind every year and that under participants agreement we assign our rights to them.*

So far there have been two patents published by SME-D but other names of participants are not mentioned in the patent document. The chief business officer of SME-D explained the reason:

> *Those collaboration projects [with other partners], if successful, may result in patents. The inventors of those patent applications can be from [BF93], [XPMC], [IEWH], and other organisation but the name of assignee in the public document will be [SME-D] and their names since we have got a prior agreement with these organisations that assign their rights to our company as well…We collaborate very extensively; all our work has been done by our collaborators since we don't have labs, we are just a management team, a sort of virtual organisations that heavily relies on collaborators like [BF93],[XPMC] and [IEWH] and they do own us as they are our shareholders.*

[24] Many universities typically contribute both cash and in-kind to support CRC activities. Although BF93 contributes considerable in-kind to CRCs, cash is also provided on certain conditions. For instance, cash may be provided by BF93 as 'tied' cash, with the money coming back to support senior staff positions which are of strategic value to the university. In circumstances where BF93 contributes cash, the university would expect to receive at least two times its total cash and in-kind contributions back from the CRC to support CRC related project activities in the university.

SME-D was located in a low to moderate central position in the whole network, and having a high density ego-network. In regard to centrality degree, this SME had a low to average score both in terms degree centrality (local centrality, 3) and closeness centrality (global centrality, 1.372), while the mean and median for these measures were 8.9 and 3; and 1.272 and 1.366 respectively[25]. Also in terms of density in its ego-network, this SME had a very close ego-network, since all of the partners had collaboration with each other as well. In the first project they worked with BF93 and in their second project they have collaborated with both BF93 and BF106. The ego-networks of this SME (BF110) and its partners (i.e. BF106 and BF93) are represented in Figure 10-13.

In the interview with BF93, the director of the research centre in the university BF93 was asked to comment on the frequency of interactions as a measure of a dense network. This interview also confirmed the close relationship between SME-D and its partner (BF93) that was expected by analysing the patent documents:

> *There is a board in the CRC with a CEO deciding about the allocation of resources; for this particular CRC [SME-D] I don't think they have representation on the board, but being a core participant, we have a lot of interactions and we have got a number of projects, and have very good and close relationships with [SME-D].*

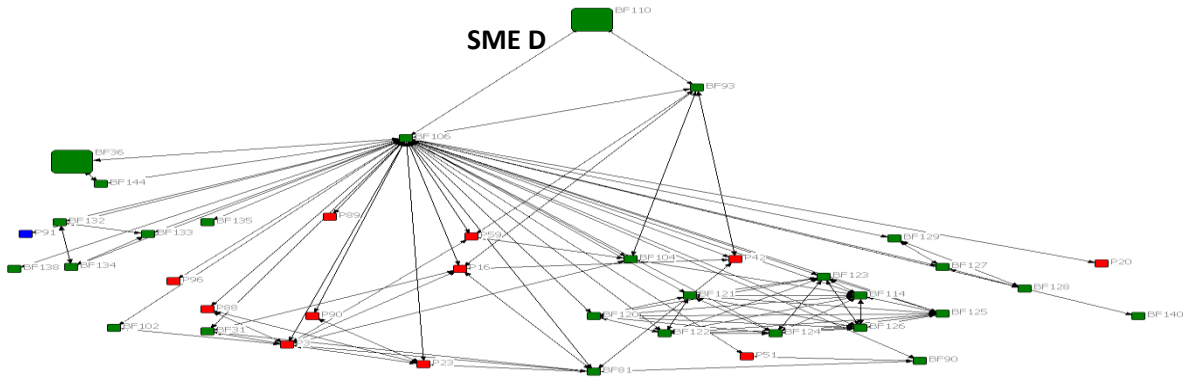


Figure 10-13 The ego-network of SME-D

SME-D, as mentioned before, has a key group of strategic partners including BF93, and BF106. When asked about the challenges during these two partnerships, the structure of this collaboration became clearer in terms of agreements and the expectations of

[25] The closeness centrality is a reverse measure so bigger numbers represent a greater distance from the centre of the network

participants. They are are essentially a collaborative consortium with a standard contract that all their projects run under. Five years ago, at the set up phase, SME-D and its partners spent a lot of time negotiating about every single important issue and, as both interviewees from SME-D and its partner believe, this is the reason that their collaborative projects move smoothly. Hence except for the limited pool of money, there was no serious problem in terms of knowledge and technology exchange.

> *And we are still working on new projects under the same agreement. So we did the work up front in setting up these processes such that the sort of discussion downstream–all scientific discussion, IP issues, contract obligations were sorted out, they are sort of standard now, so we just start a project not a contract or particular relationships and things.*

10.3.4.5. Content of the patent co-authorship network

The technological knowledge of this SME included two IPCs. Given the whole average of the network (including all large size universities and big biotechnology-pharmaceutical firms), this SME had a low level of knowledge diversity (two IPCs–knowledge diversity = 0.5). SME-D believed that given their size they have a reasonable breadth of knowledge:

> *I personally think that we are just about right, what we do in the context of Australian research, we are about the right size, right about the amount of funding to do what we can do.*

He believed that if they go any wider, they may become less expert in their field as reaching more diverse areas of technological knowledge requires more budget and people, which is not available to the company. On the other side, if they go narrower they think then probably there would be more difficulty to get enough numbers of projects each year.

However, for non-technological knowledge like managerial, market knowledge beyond the technological knowledge, they are keen to reach more diverse knowledge. As part of their agreements they have a big education component and are very keen on science education. One of their aims, according to the SME-D interviewee, is to educate Australian science in the discovery and drug development. Basically they have spent some money on seminars, courses, and teaching PhD students and post docs and giving lectures and seminars and courses about the process of discovery and drug development.

The non-technological knowledge areas like market knowledge were not acquired from these partners; however SME-D was expected to share the lessons learnt in their projects (for instance about the managing drug development projects) with the staff and students of the partner organisations. This was also confirmed by the contact person from BF93.

Regarding tacit knowledge, it was argued that the knowledge that SME-D deals with is codified knowledge, which is all they need for their collaborative projects. In this regard, the interviewee mentioned the system that they are using to capture this codified knowledge:

> *This system is very good at capturing the experiment and data but it is not designed to capture people's ideas and thoughts. So we do have a sort of backup lab system that [although] people can't get and store ideas, business strategic, or out-of-the-box thinking, it captures all we need for the patent applications. It is a data capture system not a know-how capture system. The patent process requires exemplified data, and this system captures all of that, but is doesn't capture any changes in business strategy or something that is discussed at the board level.*

The BF93 contact person also confirmed that tacit knowledge was not in the scope of knowledge exchange within the partnership. Except for know-how, the rest of the materials are captured, as they record whatever is practical to collect. To manage the know-how and reuse them in other projects, they have no obligations except using the same data that was generated within [SME-D] since these data are their own property.

10.3.4.6. Collaborative process of the patent co-authorship network

The level of the diversity of SME-D's patent partners (the exploration/exploitation index) was low (0.44 Average: 0.53) in comparison with other firms in the market. From 2001 to 2010, SME-D only collaborated with two partners with no independent project by itself. As the SME-D chief business officer explained, they do work closely with their core partners. By keeping their relations with current partners, they are also interested to explore new areas of knowledge.

To describe the ways in which SME-D acquired, created, shared and harnessed knowledge during this partnership, the interviewee also mentioned regular face-to-face contact and rarely electronic mediated project meetings and also a system called

"electronic lab notebook system" as efficient and effective ways for such knowledge exchange:

> *We have project meetings, which are face-to-face meetings …We then have a group–what we call "portfolio management group" which is a sort of our oversight committee which basically we report to review all projects within three months interval. We have people from overseas on that, so … half of people are physical, half are electronic… we have a board of directors above that meeting every three months and underlying that we do actually have an "electronic lab notebook system" – this is a system that all our scientists are having a sort of access theme. All the research experiments written up for different projects ends up in our "electronic lab notebook system", which is essentially an electronic intranet that captures all of the experiments and data. And it's also signed by all scientists and supervisors. All these people then can have access we can have access, as well to these data and records. These are all electronic.*

The objectives of sharing knowledge in this way are to capture almost every piece of information consistently and store it and getting it counter-signed so it is legally realised. As each project may have its own characteristics, this system tries to standardise everything in their projects and also centralise all the electronic data capture. This centralisation allows them to control, keep and store all their data which obviously is very useful when they want to file a patent. According to the SME-D interviewee, this took a lot of time and effort and cost 3.25 million dollars to set it up. Now it runs very well and all their projects are captured on that, and everyone knows how to use it and add data.

In a similar way, the director of the institute in BF93, believed that because of the type of partnership, and duration of partnerships, it was easier to exchange knowledge freely.

> *Most people in these organisations already know each other and had collaborations with each other before and are aware of others' different skill sets. There are complementary skills which are going to a project enhance the value of the project, so that's why it is different to an interaction we may have with other pharma or biotech companies. Where we may have access to certain platform technologies that wouldn't been available to us other than if we hadn't had that relationship with that company.*

Also, regarding the importance of having a technology-based procedure to collect the information in the patent project, the director of BF93 mentioned: 1) Managing the

project, 2) keeping the records for filing and regulatory requirements 3) lesson learned for the next project and 4) in some cases CRCs give their licence back to the university to use the data for internal research or any other purposes.

10.3.4.7. The interaction of content, process and structure of the k-network in SME-D

How do the inter-relationships of content, process and structure of the k-network of SME-D, contribute to their collaborative knowledge creation? To answer this question, all data sources of SME-D were analysed and the summary of all the themes is provided in Table 10-7. These themes include those which were identified based on the research framework and interview protocol that are also represented in the interview protocol. Emergent themes representing the contextual factors of the selected case are also listed in this table. The sources of the themes are also shown.

Table 10-7 Summary of all the themes in SME-D

Note: Sources of each theme are represented by *

Constructs in SME-D	Themes	Data sources				
		Interview protocol or emergent	Interviews	Partners' Interviews	Patent documents	Annual reports/formal documents / websites
Background	Activities	Interview protocol	*	*		*
	Size	Interview protocol	*	*		*
Content	Diversity	Interview protocol	*	*	*	
	Tacit knowledge	Interview protocol	*	*		
	Non-technological knowledge	Interview protocol	*	*		*
	Knowledge capacity	Emergent	*	*		
	Business strategy	Emergent	*	*		
Process	Partners diversity	Interview protocol	*	*	*	
	Type of partners	Emergent	*	*		
	Nature of the partnership	Emergent	*	*		*
	Exploration process	Interview protocol	*	*		
	Technology and method	Interview protocol	*	*		
Structure	Purpose	Interview protocol	*	*		*
	Challenges	Interview protocol	*	*		
	Centrality	Interview protocol			*	
	Density	Interview protocol			*	

SME-D possessed a neutral configuration which means there are no significant interactions expected. Given the data sources mentioned in Table 10-7, the knowledge

creation of SME-D in terms of patenting via its k-network can be explained by several constructs. In addition to the constructs discussed in the research framework (which were tested and confirmed in Phase 2), SME-D introduced not only knowledge diversity, partner diversity and the structure, as important constructs but also highlighted other constructs that may explain the k-network of the firm.

Type of partners and nature of the partnership: The nature of the partnership between a CRC and its partners is influential because the partnership is funded, supported, and regulated by governments. In this case, the core partners of SME-D were mainly large organisations/ companies which have several patents co-published with several diverse collaborators. For example BF93 and BF106 were among the core participants. These core participants during the period of the study (2001–2010) had a central role in the whole biotechnology network. In this regard the global position of SME-D was more central compared to other actors with similar partnerships. However, the local position is decentralised. This is because the number of partnership of SME-D was generally less than the average of other actors. The density of the ego-networks of SME-D was mainly above the average.

Due to the nature of the partnership in SME-D, it seems that they were keener on exploitation than on exploration. As part of the pre-defined agreements of SME-D, core participants were looking to get back the royalties of each patent published by SME-D. In this regard, it was expected that SME-D would keep its partners for several projects, since they were looking to get the most benefits possible from any patents. Moreover, they did not need to bother with defining new regulations and contracts with existing partners, which would be required for any random partner.

The areas of activities for SME-D could be fairly broad, but if we focus on the knowledge content as IPC of the granted patents, then diversity or heterogeneity of the knowledge is quite limited. SME-D had a better chance to acquire assets and licences through its pharmaceutical partners than by internal developments. Acquiring knowledge through buying licences might be a complementary source for other actors; however it was the main source for SME-D.

Given this background, SME-D had a moderately limited technological knowledge. The whole activities of SME-D may include diseases like cancer, which is a quite broad

area; however in regards to their patents, SME-D has focused on a narrow domain of knowledge. Compared to knowledge diversity of other actors with a similar configuration, SME-D had a very limited knowledge but thanks to its big core partners, it is possible for SME-D to draw on funds and in-kind (staff and infrastructure) contributions to support its innovative projects.

Business strategy: SME-D seemed to pursue more of a defender type of strategy rather than analyser**.** According to the four types of strategy identified by Miles et al. (1978), defenders aim to keep the current product selling to markets by establishing long-term collaborations with a few key partners. In the interview with the chief scientist of SME-D and the contact person from its key partner, university BF93, it was mentioned several times that there were intentions to identify new ventures and new markets. It also aimed re-sell existing products. Therefore they are more likely interested in exploiting current partners and current knowledge rather than exploring diverse new areas of knowledge and partners like those required for filing a patent.

Knowledge capacity: In the literature, the concept of absorptive capacity (Cohen and Levinthal 1990) was used to explain how diverse knowledge can be used to create new knowledge in intra-organisational collaborations (Tsai 2001) as well as in inter-organisational knowledge creation (Weigelt and Sarkar 2009). The capability of SME-D to create new knowledge seems another important factor to explain the intention of SME-D not to diversify their knowledge bases. SMEs are widely recognised as companies with limited resources in terms of expertise and financially (Hanna and Walsh 2002). This capability was also important for getting funding and the ability to manage new projects.

10.3.4.8. Summary of the SME-D's approach to create knowledge via its k-network

This case has a neutral type of configuration. As discussed in Chapter 9, it was expected that the interactions of content, process, and structure of the SME-D's k-network, have no significant influence on knowledge creation in this case (Figure 10-14). More precisely possessing relatively low diverse knowledge, low central position seems to have a weak influence while the close partnership through a high density ego-network seems to have a stronger impact on knowledge creation in this case. Exploration of new partners is not pursued as an effective approach to create more knowledge mainly because of the strong bond among the existing strategic partners. However, new

partnerships may be sought for the commercialisation and lower stages of the value chain not for the knowledge creation in terms of patents. Overall, the level of knowledge creation was much lower than those of other cases[26]. There was no indication to show the interaction of content, process and structure can be associated with knowledge creation. For SME-D, the type of collaboration may include the collaborations between two private firms, or between a CRC and universities. It seemed that the CRC-universities collaboration was an important factor to shape the k-network for SME-D. According to this case, there are heaps of regulations and pre-defined agreements and obligations between SME-D and core participants which are mainly universities and public research centres. Finally, all these emergent factors are discussed as illustrated in Figure 10-14.

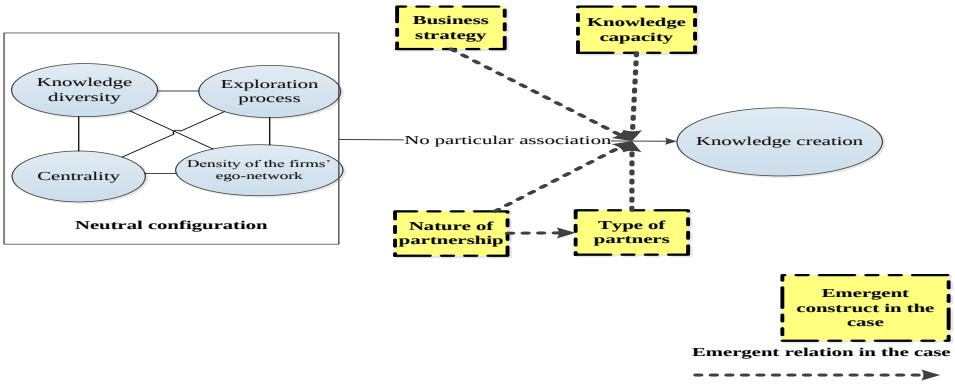


Figure 10-14 Confirmation of the initial model with the emergent constructs in SME-D

10.4 Comparative analysis

Before undertaking the cross-case analysis, a summary of the commonalities and differences of the organisational characteristics (Yin 2003) is given. Common characteristics among these SMEs are represented in Table 10-8. In terms of sector and sub sectors, all these cases were private companies involved in drug discovery and research and development within the Victorian biotechnology industry. In terms of size, all employed between three and fifteen personnel. In terms of the age, two started their business during 2007 and two were in business before 2000; hence they had been in this business between six and sixteen years.

Table 10-8 Major features of the cases– * within 2001-2011

[26] In comparison with SME-A this SME showed a lower number of patents (16 vs.11 patents) and the intention for being innovative is also represented and confirmed in interviews. This will be discussed later in the comparative analysis of cases (Section 10.4)

	SME-A	SME-B	SME-C	SME-D
Sector and sub sector	Biotechnology–drug discovery and development	Biotechnology–molecular diagnostic	Biotechnology–research and development of immunology	Biotechnology–molecule drug discovery
Private-Public	Private	Private	Private	Private
Region	Melbourne, Victoria	Melbourne, Victoria	Melbourne, Victoria	Melbourne, Victoria
Age	1997	2007	2000	2007
Size*	3–8, including 2 management team	5–15, including 3 management team	5–15, including 2 management team	7, including 3 management team
Market	Very dynamic and global competition	Very dynamic and global competition	Very dynamic and global competition	Very dynamic and global competition

However, the most important characteristic for this research was the k-network configuration of these SMEs (as discussed in Chapter 9, Section 9.5.2). There were three different configurations identified based on my network analysis. Hence the comparative analysis is mainly focused on this characteristic. Here I have SME-A and SME-B representing a favouring configuration, SME-C as an instance of mixed-impact configuration and finally SME-D of a neutral configuration.

The rest of this section reviews these cases in terms of their knowledge content, collaborative process and k-network structures. For the cross-case analysis, there are two types of constructs that needed to be considered. First, based on the research framework developed in Chapter 3 and tested in Chapters 5–9, there are four constructs of knowledge diversity, exploration/exploitation process, and centrality and density of the firm's ego-network that were discussed. Second, in the interview protocol there were other factors that were developed and studied within the cases to probe for a more in-depth understanding of the constructs. These were tacit knowledge, and non-technological knowledge studied to have a better understanding of the content of k-networks. Policies, technology and method and goals of knowledge initiatives, were studied to throw further lights on the process construct of k-networks. Finally, purposes, challenges, and details of interaction during collaborative projects were also studied to have an in-depth understanding of the cases in terms of their k-networks structure. Beyond these types of constructs and factors, there were also new themes that emerged during the interviews in the process of explaining the role of content, process and structure on knowledge creation within the cases. All these constructs, factors and

themes are illustrated in Table 10-9. Hence the constructs and factors were studied in all cases; however the emergent themes may not necessarily be discussed in all cases. This is the major source of data for the cross-case analysis.

Table 10-9 Constructs and emergent themes (represented in highlighted rows) across the cases

Themes including factors and themes	Configuration types			
	Favouring		Mixed	Neutral
	SME-A	SME-B	SME-C	SME-D
Knowledge diversity	*	*	*	*
Tacit knowledge	*	*	*	*
Business strategy	*	*	*	*
Exploration/exploitation process	*			
Knowledge capacity	*	*	*	*
Non-technological knowledge	*	*	*	*
Quality of knowledge			*	
Timeliness	*		*	
Partner exploration	*	*	*	*
Technology and method	*	*	*	*
Nature of partnership				*
Types of partnership				*
Purpose	*	*	*	*
Challenges	*	*	*	*
Centrality	*	*	*	*
Density	*	*	*	*
Knowledge creation	*	*	*	*

The following sections explain which cases raised which emergent themes, and why particular themes existed in some cases and not others.

10.4.1. Content of k-networks across the cases

Focusing on the explanatory case study approach, this section sought to confirm and explain the positive association between knowledge content and knowledge creation. As shown in Section 10.3, this result also confirmed the importance of knowledge diversity in all four cases. Those SMEswho intended to, and were able to, acquire more diverse technological knowledge, published more patents than those who tried to reuse their existing technological knowledge.

In both SME-A and SME-C, their knowledge was heterogeneous (0.77, 0.79), with diversity of their knowledge bases more than the average of the patent-authorship of the Victorian biotechnology industry (0.52). Accordingly, numbers of their patents as the measure for knowledge creation were also over the average. However, SME-D, which had more homogeneous knowledge (0.50), had only two patents, which is lower than

the average. To explain the positive role of knowledge content in knowledge creation in terms of patents, several themes emerged. These are listed in Table 10-10.

Table 10-10 Constructs and emergent themes regarding the content of k-networks in the four cases

Emergent themes	SME-A	SME-B	SME-C	SME-D
Configuration	Favouring	Favouring	Mixed-impact	Neutral
Knowledge creation	High	Medium-High	High	Low
Business strategy	Prospector	Analyser	Prospector	Defender
Exploration/ exploitation process via partners	Exploration/ exploitation via high partner diversity	Exploration/exploitation via low partner diversity	Exploration via high partner diversity	Exploitation via low partner diversity
Knowledge capacity	Important	Important	Important	Important
Timeliness	Required to be first in the market	Not addressed	A motivation for partnership	Not addressed
Quality of knowledge	A challenge for partnership	Not addressed	A motivation for partnership	Not addressed

10.4.1.1. Business strategy:

Not surprisingly, the business strategy of the cases seems to be influential on the attitude of all cases towards their knowledge diversity. Regardless of the configuration of k-network, in terms of favouring, mixed-impact and neutral types, the role of knowledge diversity in knowledge creation of the firm seemed to be affected by its business strategy. The detail of this role in each case was discussed in the previous section. Access to diverse knowledge can help knowledge creation mainly if companies pursue an aggressive knowledge strategy.

Hence business strategy seems another important factor to explain the content of cases' k-networks. According to the four-type of strategy developed by Miles et al. (1978), prospector firms like SME-A and SME-C, are more interested in developing new products and exploiting market opportunities, which require more attention to diverse areas of knowledge than focusing on the existing knowledge (like SME-D).

10.4.1.2. Exploration/exploitation process via partners

Working with different partners on new areas of knowledge can increase both knowledge diversity and knowledge creation. This was the approach taken by SME-C; however SME-D preferred to keep their existing links and exploit them over time.

SME-A and SME-B seemed to have a more balanced approach toward exploration/exploitation, though in different ways. While SME-B explored new areas of

knowledge through repeated partnerships, SME-A was more open towards changing partnerships over time or even looking for new partners.

10.4.1.3. Knowledge capacity

The capability of firms to understand and use newly acquired technologies and expertise seems another important factor to explain the role of content on knowledge creation within their k-networks. SMEs are widely recognised as companies with limited resources in terms of expertise and finance (Hanna and Walsh 2002). The need for this capacity was reflected in all cases. Given that all cases were SMEs, with the typical need for more resources and capability to manage their businesses, this is not a surprising result.

10.4.1.4. Timeliness

Having timely access to knowledge seemed to be a condition for acquiring new knowledge. It is believed that being first-mover in the market in terms of access to new knowledge and using patents to protect the position helped SME-A to create more knowledge. SME-C also mentioned that diverse knowledge worked for them to create more knowledge, when that knowledge was provided in a timely manner. This is why they tried their contacts who could provide faster access to the required knowledge.

This theme was not addressed in the analysis of SME-B and SME-D. In both cases, they preferred to work closely with repeat partners. This was also reflected in their very dense ego-networks. Accordingly, these two cases were more interested in exploitation rather than exploration. Hence, having timely access to new knowledge was not a major issue for these companies compared to SME-A and SME-C, both of which were more exploration oriented.

10.4.1.5. Quality of knowledge

Quality of knowledge according to Chiu et al. (2006) is considered with characteristics like relevancy, ease of understanding and reliability. This construct was only addressed by SME-A and SME-C as an important factor for acquiring and exchanging knowledge with partners. In SME-C for instance, the quality of expertise was mentioned by the interviewee as a reason for having various partnerships. On the other hand, this factor was implicitly mentioned by SME-B and SME-D as a contributing factor for existing

partners to keep their close and repeat collaborations with a particular scientist and a particular university.

10.4.2. Collaboration process of k-networks across the cases

From the quantitative analysis, tests showed that a firm's diversity of partners as an index for the exploration/exploitation process was not associated with knowledge creation of the firm. To explain this finding through the case studies, the results of the analysis is presented here. As shown in Section 10.3, these results also confirmed that there was no indication of direct association among process of k-networks and knowledge creation.

In both SME-A and SME-C, their approach was more exploration-oriented. The exploration/exploitation indexes for these two cases were 0.510 and 0.561 respectively, where the mean and median were 0.53, and .0625. The interviews showed the k-network approach in SME-A was more aligned with a balanced exploration/exploitation approach, with more emphasis on exploration, while SME-C's was closer to exploration. From the interview with SME-B's chief director, it was concluded that SME-B was also closer to a balanced exploration/exploitation approach; however, this approach was more focused on exploitation (exploration/exploitation index was 0.314). It is important to note that SME-B was among the firms with a high knowledge creation rate with a more exploitation orientation.

SME-D seemed also to follow more of an exploitation approach with an exploration/exploitation index of 0.444. This approach was also supported in the interview with the chief business officer of the company. To explain the mixed influence of the exploration process on knowledge creation in term of patents, the following themes outlined in Table 10-11, are also discussed.

Table 10-11 Constructs and emergent themes regarding the process of k-networks in four selected cases

Emergent themes	SME-A	SME-B	SME-C	SME-D
Configuration	Favouring	Favouring	Mixed-impact	Neutral
Knowledge creation	High	Medium-High	High	Low
Exploration/ exploitation process via partners	Exploration/exploitation via high partner diversity	Exploration/exploitation via low partner diversity	Exploration via high partner diversity	Exploitation via low partner diversity
Technology and method	Face-face communication, office tools and email	Face-face communication, office tools and email	Face-face communication, office tools and email	Face-face communication supported with lab note system
Types of partners	PROs	PROs and Individuals	PROs and Individuals	PROs
Nature of partnership	Not addressed	Not addressed	Not addressed	Affect the knowledge exploitation

10.4.2.1. Collaborative process

The study of the selected cases showed two things regarding the exploration process. First it confirmed the results of the quantitative analysis that either exploration or exploitation had no association with knowledge creation. For instance, while SME-A, SME-B, and SME-C all had a higher level of knowledge creation, the first two cases pursued a balanced approach, but the third one focused on exploration.

Secondly, the case studies showed that the configuration of the firms' k-network may have an association with the firms' approach towards the exploration/exploitation process. SME-A, and SME-B, with a favouring configuration seemed to be interested in a balanced exploration/exploitation collaborative process. However, SME-C, and SME-D respectively showed more intention to be either explorative-oriented or exploitative-oriented.

10.4.2.2. Technology and method

To process the knowledge, either for exploitation or exploration, all these cases showed little inclination to use any sophisticated information system to support their process. In all cases, face-to-face communication was preferred for discussion. The nature of the knowledge in most cases was codified so office tools and emails were used to support knowledge processing in terms of sharing and use of knowledge. Only in SME-D, a lab note system as a kind of workflow system was used to store the progress of the researchers' findings in the projects. In order to file patent applications, companies need to have complete and well-structured data to support their claims. However, in most

cases regardless of the configuration of k-networks, manual procedures and very basic office tools were used to handle the process. The reason, as observed in SME-A, SME-B and SME-C, was money. According to a very rough cost-benefit analysis in these cases, directors decided not to be involved in any sophisticated system. However, in SME-D, which had a strong partnership with universities and based on their agreements were required to keep track of all data and research findings, a more sophisticated system was used, but only for data storage and recording.

10.4.2.3. Nature of the partnership

As discussed before, a strong partnership between SME-D as a CRC with universities and public research institute made this company more focused on exploitation. As part of the pre-defined agreements of SME-D, core participants were looking to get back the royalties of each patent published by SME-D. In this regard, it was expected that SME-D keep its partners for several projects, since they were looking to get the most benefits possible from any patent. Moreover, they did not need to define new regulations and contracts with existing partners, which is required for any random partner.

In other cases, there was no reference to this factor as an important issue in the k-network for creating new knowledge. There were some partnerships between SME-A, SME-B and SME-C with universities and public sectors, and although there were some issues reported in these cases, none of them mentioned any effect on the collaborative process.

10.4.2.4. Types of partners

Similarity and differences of organisational characteristics like size and industry among participants, were considered as a factor defining exploitation/exploration process in the literature (Lavie and Rosenkopf 2006). In all four cases, public research organisations were discussed as partners of patent projects. These cases were all SMEs with limited staff and infrastructure for doing research, hence working with large universities and other public research centres was common and has been reported in other similar research as well (e.g. Powell et al. 1996; Owen-Smith and Powell 2004).

Except for SME-D, which had a close partnership with universities and other public research centres, other case companies had some concerns about collaborating with universities to create knowledge, particularly in terms of patents. The main problem was

with contracting and monetary issues that hindered knowledge creation. However, in terms of the collaborative process, SME-A, SME-B, and SME-C did not mention any influence on exploration or exploitation of process.

In SME-D, their partners influence the collaborative process approach because the aim of partnerships may encourage knowledge exploitation rather than exploration. These influences appeared in interviews with both the chief business officer of the SME-D and the director of the research institute of a key partner university. More than other case companies, SME-D is much more interested on finding new applications for existing knowledge.

10.4.3. Structure of k-networks across the cases

The third element of the conceptual model developed in Chapter 3 is structure of k-network, that includes both centrality and ego-network density. From the quantitative analysis, it was found that central position of an actor and the density of the actors' ego-network were both positively associated with knowledge creation of the actors. However, the interaction of structure with content and process showed that role of structure was moderated with collaborative process (i.e. interaction 2 and 3 discussed in Chapter 9).

To explain this finding through the case studies the results of the analysis are presented here. As shown in Section 10.3, this result also confirmed that there was no strong association between the structural aspects of cases' k-networks and their knowledge creation. It is also demonstrated in Table 10-12 that neither centrality nor density of ego-network among four cases, has a strong positive association with the knowledge creation of the cases.

For instance, SME-C with low density, and SME-B with low centrality, both had a relatively high knowledge creation. Likewise, SME-D with a relatively central position and high density ego-network had lower than average knowledge creation levels.

Table 10-12 Constructs and emergent themes regarding the structure of k-networks in the four cases

Emergent themes	SME-A	SME-B	SME-C	SME-D
Configuration	Favouring	Favouring	Mixed-impact	Neutral
Knowledge creation	High	Medium-High	High	Low
Purpose	Access to expertise and laboratories	Access to expertise and laboratories	Access to expertise and laboratories	Access to expertise and laboratories
Challenges	Finding right partners, funding and contracting	Funding and contracting	Finding right partners, funding and contracting	Funding
Centrality	High centrality	Low centrality	High centrality	Low-medium centrality
Density	High density	High density	Low density	High density
Types of partners	PROs	PROs and Individuals	PROs and private companies	PROs

10.4.3.1. Purpose of partnership

Access to knowledge is one the main reasons for partners to participate in a collaborative project. This theme, with no exception, was reflected in all cases. More than the knowledge itself, having access to other resources required for producing new knowledge in terms of patents was reflected in all cases. In some cases, the basic idea was developed in the company but to make it happen, companies asked for partnerships mainly with large size public research centres.

10.4.3.2. Challenges of partnership

Funding and protecting the company by appropriate contracting were major challenges discussed in all cases. As all these cases were SMEs, it is not a surprising result to see the importance of money and other resources to accomplish new projects. Being in the biotechnology industry with high speed of change and intensive competition, these firms were required to produce new knowledge mainly through their networks. These cases prefer to protect their intellectual properties by patenting. SME-D however, was an exception here. Given the discussion in Section 10.3.4, this company may not really be expected to create knowledge in terms of patents but rather it found new applications for existing knowledge. Moreover, SME-D which was supported by large public research centres and universities did not mention contracting as a challenge. For more than a year, they spent time with their key partners to set up an agreement where the possible issues and risks were identified and the ways to solve them were also considered in the agreement.

In SME-A and SME-C, with a high intention for exploration, looking for the right partner who can provide required quality knowledge in a timely manner was also cited as an important challenge for partnerships.

10.4.3.3. Centrality

In the literature, most research studies have considered central position of an actor as a positive influence on knowledge creation. In this research, the quantitative analysis in Chapter 8 supported this finding. However, as discussed in Chapter 9, the interaction of centrality with knowledge diversity seemed an important factor to conclude about the moderating role of centrality in knowledge creation.

Aligned with findings in Chapter 9, the case study approach also did not support the main stream of literature on the positive role of centrality and provided more insight about the role of centrality in knowledge creation.

In these cases, it is possible to see how a central position would not necessarily result in higher knowledge creation (like SME-D) and likewise, how a low level of centrality may result in above the average knowledge creation (SME-B).

According to the case studies, the role of centrality can be affected by both partner exploration (process of k-network) and diversity of knowledge (content of k-network). Of the four cases, SME-C included these interactions. SME-C showed a high central position in the whole industry network, with a high exploration approach and possessing high diverse knowledge. This interaction seemed to bring a mixed influence on knowledge creation, as explained in Chapter 9. As discussed in this case, the cost of exploring new partners for creating new knowledge was considered more than the benefit of the partnership. However, increasing diversity of knowledge seemed to provide positive results in knowledge creation.

10.4.3.4. Density

Although a dense ego-network brings its own benefits like trust and higher levels of support, in terms of providing access to new knowledge required for innovation, it is not as strong as a sparse ego-network. Hence knowledge creation of an actor in terms of patents is expected to be linked negatively with the density of the actor's ego-network as supported in the quantitative findings in Chapter 8. However, like centrality, there is

a need for considering the contingent factors (i.e. k-network process) to understand the role of density in knowledge creation (as reported in Chapter 9).

The cases here also supported the findings in Chapter 9 to highlight the role of emergent factors. For instance, SME-A and SME-B with very high density networks, still created knowledge more than the average of the industry.

According to the case studies, the role of ego-network density can be affected by partner exploration (process of k-network). Of the four cases, SME-C included this interaction. It had a low density network, with a high exploration approach. This interaction, which seemed to bring a positive influence on knowledge creation (as also supported in Chapter 9), can also result in a more central position. However, SME-C had already reached a high central position so this interaction may not result in higher knowledge. For instance, SME-A with a lower level of knowledge diversity and lower level of centrality, and lower level of partner-exploration had created more knowledge. This confirmed the mixed impact of this configuration.

10.4.3.5. Types of partners

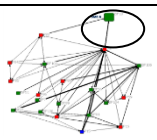
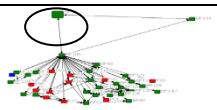
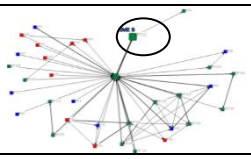
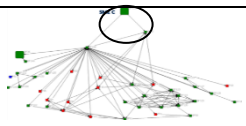
The importance of partner organisational type was addressed in Section 10.4.2.4. Excepting SME-D, the cases were not happy to have universities in their knowledge creation network, although from 2001 and 2010, all of them had experienced patent co-authorship with universities. These SMEs believed that partnership with universities was not sufficiently easy, fair, or productive.

10.5 Summary

Following the findings of previous finding chapters, this chapter reported the qualitative findings mainly to confirm and explain the quantitative results, which were discussed in Chapters 5–9. In this Chapter, first, three possible k-network configurations were identified then four companies were selected and assigned to these configuration. Next, there were within case analysis and across case analyses (Table 10-13) conducted to cover the details of the findings. In the first analysis, each of the four cases was reviewed drawing on multiple sources of data and as a result the conceptual model was revised based on the quantitative and qualitative empirical findings. Next, the three main constructs and the themes that emerged during the case studies to explain each of the constructs were reported. In the following chapter an integration of these qualitative

and quantitative findings is explained and the contribution to theory and practice discussed.

Table 10-13 Summary of the four cases

	SME-A	SME-B	SME-C	SME-D
Configuration type	Favouring	Favouring	Mixed impact	Neutral configuration
Number of Patents* Mean = 8.89 Median = 4	High 16	High 11	High 14	Low 2
Content-knowledge diversity Mean = 0.52 Median = 0.53	High – 8 IPCs – heterogeneity = 0.77	Upper Medium – 5 IPCs- heterogeneity = 0.56	High – 8 IPCs – heterogeneity = 0.79	Low – 2 IPCs – heterogeneity = 0.5
Exploration/eExploitation process: Mean = 0.53 Median = 0.625	Medium 0.510	Low 0.314	High 0.561	Low 0.444
Ego-network structure				
Centrality Degree – Median=3 Closeness (Reverse):	High centrality 6 1.364	Low centrality 2 1.368	High centrality 8 1.365	Low-medium centrality 3 1.372
Ego-network density Geometric mean	High density 1	High density 1	Low density 0	High density 1
Business strategy	*	*		*
Knowledge exploration process	*			
Knowledge capacity	*	*		*
Quality of knowledge			*	
Timeliness	*		*	
Nature of partnership				*
Types of partnership				*

Chapter 11

Discussion

Outline of Chapter 11

After analysing both quantitative and qualitative findings, this chapter reports how these analyses are mixed and embedded to answer the main research question and to develop the revised conceptual model which initially was proposed from the literature as reported in Chapter 3. In this way, I argue that this research confirms, but sometimes contrasts, the existing literature.

First, the characteristics of content, process and structure of k-networks are discussed in this chapter. Later, the role of the interactions of these constructs on knowledge creation by the firms is emphasised. Overall, this chapter shows how the results of my research can be synthesised to provide a better understanding of k-networks in the context of knowledge creation.

11.1. Introduction

The concept of networks is important in organisational research and practise. There are attempts to understand networks mainly through typology and taxonomies of network configuration. The literature has discussed inter-organisational networks through understanding the structural aspects, for instance, in terms of the position of actors in the network (Ahuja 2000; Kafentzis, Mentzas, Apostolou and Georgolios 2004). However, in all these studies, mainly the structure of the network has been considered as the main capital and has received the most attention to explain and describe the role of network. As discussed in Chapter 2 (section 2.2.2), the two main streams of research on social capital have produced seemingly contradictory results (Phelps et al. 2012).

The major argument presented in this chapter is that, in innovation-driven collaborations, explaining the role of k-network to create knowledge via social capital theory may produce contradictory results. To avoid these contradictions, there are several moderating factors that need to be understood.

With both quantitative and qualitative inquiries, my research showed that the interactions of content, process and structure provide a better understanding of k-networks in the context of knowledge creation. In the quantitative phases, three interactions are identified. In the qualitative phase, these interactions are confirmed and contextual factors were explored to understand the impact of k-networks.

Overall, by synthesising insights from both quantitative and qualitative analyses, this chapter proposes a novel approach to undestand k-networks configurations. In this novel approach, the interactions among content, process, and structure are considered simultaneously to explain the role of k-network on knowledge creation.

11.2. Characteristics of content, process and structure knowledge networks

There are two aspects discussed here to address the characteristics of each constructs: first the *initial actors* which refer to characteristics that are identified by the literature and addressed in the conceptual model (reported in Chapter 3) which was evaluated through both quantitative and qualitative inquiries. Second, *contextual factors*, explored in the qualitative phase on the basis of my case studies (as reported in Chapter 10).

11.2.1. Content of knowledge networks in the context of Victorian biotechnology industry

Based on the literature review, the content of knowledge was studied in terms of diversity of knowledge as the main focus of this research. In the patent co-authorship network, technological knowledge seems the main focus of the network. However, other constructs like nature of knowledge (tacit/explicit) and areas of knowledge (technological/non-technological) were also examined in the qualitative phase to contribute to a better understanding of content (Table 11-1).

Table 11-1 Characteristics of content reflected in quantitative and qualitative phases

From literature	Key findings	Summary of the discussion
In a patent co-authorship network, pharmaceutical-biotechnology SMEs have a lower level of knowledge diversity compared to large pharmaceutical-biotechnology actors	**Quantitative** – Hypothesis 1 was rejected. Pharmaceutical-biotechnology SMEs had the same level of knowledge diversity compared to large pharmaceutical-biotechnology actors. **Qualitative** – Quantitative findings were supported here. There were no critical issues in terms of access to technological knowledge among cases. However, in terms of commercialisation (which is outside the scope of patent co-authorship networks), SME cases were highly reliant on their partners as they don't have access to enough resources.	Access to the technological knowledge is not the major issue for SMEs. Based on the case studies, those SMEs who are able to publish their patents have relatively the same level of technological knowledge as their larger counterparts. (SME-C, SME-B and SME-A). However, in terms of non-technological knowledge (like managerial and market knowledge) SMEs do not have access to the same resources as large companies. This non-technological knowledge is mainly tacit and difficult to transfer, however the technological knowledge is available and explicit.

The literature (e.g. Sparrow 2001; Wickert and Herschel 2001; Wong and Aspinwall 2004; Sparrow 2005) reported that knowledge practices in SMEs face several challenges, which lead to less organised ways to access and manage diverse areas of knowledge compared to large sized firms. Hence one may expect to find a lower level of heterogeneous knowledge in SMEs in comparison with their larger counterparts, as reflected in Hypothesis 1. However, this was not strongly supported for the technological knowledge protected by patents in the Victorian biotechnology industry. Moreover the role of networks to provide more diverse knowledge is questioned for this type of knowledge, as explained below (Table 11-2).

In the Victorian patent co-authorship network of the biotechnology industry, the level of diversity was lower in SMEs compared to large actors. Likewise large size actors possessed more diverse areas of knowledge compared to individual inventors. However knowledge diversity in SMEs was barely higher than those of individual inventors.

Moreover, for SMEs the levels of knowledge heterogeneity among all types were the same (the details of this finding can be seen in Chapter 6).

In the SME literature, there is a general belief about the lack of resources including knowledge in SMEs (e.g. Wong and Aspinwall 2004; Levy and Powell 2005). This was accepted for the whole network. However for the commercial actors (i.e. pharmaceutical-biotechnology firms) the quantitative phase showed that, at least in terms of technological knowledge protected by patents, there was no significant difference between large organisations and SMEs. The possible explanation could be that in the competitive market, SMEs also need to acquire diverse areas of knowledge as discussed by SME-C, SME-B and SME-A. This was also mentioned in Sammarra and Biggiero's (2008) work that even SMEs in the aerospace industrial cluster of Rome, as a competitive high-tech industrial cluster, looked for diverse knowledge through their partners. According to other studies (Paniccia 2002; Lanza 2005), SMEs who are working in competitive high-tech industries, eventually have to participate actively in the market and possess required knowledge. In my research those SMEs who are able to publish patents, like their larger counterparts, seem to have some level of technological knowledge. However this does not imply that SMEs also have similar resources to turn their ideas into real products and commercialise them in the market.

The other finding was about the role of participation in the network on diversity of technological knowledge. In the Victorian patent co-authorship network of biotechnology industry, actors have almost the same level of knowledge diversity regardless of isolation or collaboration in the network. This finding is also supported for SMEs (see Chapter 6).

More detailed analysis showed that for pharmaceutical-biotechnology firms (PBFs), the levels of knowledge diversity were the same regardless of the size, however for collaborative public research organisations (PROs) the levels of knowledge heterogeneity were higher in large PROs compared to SME-PROs. Moreover, for collaborative SMEs (i.e. PBFs, Hospitals, and PROs) the levels of knowledge heterogeneity were the same regardless of the organisational type of SMEs. This was also supported for isolated SME actors. For collaborative SMEs (i.e. PBF, Hospitals, and PRO) the levels of knowledge heterogeneity were the same regardless of the

organisational type of SMEs. This was also supported for isolated SME actors (see Chapter 6).

In the k-network literature, acquiring knowledge from the network has been considered as a major reason for firms to participate in networks (e.g. Sammarra and Biggiero 2008; Whittington et al. 2009) particularly for SMEs (e.g Hanna and Walsh 2002). However the second phase of this research showed that at least in terms of technological knowledge, there is no significant difference between isolated and participative actors in the network. Based on the findings of the case studies, selected SMEs still collaborate with other companies to acquire knowledge and other resources required for their knowledge creation projects. Biotechnology firms require highly specialised capabilities and knowledge. SMEs as well as their larger counterparts were rarely able to work on several areas, and they preferred to stay focused on specific knowledge areas (IPCs) with which they were already familiar. Only large size PROs like large universities were able to have different departments to work on several knowledge areas.

Tactiness is another construct of knowledge which was evaluated in the case studies. The literature discusses the importance of tacit knowledge for knowledge creation through the network (Li et al. 2010), and difficulties with acquiring and sharing this type of knowledge in the inter-organisational collaborations. In the selected cases, tacit knowledge did not play a very important role. The reasons are twofold. 1) Patenting was the whole focus of the knowledge creation in this research. Knowledge creation in the selected cases was represented in terms of codified patents for the technological knowledge. 2) Tacit knowledge deals with the know-how which although it is important for knowledge creation projects, was not considered a challenge for knowledge creation since it is acquired by scientists and in most cases protected by legal contracts. For the non-technological knowledge areas, tacit knowledge was recognised as important, not necessarily for the knowledge creation project itself, but for other activities like finding new partners (like SME-A) or for clinical development and commercialisation (like SME-C) as reported in Chapter 10.

11.2.2. Collaborative process of knowledge networks in the context of the Victorian biotechnology industry

In inter-organisational k-network research, partner-diversity has been considered as a collaborative process attribute (Lavie and Rosenkopf 2006; Tiwana 2008; Rothaermel

and Alexandre 2009). This attribute is used on the basis of the structural exploration/exploitation process or collaborative process of k-network.

In my research, the collaborative process of k-network is understood in terms of partner exploration/exploitation, as discussed in Chapter 2 (Section 2.3.2). However, other aspects like method and technologies and the actual way that actors process their knowledge were also examined to have a better understanding of the collaborative process of k-networks. Given the nature of these characteristics, they have been examined within both stages of research, as represented in Table 11-2.

Table 11-2 Characteristics of process reflected in quantitative and qualitative phases

From literature	Key findings	Summary of the discussion
In a patent co-authorship network, SMEs have lower levels of collaborative process compared to the larger actors	**Quantitative** – Regarding SMEs, it was strongly confirmed that the level of exploration/exploitation index was lower in SMEs in comparison with large actors. It was also clear that the level of exploration/exploitation index was affected by organisational type. In PBFs the level of exploration was lower than those of Hospitals and of Individuals, while it was not significantly different from those of PROs. SMEs regardless of type had the same level of exploration. **Qualitative** – SME cases as PBFs are not very willing to have several partners. In terms of collaborative process, all cases, except SME-C, had an exploitation or balanced exploration/exploitation focus. The CEO of SME-C also stated that based on the feedback they received from their stockholders, they changed their approach to be more focused on exploitation process.	One explanation could consider the lack of resources in SMEs, as seen mainly in SME-B and SME-D. Due to this characteristic, SMEs may not have enough resources for establishing diverse projects with new partners. Following the point mentioned on characteristics of content, SMEs, at least those who published patents, were not very dependent on their partners for providing technological knowledge. Hence, another explanation is that co-authorship partnerships for those SMEs is not very vital. This can also be supported based on the number of isolated pharmaceutical-biotechnology SMEs. Among all 68 pharmaceutical-biotechnology SMEs, only 21 SMEs had co-authorship partnerships from 2001–2010.

In the Victorian patent co-authorship network of biotechnology industry, the partner exploration/exploitation process was affected by the actor size and the type of actors. For instance large PROS were more keen on exploring their partners than SME-PROs, and among the large actors, Hospitals are more keen on exploring new partners particularly compared to PBFs However there was not much difference between large and SME-PBFs; and the tendency of SMEs for partnerships was almost the same regardless of the type of the SME.

The analysis in Phase 2 showed that at least in the Victorian patent co-authorship network, there was no evidence to show any significant difference between large and

SME-PBFs. My case studies provided possible explanations. Although potential lack of resources in SMEs, as reported in cases like SME-B, could explain the result that SMEs despite their need for acquiring knowledge, may not have enough resources for establishing contracts with new partners. The chief business officer of SME-D, also explained that the company had core partners based on a comprehensive and well-established contract, which anticipated possible issues in collaborations and provided solutions for more effective partnerships. Hence the company spent substantial resources on this contract and preferred to keep it as long as it worked.

Another explanation is that partnerships, for those SMEs who are able to publish patents, are not vital. Like their larger counterparts, those SMEs own some level of technological expertise and knowledge and they may protect it via patenting. Having said that, these SMEs still may have a lack of other resources to turn their ideas to real products and commercialise them in the market.

Additionally, the way that SMEs acquire, share, store and use the knowledge was studied to enrich the findings in relation to process in the quantitative study. To process knowledge, either for exploitation or exploration collaborative process, all four cases showed little inclination to use any sophisticated information system to support their processes. In all cases, face-to-face communication was preferred for discussion. As mentioned by Alavi and Leidner (2001) and Hansen, Nohria and Tierney (1999) codified knowledge can be handled using knowledge management systems like discovery technologies and repository technologies, as suggested by Saito and Umemoto (2005). Discovery technologies aim to support knowledge creation according to a codification approach, while repository technologies support knowledge transfer. The nature of the knowledge in most cases was codified. However, among the cases, only SME-D had used a laboratory notebook system as a tool representing repository technologies to document the researchers' projects. Although filing patent applications requires complete and well-structured data to support the claims, in three cases, manual procedures and very basic computerised office tools were used to handle the process. The reason was money. According to a very rough cost-benefit analysis in these cases, directors decided to not be involved in any sophisticated system. However, in the case of SME-D, which has a strong partnership with universities and agreements that require them to keep the track of all data and research findings, a more sophisticated system was used for data storage and recording. The role of big customers-partners in adopting

information system in SMEs, is also discussed in the literature (Levy and Powell 2005) particularly for the company with a *defender* type of business strategy (Sabherwal and Chan 2001) like SME-D as discussed in Chapter 10.

11.2.3. Structure of knowledge networks

In my research, the structure of k-network is understood with different characteristics in terms of the centrality of an actor within the whole network, and the density of the actor's ego-network. However, other characteristics like the purpose of participating in the network and forming the structure and the role of actor size and type were also considered and represented in Table 11-3.

Table 11-3 Characteristics of structure reflected in the quantitative and qualitative phases

From literature	Key findings	Summary of the discussion
In a patent co-authorship network, pharmaceutical-biotechnology SMEs have lower levels of centrality compared to their larger counterparts.	**Quantitative** – Hypothesis 10 Rejected – The level of centrality is lower in SMEs compared to large actors. Although the level of centrality was always lower for SME actors, the differences between large, individual and SME actors were not statistically significant. **Qualitative** – SME cases as PBFs, possessed a range of positions from low to relatively high central. While SME-A and SME-C had relatively high central position in the network, SME-B and SME-D were relatively de-centralised.	Size of the SMEs cannot be major difficulties to stop them from playing a relatively central position in the whole network. In terms of global centrality in the whole co-authorship network, PROs like universities play the most central role. SMEs also have a chance to possess relatively high central position if they keep their relations with these large PROs. However, to be central in their local network, SMEs need to have frequent partnerships, which in the private companies (i.e. PBFs), the number of partnerships is relatively low in both large companies and SMEs. Overall, size is not a major barrier for actors to play a central role.
In a patent co-authorship network, pharmaceutical-biotechnology SMEs have the same level of ego-networks density compared to large pharmaceutical-biotechnology actors and individual inventors.	**Quantitative** – Although the level of ego-network density for pharmaceutical-biotechnology SMEs was higher than their larger counterparts but lower than individuals, as shown in Figure 8-5, the differences between large organisations, individuals and SME actors were not statistically significant. **Qualitative** – The ego-network density in the cases (as pharmaceutical-biotechnology SMEs) ranged from very sparse to very dense. All SMEs had a high ego-network density except SME-C.	In patent co-authorship network, size is not a major factor for having dense or sparse networks. On on hand, SMEs are motivated to access more supportive networks, so they are expected to maintain closed and frequent relationships with their partners. On the other hand, having a dense ego-network has its own costs regarding contracting and coordination with partners. The more obvious explanation was found in SME-C with a very sparse network. Focusing on a diverse area of knowledge seemed the main reason that SME-C has been working in a sparse network with partners who they didn't have partnerships with each other.

The position of an actor within a k-network is an influencing factor on the actor's knowledge creation (e.g. Salman 2002; Soh 2010). The size and types of actors with which these biotechnology firms had relationships, was also considered as an important factor. For instance, knowledge from public entities, such as universities or government institutes was more accessible for firms mainly because of public organisations' rules on the dissemination and use of scientific findings (Dasgupta and David 1987, 1994; Owen-Smith 2003).

In my research, the level of centrality is lower in SMEs compared to large actors. PBFs had a lower level of centrality than that of Hospitals, however, there was no significant difference in compared to PROs. This was because of sharply divergent selection environments of these large size public organisations, as mentioned by Owen-Smith and Powell (2004). In the Victorian patent co-authorship network of the biotechnology industry, although the level of centrality was always lower for SME actors as shown in Figure 8-2, the difference between large, individual and SME actors was not statistically significant (H10). It shows size of the actor was not a major factor that prevents SMEs playing a relatively central position in the whole network. This was also reflected in the case studies. Among the four cases, SME-A and SME-C possessed a relatively more central position within the whole network both in terms of degree centrality and closeness centrality which were beyond the average of the industry.

In the content of knowledge creation, density of ego-network has been considered an important construct in the literature (Borgatti et al. 2002; Rodan and Galunic 2004). It was expected that SMEs do not have a more dense ego-network than large actors (H13a). This is supported in the Victorian patent co-authorship network of biotechnology industry. However SMEs had the same level of density as large actors, but the level of density is lower in SMEs compared to individual inventors as more demanding actors for network participation. Hence, in patent co-authorship network, size of company is not a major factor for having dense or sparse networks. To address the role of type, as mentioned by Owen-Smith and Powell (2004), non-commercial actors, also called PROs like universities, are more diverse and more open to new partners, hence they are more likely to substitute their partners than are commercial actors. In my research, private actors, had a lower level of density than that of Individuals and were slightly lower than Hospitals. However, there was no significant

difference compared to PROs. Individuals Hospitals showed a higher level of density compared to other organisational types.

Overall, although the level of density for pharmaceutical-biotechnology SMEs was higher than their larger counterpart but lower than Individuals, the difference between large, individuals and SME actors was not statistically significant. Of the case studies reported in Chapter 10, three cases had very dense ego-networks (SME-A, SME-B and SME-D) while the other one had a very sparse ego-network (SME-C).

For an actor, there are several advantages of having a sparse ego-network. For instance, the actor by using structural holes of its network can have access to a knowledge rich network (Operti and Carnabuci 2011). The more obvious confirmation was found in SME-C with a very sparse network. Focusing on diverse areas of knowledge, seemed the main reason that SME-C has been working in a sparse network with partners who they didn't have partnerships with each other. Yet, on the one hand, SMEs are motivated to access a more supportive network so they expect to maintain closed and frequent relationships with their partners (SME-D). But, having dense ego-network has its own costs regarding contracting and coordination with partners (Bae and Gargiulo 2004).

The purpose of the participation in the network was also explored in all four case studies. Access to knowledge and expertise is one the main reason for partners to participate in a collaborative project (Lengrand and Chatrie 1999; Hanna and Walsh 2002). This theme, with no exception, is reflected in all cases. But more than the knowledge itself, having access to other resources like laboratories required for producing new knowledge in terms of patents was reflected in all cases as well. In some cases, the basic idea was developed in the company but to make it happen, companies asked for partnerships mainly with large-size public research centres to provide the required equipment like clinical trials.

Regarding the challenges of participation in the network, funding and protecting the company by appropriate contracting, were addressed in all cases. As these cases were SMEs, it was not a surprising result to see that access to money and other resources to accomplish new projects were important, as reported in other studies (Janasz and Forret 2008; Weber and Khademian 2008). Being in the biotechnology industry with its high

rate of change and intensive competition, these cases were required to produce new knowledge, mainly through their networks. These cases preferred to protect their intellectual properties by patenting. SME-D however, was an exception here. This company may not have been really expected to create knowledge in terms of patents, rather it found new applications for existing knowledge. Moreover, SME-D, which was supported by large public research centres and universities, did not mention contracting as a challenge. With high intentions for exploration, SME-A and SME-C were looking for the right partners who could provide quality knowledge in a timely manner. This was also cited as an important challenge for partnerships.

The importance of partner organisational type has also been addressed. Except for SME-D, none of the cases were happy to have universities in their knowledge creation network. So far, all of them had had universities as a main partner. However, these case companies were not very keen to consider universities for their future partnerships.

11.3. Interaction of knowledge networks constructs on supporting knowledge creation

This section addresses two key points.. First, as expected in the research design, my research showed that there are bilateral associations among the knowledge diversity, collaborative process, density and centrality constructs. Second, to consider the interaction of all constructs, three significant interactions were explained in my research.

11.3.1. Associations of content with other constructs and knowledge creation

The list of the associations of content with collaborative process, structure and knowledge creation is outlined in Table 11-4.

The positive association between knowledge diversity with exploration collaborative process which also has been reported in the literature (e.g. Cross and Cummings 2004), was measured by the correlation between diversity of knowledge (content) and diversity of partners (collaborative process). It was expected that diversity of knowledge would be positively associated with diversity of partners. Actors who possessed more diverse knowledge showed more intention for exploring new partners. This finding over the whole Victorian biotechnology network, showed a weak positive correlation between content and process. However, there is no strong indication of a significant correlation

between diversity of knowledge and diversity of partners in the whole SME sector as well as in PBF-SMEs; the group from which the case studies were selected.

Table 11-4 Association of content with other constructs of k-network as reflected in the quantitative and qualitative phases

From literature	Key findings	Summary of the discussion
In a patent co-authorship network, the level of knowledge diversity of actors including pharmaceutical-biotechnology SMEs is positively associated with the collaborative process and with central position of the actors and with the number of patents of the actors, but is negatively associated with ego-network density of the actors.	**Quantitative** – Diversity of knowledge (content) in an actor had a weak positive correlation with diversity of partners (process), the central position of the actor and a strong positive correlation with knowledge creation of the actor. Also, a weak negative correlation between knowledge diversity and density of actors' ego-network was found. Except for the association between knowledge diversity and knowledge creation, other relationships were not statistically confirmed for SMEs at the 95% confidence interval. **Qualitative** – SME cases with high knowledge diversity had higher levels of collaborative process and more central positions as well. However, SME-B with a lower level of collaborative process and less central position had a higher level of knowledge diversity compared to SME-D. In terms of density, SME-A with a high density network and SME-C with a low density network both had a high level of knowledge diversity. Business strategy, knowledge capacity, timeliness and quality of knowledge were also contextual factors that emerged to explain the cases attitudes toward knowledge diversity.	For SMEs, patent co-authorship networks are still about complementing the knowledge gap however this gap rarely requires finding new area of technological knowledge (i.e. in terms of new IPCs). As explained in all cases, exploration of new partners mainly is represented in providing laboratories equipment and expertise, which does not necessarily mean new areas of technological knowledge assigned by patent offices to the filed patent. Having a more central position is still a mechanism for finding the required knowledge as reported in literature (e.g. Burt 1995), however such knowledge was rarely represented as a new area of technological knowledge (i.e. in terms of new IPCs). SME-B for instance, with a relatively low central position and high knowledge diversity is an exception. The CEO of the company highlighted the role of his personal network to fill knowledge gaps in their projects. Regarding the negative association of density and knowledge diversity, it is clear that brokering knowledge between non-redundant partners is still a mechanism for finding the required knowledge (SME-C), however not the only one. The reason for the findings is that having partnerships with big universities and other large public research centres is common among SMEs. In this way even companies with closed networks with a few partners may gain access to diverse areas of knowledge. In their knowledge creation projects, SMEs with more aggressive business strategies, and higher knowledge capacity, would be more interested to use diverse knowledge while they concern about timely and quality knowledge.

For SMEs, patent based partnerships are still about complementing the knowledge they need for their innovative projects. However, these partnerships may not necessarily require finding new areas of technological knowledge (i.e. in terms of new IPC). As explained in the four cases, exploration of new partners mainly was represented in providing laboratories, equipment and expertise, which did not necessarily mean new areas of technological knowledge (IPC).

In general, partnerships, particularly with new partners, were avoided by all cases unless there was a very appealing motivation behind the partnership. For instance, SME-B was a company that captured relatively diverse areas of knowledge but did not pursue new partners, mainly because of difficulties with contracting and the cost of coordination with partners (as reported in Chapter 10). On the other hand, SME-A had diverse knowledge and at the same time was interested to work with more partners to extend its powerful portfolio in a timely manner and within new markets.

Actors located in a more central position tend to possess more diverse knowledge. The statistical result showed a positive correlation, though a weak one. For the SME actors, as well as the pharmaceutical-biotech SMEs (PBF-SMEs), there was no significant correlation between diversity of knowledge and the network position.

Having a more central position is still a mechanism for finding the required knowledge as reported in literature (e.g. Burt 1995), however such knowledge rarely can be represented as a new area of technological knowledge (i.e. in terms of new IPCs). SME-D for instance with an average centrality, had a low level of knowledge diversity, mainly because SME-D was mainly receiving in-kind and infrastructure support for their projects. On the other hand, for SME-B, located in a relatively low central position, the diversity of knowledge in its portfolio was above the average of the industry. To find partners to work on diverse areas of knowledge the director SME-B mentioned the role of his personal network rather than the role of the company's network. The role of personal networks of SME owners/managers has been recognised in the literature (e.g. MacGregor 2004). For an SME, having inter-organisational relationships particularly with other SMEs may rely highly on personal contacts of the CEO.

Actors located in less dense (more sparse) positions tend to possess more diverse knowledge. The result was supportive, although the statistical analysis showed a weak negative correlation between density and diversity of knowledge. This finding was supported by the literature as well (Walker et al. 1997; Burt 2004). The less dense ego-network may allow actors a higher chance to access novel knowledge areas. For the SME actor as well as in the PBF-SMEs, however, there is no strong sign to see a significant correlation between diversity of knowledge and the density of SMEs' ego-networks.

Brokering knowledge between partners is still a mechanism for finding the required knowledge. For instance, SME-C was a company with a very sparse ego-network that possessed the most diverse areas of knowledge compared to the other case SMEs. However, SME-A and SME-B with dense ego-networks also had relatively high knowledge diversity. To explain their attitude to accessing diverse knowledge within dense networks, it is possible to mention that it is common for SME cases to have partnerships with universities and other large size PROs. These large organisations have various departments and even semi-independent research institutions which collaborate with SMEs. When it comes to legal contracts and patent rights, the name of corporate organisations or universities will be mentioned in the legal documents. In this way, for SMEs, the actual network may be denser than the network revealed by patent co-authorship. For example, this was observed in SME-C and SME-D, which both had collaborations with the same university, however with two different and un-related institutions, within the university.

Finally, actors who possess more diverse knowledge publish more patents as well. The results showed a very strong positive correlation. Likewise there was a significant correlation between content and knowledge creation among all SME actors as well as in the pharmaceutical-biotechnology SMEs.

As supported in SME-A, SME-B and SME-C, those SMEs who were able to acquire more diverse technological knowledge, published more patents than those who tried to reuse their existing technological knowledge like SME-D. Regardless of the configuration of their k-networks, these cases also supported the view that having diverse knowledge was associated with more knowledge creation; however, IPC is a conservative measure for identifying new area of knowledge, as mentioned above. Although the statistical regression is not able to define the cause and effect relationship, based on the case analysis it was observed that SME-A created more knowledge, based on accumulated diverse knowledge to strengthen their portfolio.

The business strategy of the actors also seemed to play a role in the attitude of all cases towards the association of knowledge diversity with knowledge creation. According to the literature on business strategy, companies try to devise a knowledge strategy appropriate to the firm’s business strategy (Zack 1999; Tiwana 2002). Regardless of the configuration of k-network, in all cases, the role of knowledge diversity on knowledge

creation of a case seems to be affected by the business strategy of the case company. The detail of this role in each case is discussed in Chapter 10. Access to diverse knowledge can help knowledge creation mainly if companies pursue an aggressive strategy. According to the four-types of strategy identified by Miles et al. (1978), prospector firms like SME-A, and SME-C with aggressive strategies, were more interested in developing new products and exploiting market opportunities, which require more attention to exploring new knowledge than exploiting the existing knowledge (like SME-D).

The capability of selected cases to understand and use newly acquired technologies and expertise seems another important factor to explain the role of content on knowledge creation within their k-networks. The concept of absorptive capacity (Cohen and Levinthal 1990) was used similarly to explain how heterogeneous knowledge can be used to create new knowledge in intra-organisational collaborations (Tsai 2001) as well as in inter-organisational knowledge creation (Weigelt and Sarkar 2009). SMEs are widely recognised as companies with limited resources in terms of expertise and finance (Hanna and Walsh 2002). The need for this capacity was reflected in all cases. As all cases were SMEs, with typical needs for more resources and capability to manage their businesses, this is not a surprising result.

Having timely access to knowledge seems to be a condition for acquiring new knowledge. For instance, SME-A believed that knowledge diversity works for them to create more knowledge. It is believed that being first-mover in the market in terms of access to new knowledge and using patents to protect the position helped SME-A to create more knowledge, and be even more innovative. SME-C also mentioned that diverse knowledge works for them to create more knowledge, when it is provided in timely manner. This is why they chose their contacts that could provide faster access to the required knowledge as proposed in the literature (Powell et al. 1996; Mu, Peng and Love 2008).

Quality of knowledge, according to Chiu et al. (2006) is considered with characteristics like relevancy, ease of understanding and reliability. This was only addressed by SME-A and SME-C as an important factor for acquiring and exchanging knowledge with partners. In SME-C for instance, the quality of expertise was mentioned by the interviewee as a reason for having partnerships. Like timeliness, this factor again

seemed not very important for SME-B and SME-D, which have close and repeat partners. SMEs with more aggressive business strategies and higher knowledge capacities would be more concerned about knowledge diversity when developing knowledge creation projects; particulalrly those who are moe concerened with the timeliness and quality of knowledge.

11.3.2. Associations of collaborative process with other constructs and knowledge creation

The association between content and process has been mentioned above (11.3.1). The list for the rest of the associations of collaborative process is summarised in Table 11-5.

Table 11-5 Association of collaborative process with other constructs of k-network reflected in quantitative and qualitative phases

From literature	Key findings	Summary of the discussion
In a patent co-authorship network, the level of collaborative process of actors including pharmaceutical-biotechnology SMEs is positively associated with central position of the actors and is negatively associated with ego-network density of the actors; however have no association with knowledge creation.	**Quantitative** – The level of collaborative process in terms of partner exploration/exploitation had no association with level of knowledge creation. However, the analysis revealed a moderate positive correlation between exploration and centrality for all actors including pharmaceutical-biotechnology SMEs. However, actors located in the k-network with a certain level of ego-network density tended to possess more diverse partners or, in other words, actors located in a very sparse network or very dense network rarely looked for new partners. **Qualitative** – SME cases with balanced exploration/exploitation or with high exploration collaborative process had higher more central positions and cases with lower centrality had more exploitation process. Regarding their ego-network density, SME cases with high density had balanced exploration/exploitation or even high exploitation; likewise, SME-C with a high level of exploration process had a very sparse ego-network (similar to Hypothesis 8). Finally no association had been observed between collaborative process and level of knowledge creation. In my research the nature of partnerships, organisational types of partners and organisational characteristics of partners seemed as relevant contextual constructs.	Central actors have a better chance to find new partners and such new partnerships will increase their centrality. Regarding the ego-network density, it was not very expected for other actors particularly for SMEs, to have frequent and close relationships with various partners. Although this hypothesis (H8) was rejected, it was not totally wrong. The scatter plots and the explanation in cases showed that this association seemed not like a linear association but an inverted u-shape one. In this industry, actors like large PROs have a very high exploration collaborative process while located in a sparse network. Indeed, the large number of partners in their network makes large PROs like University of Melbourne have a sparse network. On the other hand, firms, particularly SMEs, can be located in a dense network, but exploring their few partners during their knowledge creation projects (SME-A). In their knowledge creation projects, SMEs with either high exploration or high exploitation process or balanced exploration/exploitation process may have high rates of knowledge creation. The level of collaborative process in terms of exploration/exploitation process may be affected by the level of constraints/flexibility as types of partnership, organisational types of partners and similarity/dissimilarity as an organisational characteristic of partners.

The exploration collaborative process of an actor seems to be associated with the position of the actor in the network. Central actors have a better chance of finding new partners and such new partnerships will increase their centrality. As supported in the whole k-network of the Victorian biotechnology industry, there have been strong positive correlations between process and centrality for the whole k-network, as well as for SMEs and pharmaceutical-biotechnology SMEs (PBF-SMEs) – the sectors which were selected for qualitative analysis. Regarding associations of process and density of actors' ego-networks, there were moderately positive correlations for the whole k-network, as well as for SMEs and for PBF-SMEs. More precisely, this association did not seem to be a linear association. Actors who were located in k-network with a certain level of network density tend to possess more diverse partners, while actors who are located in a very sparse network or very dense network rarely looked for new partners. The reason for that could be because of the nature of ego-network density, which tends to be zero or one in most common partnership as shown in Chapter 7. However, in this industry, actors like large PROs had a very high exploration process while located in a sparse network. Indeed, the large number of partners in their network makes large PROs, like a university, have a sparse network. On the other hand, few firms, particularly SMEs, can be located in a dense network and have high exploration processes in their knowledge creation projects.

Within the SME sector, the results discussed in Chapter 7, showed that size of the actor does strengthen the process-density relationship. Likewise, the results of the analysis were confirmed for both the whole SME sector and even more strongly for PBF-SMEs.

This inverted u-shape association between process and density of ego-network, shown in Chapter 7 (Section 7.3.2), were also supported in selected cases in Phase 3. In SME-B and SME-D (as showed in Chapter 10), dense ego-network and close relationships with partners over a long period of time, resulted in easier knowledge transfer and more exploitation as supported in the literature (Yli-Renko et al. 2001; Verspagen and Duysters 2004). Likewise, in SME-C, as the only case with a sparse ego-network, more emphasis on exploration process can be observed. Only SME-A can completely support the association of process and structure as mentioned in the quantitative Phase 2. This company, which was located in a dense network, was also keen on exploration. Indeed,

the approach of the company seems more like a balanced exploration-exploitation, with more emphasis on exploration (as mentioned in Chapter 10).

The collaborative process was not associated with knowledge creation for the whole k-network and for SMEs and pharmaceutical-biotechnology SMEs (PBF-SMEs). In the literature, close relationships with partners have shown a significant effect on exploitation processes (Yli-Renko et al. 2001). However there is no clear association regarding knowledge creation that has been reported (Beckman et al. 2004; Verspagen and Duysters 2004; Baum et al. 2005). This is also supported through the case study approach in Phase 3.

In the case analysis in Phase 3, neither exploration nor exploitation had an association with knowledge creation. For instance, while SME-A, SME-B, and SME-C all have a higher level of knowledge creation as measured by patents, the first two cases pursue a balanced approach of exploration/exploitation with more focus on one or the other, but the third one focused on exploration. The director of SME-B mentioned that the company pursued both approaches, but confirmed that their focus was on exploitation.

As discussed in Chapter 10 (Section 10.4.2.3), the nature of partnership seems to be another emergent factor influencing the exploration/exploitation process. Gauvin, Montreuil and Poulin (1994), as cited by Lengrand and Chatrie (1999), define the nature of partnership by factors like level of constraints, nature of constraints, and duration and degree of flexibility. As reported in SME-D, there was a strong partnership between this case as a Cooperative Research Centre (CRC) with large universities and public research institutes in terms of long-term partnerships, and high level of constraints that made this company more focused on exploitation. As part of the pre-defined agreements of SME-D, core participants were looking to get back the royalties of each patent published by SME-D. In this regard, it was expected that SME-D would keep its partners for several projects, since they were looking to get the most benefits possible from any patents. Moreover, they did not need to define new regulations and contracts with existing partners, as would be required for any random partner. However, there was no reference to this factor as an important issue in the k-networks of other case companies for creating new knowledge. There were some partnerships between SME-A, SME-B and SME-C with universities and public sector bodies, and although there were

some issues reported in these cases, none of them mentioned any effect on collaborative process.

Organisational characteristics of partners, also seem to be another important factor to understand how k-networks may lead to knowledge creation. This is also reflected in the k-network literature review of Phelps et al. (2012). In the literature on one hand it is argued that having similar partners reduces the chance of knowledge transfer and creating new knowledge (e.g. Simonin 1999). However, large partners who are dissimilar can make it hard for them to communicate and learn from each other (e.g. Sampson 2007). In contrast, Rosenkopf and Almeida (2003) posited that organisational similarity/dissimilarity among partners may have no effect on knowledge transfer. In my research, large universities as the main patent partners were described as "*non-strategic and too big partners*". Similarity and differences of organisational characteristics like size and industry among participants, were also considered as an attribute for collaborative process in terms of exploitation/exploration in the literature (Lavie and Rosenkopf 2006). In all four cases, public research organisations were discussed as partners of patent projects. These cases were all SMEs with limited staff and infrastructure for doing research, hence working with large universities and other public research organisations was common and reported in other similar research as well (e.g. Powell et al. 1996; Owen-Smith and Powell 2004). Except for SME-D which had a close partnership with universities and other public research centres, as described above, other case companies were concerned about having collaboration with them to create knowledge particularly in terms of patents. The main problem is with contracting and monetary issues that hinder knowledge creation. Hence, although torganisational characteristics seem to be an important factor for collaborative process, previous experiences in partnerships with companies with particular type and characteristics may have a higher influence on this process.

In the case of SME-D, large universities and PROs influenced the collaborative process approach because the aim of partnerships encouraged knowledge exploitation rather than exploration. These influences appeared in both interviews with the chief business officer of the SME-D and the director of the research institute of a key partner university. More than other case companies, SME-D was much more interested on finding new applications for existing knowledge.

11.3.3. Associations of structure with other constructs and knowledge creation

The association between structure with content and process have been mentioned above (11.3.1 and 11.3.2). The list for the rest of the associations is outlined in Table 11-6.

Table 11-6 Association of centrality and density with each other and with knowledge creation reflected in quantitative and qualitative phases

From literature	Key findings	Summary of the discussion
In a patent co-authorship network, the association of centrality and density with each other and also their associations with knowledge creation are affected by organisational size and type. More specifically, there is a positive association between centrality and density; however for pharmaceutical-biotechnology SMEs, this association is not strong. Also the level of centrality of actors including pharmaceutical-biotechnology SMEs is positively associated with knowledge creation. Moreover the ego-network density of actors is negatively associated with the number of actors' patents; however for pharmaceutical-biotechnology SMEs this association is not strong.	**Quantitative** – The analysis revealed a moderately positive correlation between centrality and density for all the actors in the Victorian biotechnology industry including pharmaceutical-biotechnology SMEs. Also the number of patents published by actors is to some extent associated with the position of the actors in the whole k-network. This was the case for pharmaceutical-biotechnology SMEs as well. Finally, the number of patents published by actors was to some extent associated negatively with the density of actors' ego-network in the whole k-network. However, the results of the analysis showed no significant relation for the pharmaceutical-biotechnology SMEs. **Qualitative-** – Except for SME-A, cases showed no strong association between centrality and density. Moreover no strong indication was found between their knowledge creation and their level of centrality and density.	It seems that there could be a non-linear relationship between centrality and density. It means that for actors, particularly SMEs with extremely high or extremely low density ego-network, actors are more inclined to possess non-central position. It is not affordable for the central actors particularly central SMEs to maintain closed and frequent relations required for high density ego-networks. It seems that knowledge creation is to some extent associated positively with the position of the actors in the whole k-network. This is also the case for pharmaceutical-biotechnology SMEs. This result however, seems more reliant on the moderating role of content, a point that is elaborated later in this chapter. Finally, dense networks bring benefits like trust and higher level of support; however they are not as strong as sparse ego-networks in terms of providing access to new knowledge required for knowledge creation.

To understand the association of centrality and density, Soh (2010) argued that the benefits of a central position are likely to be higher for actors with a dense ego-network. As explained by Soh (2010) there are two reasons for this relation: first, having a central position enables actors to access diverse knowledge and opportunities, while being in a dense ego-network is supposed to improve the value of the knowledge; second, central actors who are located in a dense network have better support from their partners to exploit these opportunities. In my research, as reported in Chapter 8, the analysis revealed a moderately positive correlation between centrality and density for all the actors in the Victorian biotechnology industry, including pharmaceutical-biotechnology SMEs. However, my analysis showed that there could be a non-linear relationship between centrality and density. This means that actors, particularly SMEs, with

extremely high or low density ego-networks, are more likely to possess non-central positions. It is not affordable for the central actors, particularly SMEs, to maintain closed and frequent relations required in a high density ego-network. Of all the cases, SME-C had the most central position and was the only SME with a sparse ego-network, while lower centrality actors possessed high density ego-networks. Hence my research found that Soh (2010)'s conclusion may not be applied to patents co-authorship networks particularly as SMEs are more likely to have either a central position with a sparse network or a peripheral position with a dense network. This finding, though, requires further investigation.

Regarding the role of centrality on knowledge creation, in summary, the literature reported mixed results. Soh et al. (2004) explained the positive role of central position in providing more partners and accordingly timely access to diverse knowledge. They argue that central firms, who have many partners to assist them, can reach higher integrative knowledge with lower uncertainty, thereby leading to a faster response to market (Soh et al. 2004). In a similar way, Gibbons (2004), by using a simulation technique, found that central organisations, in comparison with other network members, are associated with higher network connectivity and faster collection of knowledge. However, there are other studies that show central position may have weak positive (Whittington et al. 2009) or even no influence on knowledge creation in terms of patenting (Owen-Smith and Powell 2004) among biotechnology firms. In my study, the number of patents published by actors was to some extent associated with the position of the actors in the whole k-network. This was also the case for pharmaceutical-biotechnology SMEs (as reported in Chapter 8). This result however, was elaborated in Chapter 9 where the interactions of all constructs were addressed simultaneously. By introducing the moderating role of content, this approach was helpful to provide more insight about the role of centrality in knowledge creation (the details are discussed later on in this chapter).

Regarding the role of density, the structural hole theory and the closed network theory are considered in the k-network literature. According to the structural hole theory, actors can benefit from bridging ties to access novel knowledge (Burt 1995). In an inter-organisational context, this tie which serves as a bridge to new opportunities, connects actors separated by a structural hole who otherwise would not be accessible to each

other (McEvily et al. 2012). On the other hand, more studies highlighted the role of dense ego-networks of an actor on its knowledge creation (e.g. Phelps 2010). They mainly have focused on the existence of significant trust between the partners in order to reap the resource-sharing benefits of collaboration, including combining their skills, sharing their knowledge, and conducting joint projects to obtain scale economies (Simonin 1997; Lavie et al. 2007; Tiwana 2008).

In my research, given the legal protection of collaboration under confidentiality agreements, it was expected that actors would not be very concerned with their partners' trustworthiness as the legal framework protects the actors. Although a dense network brings its own benefits, like trust and higher levels of support, it is not as strong as a sparse ego-network in terms of providing access to new knowledge required for knowledge creation. Hence knowledge creation of an actor in terms of patents is expected to be linked negatively with the density of the actor's ego-network. However, in regard to the characteristics of SMEs, it was expected that SMEs would be less likely to be able to enjoy the benefits of sparse ego-networks.

In the Victorian patent co-authorship network of the biotechnology industry, there were moderately positive correlations reported between density and knowledge creation. This means that the number of patents published by actors is, to some extent, associated with the density of the actor's ego-network within the whole k-network. However, the result of the analysis showed no significant relation for the pharmaceutical-biotechnology SMEs.

In the case studies, SME-C was the only SME with a sparse ego-network, but had, interestingly enough, filed the highest number of patents. However, as mentioned by the CEO of the company, although this approach created more knowledge (i.e. provided several patents), the whole business is not about the patenting. To make this new knowledge applicable and profitable in the business the SME required a strategic closed ego-network.

11.3.4. Interactions of content, process and structure of knowledge networks

As discussed in the previous section, my research showed that there were bilateral associations among the knowledge diversity, collaborative process, density and centrality constructs. Now, considering the interaction of all constructs (Hypothesis 15),

there were three significant interactions identified in Chapter 9, that are discussed here. Hence, my research argues that although all the constructs are linked together, there were three interactions that were more significant in this context. In the context of knowledge creation, there were some trade-offs between these interactions as shown in both the quantitative and qualitative findings. These trade-offs provide more complexity for analysing the role of k-networks configurations on knowledge network creation. These interactions provide a significant contribution to the exisiting literature. These interactions and their contributions to the k-network literature are presented here.

11.3.4.1. Interaction of knowledge diversity-centrality

In the literature, there is no consensus on the role of centrality that an actor has with its partners on knowledge creation (as reported in Chapter 2 section 2.2.2.1). My research found two important points regarding the interaction of content-centrality.

First, having a central position showed less contribution to the actors' knowledge creation compared with possessing diverse knowledge. Second, in some circumstances, the synthesis of these two constructs helped actors to create more knowledge. More precisely, if an actor possessed some level of diverse knowledge, then gaining a more central position might lead to a higher level of knowledge creation. This finding is aligned with Wadhwa and Kotha (2006), as they found that corporate investors' technological knowledge diversity will positively moderate the relationship between the number of corporate venture capital investments and knowledge creation. However, my research provides more explanation about the complementary role of content and centrality to support knowledge creation. In the intra-organisational network, Rodan and Galunic (2004) also found a similar relationship between centrality and knowledge diversity.

In the selected cases, three SMEs (SME-A, SME-B and SME-C), had diverse knowledge and possessed a central position in the whole network. All these SMEs acquired diverse areas of knowledge, which helped them to acuqire more knowledge. Among them, SME-A and SME-C possessed a relatively central position, mainly through having multiple links and strong relations to very central nodes like big PROs. SME-B had a lower central position, and lower rate of knowledge creation compared to SME-A and SME-C. However, compared to other actors in the whole network, SME-B possessed highly diverse areas of knowledge and had a better rate of knowledge

creation. As described in Chapter 10, it seems that having multiple close relations with the other partner (an individual inventor) helped SME-B to create more knowledge. Hence this interaction seemed to be more related to content-density rather than content-centrality, although this interaction was not supported by the quantitative findings. This means very few companies followed this strategy to create knowledge. Following up this case, I found that this individual inventor partner, has now joined the company, by acquiring shares in SME-B, in order to have closer collaboration. This company showed that they had no more interest to explore new areas of knowledge as the company preferred to focus on the portfolio that they had created so far. In this way, the strategy of this company was not similar to SME-A. However both had similar k-network configurations.

11.3.4.2. Interaction of collaborative process-density

The second interaction refers to the interaction role of density with collaborative process to create knowledge. This finding may contribute to the debates arounds structural hole vs. closed network theory (Coleman 1988; 1994; Burt 2004).

In the literature there are two competing views about the role of ego-network structures, namely closed network vs. sparse network (Coleman 1988; 1994; Burt 2004). In my research, sparseness or low density of ego-networks showed a positive correlation with knowledge creation. Specifically, focusing on partner exploration may lead to higher knowledge creation only for actors with a low density network. This interaction was still positive until the actors reached a certain medium level of density. In contrast, for the actors with high density ego-networks, pursuing exploration resulted in lower knowledge creation. The exploration process also shed more light on the mixed results of the structural hole theory as reported in the literature (Beckman and Haunschild 2002; Phelps 2010; Demirkan and Demirkan 2012). According to this theory, a sparse network with high structural holes is a suitable network for brokering (Burt 2004) and bridging with new partners (exploration process).

Among the cases, only SME-C possessed a configuration that matched this situation. According to the patent documents three companies (SME-C and its two partners) worked closely in several projects but in a sparse network.

The reason why this company worked in a sparse network was that for their new project SME-C needed a particular laboratory which was not available to the existing partner (a large university). They also believed that their main partner was not strategic enough so they did not want to repeat another project with them.

In summary, the research showed that both closed and sparse networks can help actors to create more knowledge. However, the collaborative process (i.e. partner exploration/exploitation process) seems to play a contingency role. If actors pursue an exploration process, it seems that it is more effective for them to keep their network sparse. It means it is not really recommended to close their partnership by introducing their partners to each other. According to structural hole theory, having a structural hole can provide the opportunity for the actor to reach novel and up-to-date knowledge. In the analysis of SME-C, this novel opportunity had been presented via introducing the first laboratory in Australia, co-funded with the new partner. On the other hand, it is possible to see that the quantitative analysis showed how closed network theory (Coleman 1994) is associated positively with knowledge creation for those who have focused on exploitation.

11.3.4.3. Interaction of collaborative process-centrality

The third significant interaction in the knowledge creation context, was found among process and centrality. This interaction, in summary, posits that focusing on exploration may lead to higher knowledge creation only for actors with a peripheral position in the k-network. In other words, actors with a high central position cannot expect to increase their knowledge creation by emphasising the exploration collaborative process through contracting with new partners. For these actors, it would be better if they keep their relations with their current partners. This interaction may contribute to two seemingly different streams of research: cost of partnership (Bae and Gargiulo 2004) and exploration/exploitation process (March and Levinthal 1993).

According to transaction cost theory, there are some costs associated with coordination, communication and searching for new information within every partnership. On the other hand, Bae and Gargiulo (2004) also discussed the possible consequences of increasing reliance on a few partners' knowledge for knowledge creation. They conclude that, *"although firms are expected to benefit from the exclusive resources brought in by resource-rich, non-substitutable alliance partners, the costs of allying with such partners*

could offset those benefits" (p. 834). They discussed other types of cost associated with non-substitutable partners. In my research, I showed that focusing on the exploration collaborative process does not necessarily improve knowledge creation nor is it necessarily associated with adding centrality or diverse knowledge as supporting factors for knowledge creation. Only for actors who have peripheral positions and are at risk from unsubstitutable partners as described by Bae and Gargiulo (2004), does emphasising the partner diversity (exploration collaborative process) increase knowledge creation.

Among the cases, only SME-C had a configuration where emphasising on exploration collaborative process was not supporting their knowledge creation. As mentioned in Chapter 10, the company reported complaints from its investors about too much exploration. As SME-C had participated in various projects with various partners over time, the director decided to change the approach to focus more on exploitation rather than exploration through new partners.

Another possible explanation could be based on the partner exploration/exploitation process (Lavie and Rosenkopf 2006). There is still an open debate on the role of partner exploration and exploitation on knowledge creation. My research confirmed that focusing on exploration may lead to higher knowledge creation only for actors with a peripheral position in the k-network. Having said that, it is important to mention that even in this situation, additional partnerships are not the main factors that contribute to knowledge creation. In contrast, for actors with a more central position, pursuing exploration may result in lower knowledge creation. Given the findings for an actor with medium centrality and medium density, increasing the exploration collaborative process is expected to produce a mixed result as reported in SME-C.

11.3.5. Three possible k-network configurations

This research shows that beyond structural constructs, content and process and the interactions of them are important for understanding k-networks in the knowledge creation settings. Hence, to define the configurations of k-networks, here I propose a novel configuration. Indeed the interactions found in the study were used to propose a new typology of the k-network (as explained in Chapter 10). In this novel approach, more than structural aspects of networks, the interactions among content, process, and structure as interrelated constructs, are used to explain the role of k-networks on

knowledge creation. Based on how these interactions support or hinder knowledge creation, three possible configurations have emerged in this study: favouring (i.e. supportive), mixed-impact (i.e. both positive and negative impact) and neutral (i.e. no strong impact) configurations.

11.3.5.1. Favouring configurations

In this research, there were five possible configurations that seemed to provide a positive impact on knowledge creation. The description of those favouring configurations is shown in Table 11-7. These five configurations seem to provide support for knowledge creation. However the amount of support is not equal among them. Some of them are expected to provide greater support. As two of the configurations did not include any actors in this study, it is not possible to declare the degree of network impact mathematically. However, given two cases selected in this configuration, i.e. SME-A and SME-B, it is clear that the configuration of SME-A (Config. F1) was more supportive than SME-B's (Config. F4) (as discussed in Chapter 10).

Table 11-7 Possible favouring configurations

Configuration	Centrality	Density	Process	Content	Interactions		
					I	II	III
Config. F1	High	High	Low	High	+	0	0
Config. F2	High	Low	Low	High	+	0	0
Config. F3	Low	High	Low	High	+	0	0
Config. F4	Low	Low	High	High	0	+	+
Config. F5	Low	Low	Low	High	+	0	0

In the patent co-authorship network of the Victorian biotechnology industry, most of these configurations, like the configuration of SME-A and SME-B's networks, deal with a positive interaction between content-centrality. More precisely, high knowledge diversity co-existed with the central position of the case. This interaction had a positive effect on knowledge creation (as discussed in Chapters 9 and 10). Based on the case analysis (SME-A and SME-B), the positive association of the favouring configuration and knowledge creation was influenced by several factors that emerged from the empirical data of the case study, as reported in Chapter 10. These factors were timeliness, business strategy and knowledge capacity.

11.3.5.2. Mixed-impact configurations

There are six possible configurations that provide mixed impact on knowledge creation. This means that some of the interactions of the constructs support knowledge creation while others may hinder it. The description of these mixed-impact configurations, is illustrated in Table 11-8.

Table 11-8 Possible mixed impact configurations

Configuration	Centrality	Density	Process	Content	Interactions		
					I	II	III
Config. M1	High	High	High	High	+	-	-
Config. M2	High	High	High	Low	+	-	-
Config. M3	High	Low	High	High	+	+	-
Config. M4	High	Low	High	Low	+	+	-
Config. M5	Low	High	High	High	+	-	+
Config. M6	Low	High	High	Low	0	-	+

These six configurations provide a mixed influence on knowledge creation. However the amount of support or challenge is not equal among them. Some of them are expected to provide greater support, even more than the possible support that maybe provided by favouring configurations. For instance, Config. M3 (Table 11.8) showed a very high support for knowledge creation. Majority of the actors who have published the highest rate of patents belonged to this configuration. The only negative effect of this configuration is the inefficiency of knowledge creation for very central actors who are still exploring new partners for new projects. The negative effect of this interaction, however, is not very strong as explained above (Section 11.3.4) and in Chapter 9.

This configuration in the Victorian biotechnology industry has the highest number of members (40 in total), including all types and size of actors. SME-C, as a case explained in Chapter 10, matched with Config. M3 (Table 11.8). As discussed there, this configuration has some negative effects, particularly for SMEs. In summary, Config. M3 requires a higher level of resources which may not be available to SMEs. Companies in this configuration tend to play the role of knowledge broker which requires more resources and knowledge capacity (Meyer 2010)

Config. M1 was mainly followed by hospitals and two very large private companies and PROs.

11.3.5.3. Neutral configurations

There are also six possible configurations that provide no positive or negative impact on knowledge creation. This means that the interactions of the constructs in these

configurations, do not support knowledge creation. The description of these configurations is illustrated in Table 11-9.

Table 11-9 Possible neutral configurations

Configuration	Centrality	Density	Process	Content	Interactions		
					I	II	III
Config. N1	Low	High	Low	Low	0	0	0
Config. N2	Low	Low	Low	Low	0	0	0
Config. N3	Low	Low	High	Low	0	0	0
Config. N4	High	High	Low	Low	0	0	0
Config. N5	High	Low	Low	Low	0	0	0
Config N6	Low	High	Low	High	+	0	0

In my research there were 16 actors with neutral configurations within the entire network, of which half were pharmaceutical-biotechnology SMEs like SME-D, which was reported in Chapter 10. There are no significant positive or negative characteristics among these configurations. This means that although the companies with these neutral k-network configurations create knowledge, the rate of their knowledge creation is much lower than the other two types of configuration. This configuration is mainly useful for companies like SME-D which tried to find new markets for existing patents rather than exploring new areas of knowledge aggressively.

11.4. Summary

The conceptual model was introduced in Chapter 3 to provide a guideline to study the interactions of constructs in k-networks. Using the mixed method research inquiry, I revised the initial model. Figure 11-4 illustrates how the interactions of content, collaborative process and structure of the k-network as initial interrelated constructs can be understood by three proposed k-network configurations. In Figure 11-4, the role of contextual factors are also highlighted to show that these important emergent factors in the setting of this research should be considered to explain the role of initial constructs in the patent co-authorship k-networks.

This refined conceptual model shows that there are only three main interactions among content, collaboration process, and structure of k-networks that can explain the knowledge creation in patent-driven k-networks. There are also several contextual factors that are of importance.

Among the three interactions, one of them is between content and structure and the other two are between structure and process of k-networks. Using these interactions, three possible k-network configurations are proposed including: favouring, mixed-

impact and neutral k-network configurations. Through cases studied in SMEs with these configurations, this study highlighted the role of contextual factors (Figure 11-4) to understand the role of each configuration in the knowledge creation setting. The details of each configuration and emergent contextual constructs are discussed in the previous section (11.3), though an overview of all constructs are illustrated here in Figure 11-4.

Overall, the interactions of content, collaboration process and structure of patent co-authorship network contribute to knowledge creation in Victorian biotechnology industry. However, there are also several emergent constructs raised by the cases. More aggressive business strategies of companies, encourages companies to focus on more diverse knowledge. These companies, particularly those that follow favouring and mixed-impact configurations, are more keen on possessing a central position in the k-network.

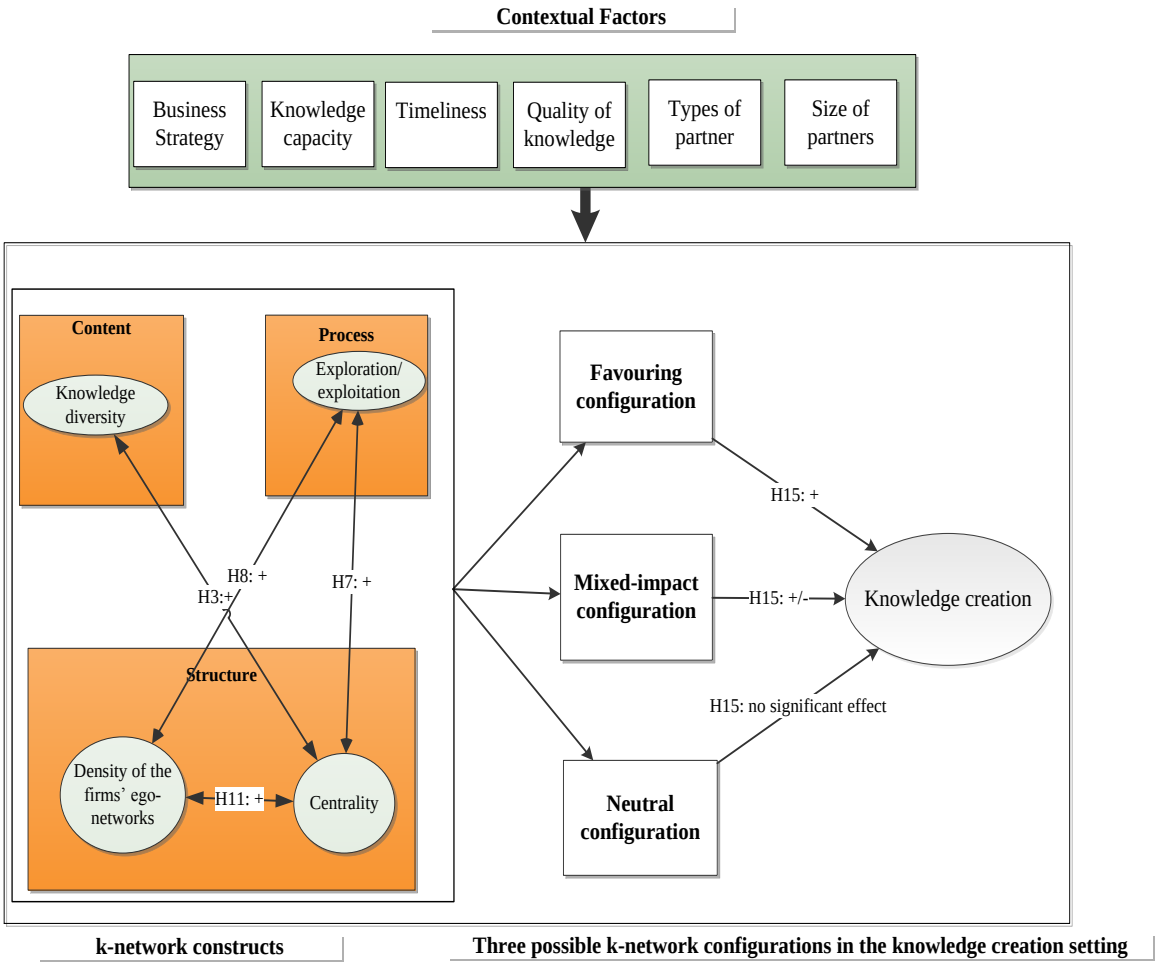


Figure 11-1 The refined conceptual model

In my research, companies with a favouring or mixed-impact configuration may follow an aggressive business strategy, but this has not observed in the case with neuteral configuration(SME-D). The aggressive companies most likely are interested in some level of exploration collaborative process to work with various partners to acquire diverse knowledge in a sparse ego-network, this situation found in Config F2 with moderate level of exploration and in Config M3 with high level of exploration collaborative process. My research shows that in a patent co-authorship network, too much emphasis on exploration within this configuration may not the best option for biotechnology companies particularly for SMEs with lower levels of knowledge capacity (e.g. SME-C). This can be found in all sorts of mixed-impact configurations, as all of them emphasise high levels of exploration collaborative process (Configs. M1 to M6).

Those who have not followed exploration collaborative process are companies that prefer to keep working more tightly with a few large resourceful partners like large universities with various departments and research programs in order to access diverse knowledge in a dense ego-network (Config. F1). In this configuration there was a public research SME owned by the state government. Here the level of knowledge capacity seemed to play a key role in making the decision to have various infrequent partners or closed frequent partners. In the latter scenario, companies need less knowledge capacity as repeating partners learn how to collaborate with each other over time. However, less frequent partnerships may require more knowledge capacity. Access to timely and high quality knowledge that a company receives through a partner is considered to be another factor for more exploitation in the partnership or in looking for new partners. Companies with Config. F3, i.e. high knowledgen diversity, and high exploration collaborative process but low ego-network density and centrality, indeed can play a brokering role in k-networks by using their sparse ego-networks. Also because of their de-centralised positions in the k-network, they look for various partnerships through high exploration collaborative processes. In my research, no companies had this configuration so the emergent factors for this type are not discussed. For two other favouring configurations (Configs. F4 and 5), although they do not possess a central position, access to relatively high knowledge diversity seems the main positive factor in their knowledge creation. To acquire diverse knowledge, they either work closely with few key partners (i.e. high exploitation collaboration processes within a dense network)

like SME-B, or may prefer to work in a sparse network with a high focus on exploration collaborative processes. Here, again, quality of knowledge that is received from previous relationships and knowledge capacity of the company seems critical.

In summary, three aspects of the research were discussed in this chapter. First, the results of the hypotheses were reviewed and second, the contextual factors to explain these results were reported. Third, the interactions of the constructs were addressed to propose a new taxonomy of the k-network configuration in the knowledge creation setting. Finally, the refined conceptual model was illustrated to show how the three aspects were synthesised to address the main goal of the research.

Chapter 12

Conclusion

Outline of Chapter 12

This chapter reports the overall conclusions for this research. After providing a summary of results, the results of the research are reviewed to show how they answer the research questions and make contributions to theory and practice. Then the limitations of the research are discussed and recommendations for further research are proposed.

12.1. Summary of the research project

The objective of this research was to study the k-network in the setting of the innovation-driven collaborations of high-tech industries. To address this aim, the patent co-authorship network of the Victorian biotechnology industry was studied through a mixed method research inquiry. The main research question of this study was: How do k-networks contribute to knowledge creation in innovation-driven collaborations?

To answer this question, first the characteristics of the k-network were reviewed in the literature. The structure of the network had been emphasised in the existing literature, but content and process of k-networks were also studied.

In my research I found that, to identify how k-networks contribute to knowledge created in the context of high-tech industry, more than the network structure of the actors is needed. It is also necessary to understand the content and process of the k-network. In particular, to explain the contribution of k-networks to creating knowledge, there are key constructs that should be understood:

- The content of the k-network in terms of diversity of technological knowledge: whether the actor is looking for various knowledge areas or a narrow and focused area of knowledge.
- The collaborative process in terms of partner exploration and/or exploitation: whether the actor is looking to collaborate with various partners or is focused on a few long-term partnerships.
- The position of the actor inside the whole network: whether the actor is in a central position of the whole network or has a peripheral position.
- The immediate network (i.e. ego-network) of the actor in terms of density: whether or not the actor is looking for close and frequent relationships with their partners.

It was found that these constructs are not independent. Knowledge diversity has a positive association with central position, exploration collaborative process and sparse ego-network. Higher exploration collaborative process is associated with a more central position and more dense ego-network. Finally there is a positive association between

central position of the actors and having a dense-ego-network. The details of how these interplay were reported in Chapter 6–8 and discussed in Chapter 11.

I argue that to identify the contribution of the k-network to knowledge creation, it is important to realise these associations. In summary, the results showed that for Victorian biotechnology actors, having more diverse knowledge, a more central position and more sparse ego-networks were associated with more patents as a measure of knowledge creation. More interestingly, it was shown that while exploration or exploitation had no direct influence on knowledge creation, it worked as a contingent factor to moderate the associations of centrality and ego-network density with knowledge creation. In a similar way, knowledge diversity was contingent factor to explain the association between centrality and knowledge creation. This latter finding was reported in the literature (Wadhwa and Kotha 2006), though my research provided more explanation about the complementary role of content and centrality to support knowledge creation. Hence this research found three interactions among the constructs of the k-network. Finally, in a novel approach, this research proposed a new configuration on the basis of these three interactions. In particular, it is argued that there are three possible k-network configurations in terms of the contribution to knowledge creation:

- Favouring configuration
- Mixed-impact configuration
- Neutral configuration.

While the combination of content, process, and structure favour the actors' knowledge creation in the favouring configuration, there are mixed positive and negative influences in the mixed-impact configuration. Finally, in the neutral configuration, the combination of content, process and structure have no particular influence to favour or to hinder the actors' knowledge creation.

To gain further insight into these three possible configurations, four cases from the Victorian biotechnology industry were investigated. These in-depth case studies confirmed the previous findings in each configuration, and led to emergent factors to explain the contribution of these constructs within each configuration. These emergent constructs were knowledge capacity, business strategy of actors, timeliness, quality and

type of knowledge in terms of public vs. private, and finally the type and size of partners. The details of each of these constructs and the ways they influence the k-network were reported in Chapter 10 and discussed in Chapter 11.

Based on all these findings, the details of possible configurations in each of the three types were discussed in Chapter 11 (Section 11.3).

12.2. Implications of the research

How do knowledge networks contribute to knowledge creation? By answering this question, my research aimed to extend KM theory particularly in the context of inter-organisational knowledge creation. Particularly in the last phase, SMEs as key participants of the whole high-tech industry k-networks were studied, whereas the majority of past research focused on large companies. In terms of practical implications, my study provides a guideline for practitioners in this area. These practitioners may include: SMEs which have the largest number of actors, larger pharmaceutical-biotechnology companies, public research organisations (mainly big universities) as the main player in the network and policy making agencies like government.

12.2.1. Theoretical contributions

The extensive literature review in Chapter 2 revealed that existing studies have tended to use structural aspects of social capital theory to explain the role of k-networks in the context of knowledge creation. Chapter 2 also reported how this theory produced contradictory results (section 2.2.2).

The need for understanding k-network beyond the structural aspects is strongly supported in my research. Using binominal regression analysis followed by the interaction analysis, it is completely clear that the effects of k-network structure (centrality and density) are strongly integrated with two other constructs on k-networks: knowledge content and collaborative process. Likewise the findings from case organisations support the importance of both content and process in knowledge creation. To have a better understanding of the role of k-networks in knowledge creation, the integration of knowledge content, collaborative process and network structure and their interactions will give a more comprehensive view.

As reported in Chapter 2 (Table 2-5) , there is no consensus on the role of central position of an actor in the network with knowledge creation. My research contributed to the seemingly contradictory results by highlighting the interaction between centrality and knowledge diversity in the setting of knowledge creation. In particular, having a central position shows less contribution to the actor's knowledge creation compared with possessing heterogeneous knowledge. Moreover in some circumstances these two complement each other. In other words, if an actor possesses some level of heterogeneous knowledge, then gaining a more central position might lead to a higher level of knowledge creation. This finding is aligned with Wadhwa and Kotha (2006), but I provide more explanation about the complementary role of content and centrality to support knowledge creation. This explains the influence of synergy between central position and having diverse areas of knowledge as a favouring factor to promote knowledge creation for actors.

In the social network research, there are two competing views about the role of ego-network structures, namely closed network vs. sparse network. The interaction of ego-network density with exploration collaborative process seems to be able to contribute to these two seemingly contradictory theories (Beckman and Haunschild 2002; Phelps 2010; Demirkan and Demirkan 2012). According to the sparse network theory, a sparse network with high structural holes is a suitable network for brokering (Burt 2004) and bridging with new partners (exploration collaborative process). My research found that sparseness or low density of ego-networks showed a positive correlation with knowledge creation. This study showed that focusing on exploration may lead to higher knowledge creation only for actors with a low density network. This association was still positive until the actors reached a certain medium level of density. In contrast, for the actors with high density ego-networks, pursuing exploration may result in lower knoweldge creation.

There is still an open debate on the role of exploration and exploitation on knowledge creation in various contexts including the inter-organisational collaborations (e.g. Lavie and Rosenkopf 2006; Li et al. 2008; Kim et al. 2011). My research shows that while there is no direct clear link between exploration/exploitation and knowledge creation, the interaction of exploration/exploitation and inter-organizational network structure is significant. This interaction posits that focusing on exploration may lead to higher knowledge creation only for actors with a peripheral position in the k-network. In

contrast, for actors with a more central position, pursuing exploration may result in lower knowledge creation. Given the findings for an actor with medium centrality and medium density, increasing the exploration collaborative process is expected to produce a mixed result.

Overall, given the three interactions among k-network constructs, a novel typology of configurations was proposed which contributes to understanding k-networks from the social capital perspective in the setting of the knowledge creation. This contribution is manifested in combining structural aspects of k-networks with content and process aspects. My research showed that considering these three aspects provides more insights to understanding how k-networks contribute to knowledge creation. To my knowledge, there is no taxonomy of configuration that takes into account the interactions of structural and non-structural constructs of the k-networks. Using this novel approach, it is possible to examine the impact of the k-network given the combination of the k-network constructs. As discussed in Chapter 11 (Section 11.3), five possible favouring configurations, six possible mixed-impact configurations and three possible neutral configurations are proposed with an example of a case analysed in the context of the Victorian biotechnology industry.

Regarding the methodology, I also believe that my research provides a mixed method perspective to k-networks research. This is important because, as has been mentioned, there is a need to accomplish more research with a mixed method inquiry. For instance as mentioned by Ågerfalk (2013), most literature in this field is either quantitative or qualitative. Combining patent co-authorship networks, as an example of formal and resource-sharing knowledge networks, with case studies my research provides an example of mixed method research in this field.

Given the emergent constructs, more avenues have appeared for future research, as discussed in detail in Section 12.4. In this way, this research shows the potential of k-network research to contribute to other theories like absorptive capacity (Cohen and Levinthal 1990), and business strategy as defined by Miles et al. (1978).

12.2.2. Practical contributions

The Victorian biotechnology industry was selected as the setting of this research, mainly because biotechnology typically is considered a knowledge intensive industry

with high rates of innovation and collaboration. Walker et al. (1997), assert that the motivation for inter-organisational collaboration in this industry is strong. Moreover according to Ernst and Young (2011), Australia is "the largest presence in the Asia-Pacific region", and Victoria is among the leading states within Australia, since more than 75% of biotechnology companies are located in the state (Allen Consulting Group 2010).

There are several several sectors participating in this industry including SMEs – which has the largest number of actors – larger pharmaceutical-biotechnology companies, public research organisations (mainly big universities) as the main players in the network, and policy making agencies like government. My research sought to understand how actors in the Victorian biotechnology industry can use the characteristics of their k-networks in order to produce more knowledge. Generally, for all kind of actors in the Victorian patent co-authorship network, my research argues that managers may need to consider the interplay between knowledge content, collaborative processes and structure of k-networks. This proposed content-process-structure framework can help managers to evaluate their organisational mechanisms and inform their managerial interventions to facilitate their knowledge creation /innovation projects. Based on the three possible types of configurations proposed in this thesis, it is possible to provide a description of the actors' network and the characteristics of the network configuration towards the knowledge creation projects.

For SMEs, participating in a network is one of the most important challenges that an owner/manager faces from the beginning of their business. The networking phenomenon for SMEs seems primarily a source for knowledge creation as a competitive response. However, to manage the networking practice, this research suggests that SMEs owner/managers may also need to consider the interplay between knowledge content, collaborative processes and structure of k-networks. According to my research, many SMEs possess a neutral configuration which cannot be an effective position for promoting their knowledge creation projects. Given an SME's business goal and its current configuration, the detailed typology I have proposed can be used to provide recommendations to improve the k-network of the SME.

For policy makers, this research provides a profile of the industry including the patent collaborations, and the diversity of the 160 technological knowledge domains created

by actors in this industry. This research highlighted the key players in the industry and showed that almost 45% of all biotechnology actors in the period of 2001–2010 were isolated. Likewise there was a substantial number of patents published by a single firm or actor. However, the map of technological overlaps which shows the potential of collaboration (Cantner and Graf 2006) indicates the potential k-network could be seven times denser than the actual patent co-authorship k-network. There is still room for improvement to support the patent-based knowledge creation by biotechnology actors in Victoria.

12.3. Limitations of the research

All research studies have their own limitations, and this research is not an exception. Always there are some risks for generalising the results. Although data were collected on the whole Victorian biotechnology industry (126 actors), only 69 actors participated in the patent k-network. The relatively low number provided some challenges for analysis. In the qualitative phases, the cases were selected among the SMEs as major participants of the whole industry network because it was not possible to study all the other groups of actors, as explained in Chapter 4 (Section 4.4.3.2). Hence, the generalisability of findings to other groups could be problematic. Likewise, there should be caution in generalising the result to the other groups of SMEs as only four pharmaceutical-biotechnology cases were included in this study.

The definition of knowledge creation in this research was narrow, and was limited to patents. However, the full range of each firm's knowledge creation would not be captured by patents. Some knowledge may not be patentable but still have economic value. Likewise, the concept of quality of created knowledge is not captured by counting the number of patents. Therefore this research cannot address the quality of the patents but focuses on whether certain characteristics of k-networks can impact on patents as a measure of knowledge creation.

Through my interviews I frequently heard from interviewees that SMEs had more partners than those identified from patent documents. However, for the purpose of this research, the networks can represent the patent-based innovation collaborations. Therefore although these networks are k-networks, the generalisation of this result,

particularly the statistics on centrality and density of the network, to non-patent based k-network could be arguable.

My research approach was not longitudinal and therefore was a snapshot of the k-networks configurations of the Victorian biotechnology industry. However, the cases in Phase 3 of the research have been quite receptive and have invited further research. I intend to take up this opportunity to explore the questions I still have.

12.4. Suggestions for future research

Despite the contributions mentioned above, this research provides many avenues for further mixed method inquiries to address k-networks. This research discussed the role of k-networks in the context of the knowledge creation, however, having a patent could be considered as the first step for the companies' innovativeness and it is not enough for the survival in the competitive markets. The constructs identified in this research like absorptive capacity and business strategy can link the knowledge creation network to the knowledge integration network which deals with commercialisation and mass production of the patents.

One of the other aspects for potential future research is realising the priority of the three interactions found in this research. Then it would be possible to look for the most supporting configuration of k-networks in the setting of the knowledge creation.

The dynamics of k-network configurations over time can also be pursued in future research. It is worthwhile research to study the k-network transformations over the life cycle of the companies. This is particularly important for SMEs which have the highest number of actors in the high-tech industry, mainly because these companies have a higher rate of growth, birth and death (Levy and Powell 2005).

There were four types of k-networks identified in Chapter 3 (Table 3-1). My research has focused on one of them (the formal and resource sharing network like patent co-authorship network). Future research, can address three relevant domains: first, the impact of other types of network on knowledge creation; second, a comparison and contrast of these networks in the context of knowledge creation; third, the inter-relations among these networks to provide a more comprehensive understanding of k-networks. In reality, a comprehensive k-network of an actor may include all four types of inter-

organisational networks. Hence, it is a worthwhile research to study the inter-play of all networks.

Finally, I found that SME-university collaboration towards new product development requires more targeted study. As is the case in the US and Europe, in Victoria, universities are key players in the biotechnology industry. Also the majority of actors are SMEs. However the relationships between SMEs with universities are not very effective, as cited by several cases:

- Australian universities are "too big and not strategic enough" as the people are academic and they do not necessarily have a deep understanding of the market and business.
- It is hard to get realistic deals with major universities since it is a long and complicated process and takes lots of resources
- The linkages between the universities and the industry partners are "antagonistic" since academics tend to over value what they know. Overall the Australian universities tend to have a more "opportunistic" rather than supportive manner.

My research first highlighted the importance of SME-University relationship for SMEs and for the whole industry, then provided a glimpse at the SME-University relationship challenges which would be worth studying in the future.

12.5. Concluding comments

My research identified the relevant constructs of the k-networks and explored the interaction between them to propose a novel approach for k-network configurations. In conclusion, there is no single or unified theory of k-networks. My research introduced the integrative framework in the k-network research that could contribute to resolving contradictions reported in k-network research about network position and structural hole theory, and exploration/exploitation literature.

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Appendices

Appendix 1: Literature review

The summary of the work done from 1970–2012 on k-networks is provided in this table. The table includes studies that have focused on the interactions of content, process and structure of k-networks, to update and complete the literature reviewed by Phelp et al. 2012.

	Inter-personal	Intra-organisational	Inter-organisational
Interaction of content, process, structure	Rodan & Galunic 2004; Singh, Hansen and Podolny 2010, (Net position and nodal) Zhang, Soh and Wong 2012 (Weak ties, prior knowledge)	Tsai 2001, (Centrality – absorptive capacity) Reinholt, Pedersen,and Foss 2011, (Centrality – motivation – sharing capacity) Chung and Jackson 2012, (Density – trust – task routineness – content) Carnabuci and Operti 2013, (Networks, knowledge diversity)	Baum, Cowan, and Jonard 2010, (Structural and content) – network evolution Li, Poppo and Zhou 2010 – (Relational and Content) – China – various industries Soh 2010 (Structural-nodal) – IT industry – some US Operti and Carnabuci 2011 (Structural and nodal) – patent – semiconductor – some US Yu, Glibert and Oviatt, 2011 (Network content) – US biotechnology Demirkan, Deeds, and Demirkan 2012 (Tie strength, and the knowledge quality – network evolution) Vasudeva, Zaheer and Hernandez 2012, (Structural and nodal) – fuel cell industry Lavie and Drori 2012, (Structural content)

Appendix 2: Patents classifications

This list provided by OECD (2005) was used to avoid two types of errors in my data collection: the inclusion of non-biotechnology patents and the exclusion of relevant biotechnology patents.

IPC codes	Title
A01H 1/00	Processes for modifying genotypes
A01H 4/00	Plant reproduction by tissue culture techniques
A61K 38/00	Medicinal preparations containing peptides
A61K 39/00	Medicinal preparations containing antigens or antibodies
A61K 48/00	Medicinal preparations containing genetic material which is inserted into cells of the living body to treat genetic diseases; Gene therapy
C02F 3/34	Biological treatment of water, waste water, or sewage: characterised by the micro-organisms used
C07G 11/00	Compounds of unknown constitution: antibiotics
C07G 13/00	Compounds of unknown constitution: vitamins
C07G 15/00	Compounds of unknown constitution: hormones
C07K 4/00	Peptides having up to 20 amino acids in an undefined or only partially defined sequence; Derivatives thereof
C07K 14/00	Peptides having more than 20 amino acids; Gastrins; Somatostatins; Melanotropins; Derivatives thereof
C07K 16/00	Immunoglobulins, *e.g.* monoclonal or polyclonal antibodies
C07K 17/00	Carrier-bound or immobilised peptides; Preparation thereof
C07K 19/00	Hybrid peptides
C12M	Apparatus for enzymology or microbiology
C12N	Micro-organisms or enzymes; compositions thereof
C12P	Fermentation or enzyme-using processes to synthesise a desired chemical compound or composition or to separate optical isomers from a racemic mixture
C12Q	Measuring or testing processes involving enzymes or micro-organisms; compositions or test papers therefor; processes of preparing such compositions; condition-responsive control in microbiological or enzymological processes
C12S	Processes using enzymes or micro-organisms to liberate, separate or purify a pre-existing compound or composition processes using enzymes or micro-organisms to treat textiles or to clean solid surfaces of materials
G01N 27/327	Investigating or analysing materials by the use of electric, electro-chemical, or magnetic means: biochemical electrodes
G01N 33/53*	Investigating or analysing materials by specific methods not covered by the preceding groups: immunoassay; biospecific binding assay; materials therefore
G01N 33/54*	Investigating or analysing materials by specific methods not covered by the preceding groups: double or second antibody: with steric inhibition or signal modification: with an insoluble carrier for immobilising immunochemicals: the carrier being organic: synthetic resin: as water suspendable particles: with antigen or antibody attached to the carrier via a bridging agent: Carbohydrates: with antigen or antibody entrapped within the carrier
G01N 33/55*	Investigating or analysing materials by specific methods not covered by the preceding groups: the carrier being inorganic: Glass or silica: Metal or metal coated: the carrier being a biological cell or cell fragment: Red blood cell: Fixed or stabilised red blood cell: using kinetic measurement: using diffusion or migration of antigen or antibody: through a gel
G01N 33/57*	Investigating or analysing materials by specific methods not covered by the preceding groups: for venereal disease: for enzymes or isoenzymes: for cancer: for hepatitis: involving monoclonal antibodies: involving limulus lysate
G01N 33/68	Investigating or analysing materials by specific methods not covered by the preceding groups: involving proteins, peptides or amino acids
G01N 33/74	Investigating or analysing materials by specific methods not covered by the preceding groups: involving hormones
G01N 33/76	Investigating or analysing materials by specific methods not covered by the preceding groups: human chorionic gonadotropin
G01N 33/78	Investigating or analysing materials by specific methods not covered by the preceding groups: thyroid gland hormones
G01N 33/88	Investigating or analysing materials by specific methods not covered by the preceding groups: involving prostaglandins
G01N 33/92	Investigating or analysing materials by specific methods not covered by the preceding groups: involving lipids, *e.g.* cholesterol

* Those IPC codes also include subgroups up to one digit (0 or 1 digit). For example, in addition to the code G01N 33/53, the codes G01N 33/531, GO1N 33/532, etc. are included.

Appendix 3: Knowledge diversity

This appendix provides more details for the analysis reported in Chapter 6 in relation to content of k-networks.

Descriptive analysis

As mentioned in Chapter 5, the concept of IPC was used to calculate knowledge diversity for all 126 actors. The lowest degree of diversity is 0 for actors with only one IPC, while the highest is .929 for the University of Melbourne. As shown in Figure A3-1 below, there are 33 actors with zero score of the knowledge diversity. It means they only have focused on a single area of knowledge. In this figure, the top diagram illustrates the histogram of the diversity of knowledge (KHetero) among all the 126 actors. Among these 126 actors, only 69 actors were collaborating with others as shown in the right diagram. It means that other 57 actors were isolated. These histograms are used to choose the right technique to test the hypothesis.

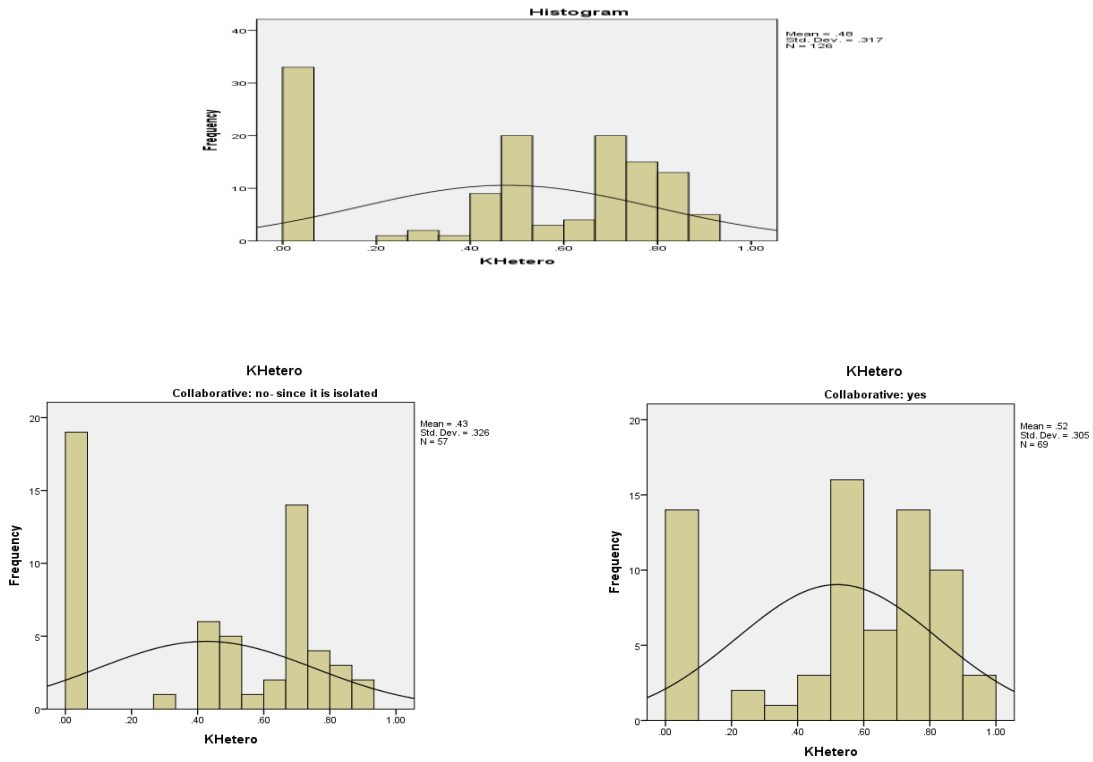


Figure A3-1 The histograms of the knowledge diversity for the whole industry (top diagram), collaborative actors (right) and the isolated actor (left)

Factorial ANOVA to test H1

Based on the histogram (Figure A3-1) and the normality test, it is clear that the distribution of the diversity is not normal (Table A3-1).

Table A3-1 Normality test for knowledge diversity based on Kolmogorov-Smirnov and Shapiro-Wilk

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
KHetero	.196	126	.000	.850	126	.000

a. Lilliefors Significance Correction

Regarding the homogeneity of variances, as the data are distributed far from a normal shape, to check the equality of variances I used a non-parametric Levene's Test (Nordstokke et al. 2011) As illustrated in Table A3-2, it is not possible to assume the variances among three groups of large, SME and individuals are significantly the same ($F = 4.60$, and $\alpha = .012 < .05$).

Table A3-2 Variances among three groups of large, SME and individuals

ANOVA

khetro_difference_rank_abs

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2430.903	2	1215.452	4.600	.012
Within Groups	32500.086	123	264.228		
Total	34930.989	125			

Therefore I used transformation to have a better fit for my data, here I used rank transformation (Wood, Weinstein, Podbielski, Kreikemeyer, Gaughan, Valentine and Buttaro 2009; Del Vecchio et al. 2012) and log transformation (Conover and Iman 1981). I also checked all the considerations and limitations (Conover and Iman 1982) of such transformations. For the purpose of my analysis, given the relatively large sample data, the results can be used with confidence. After transformation, based on a non-parametric Levene's Test (Nordstokke et al. 2011), the results show that there is no significant difference between different group of SMEs, large and individuals ($F = 1.973$, and $\alpha = .143 > .05$). Hence factorial ANOVA is used to answer this question.

Table A3-3 Variances among three groups of large, SME and individuals

ANOVA

khetro_rank_log_diff

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.465	2	.232	1.973	.143
Within Groups	14.492	123	.118		
Total	14.957	125			

Interaction tables regarding H1c:

Table A3-4 Comparing knowledge diversity of actors with different size within each actor type

Pairwise Comparisons

Dependent Variable: KHetero

OrgType	(I) size	(J) size	Mean Difference (I-J)	Std. Error	Sig.[e]	95% Confidence Interval for Difference[e]	
						Lower Bound	Upper Bound
FBF	II	Large	.[a]	.	.	.	.
		SME	.[a]	.	.	.	.
	Large	II	.[b]	.	.	.	.
		SME	.006	.094	.951	-.180	.192
	SME	II	.[b]	.	.	.	.
		Large	-.006	.094	.951	-.192	.180
H	II	Large	.[a,c]	.	.	.	.
		SME	.[a,b]	.	.	.	.
	Large	II	.[b,d]	.	.	.	.
		SME	.[b,d]	.	.	.	.
	SME	II	.[a,b]	.	.	.	.
		Large	.[a,c]	.	.	.	.
II	II	Large	.[b]	.	.	.	.
		SME	.[b]	.	.	.	.
	Large	II	.[a]	.	.	.	.
		SME	.[a,b]	.	.	.	.
	SME	II	.[a]	.	.	.	.
		Large	.[a,b]	.	.	.	.
PRO	II	Large	.[a]	.	.	.	.
		SME	.[a]	.	.	.	.
	Large	II	.[b]	.	.	.	.
		SME	.110	.186	.553	-.257	.478
	SME	II	.[b]	.	.	.	.
		Large	-.110	.186	.553	-.478	.257

Based on estimated marginal means

a. The level combination of factors in (I) is not observed.

b. The level combination of factors in (J) is not observed.

c. An estimate of the modified population marginal mean (J).

d. An estimate of the modified population marginal mean (I).

e. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table A3-5 Comparing knowledge diversity of actors with different size and type within each group of isolated and collaborative

Pairwise Comparisons

Dependent Variable: KHetero

Collaborative	(I) OrgType	(J) OrgType	Mean Difference (I-J)	Std. Error	Sig.[f]	95% Confidence Interval for Difference[f] Lower Bound	Upper Bound
no- since it is isolated	FBF	H	.[a,b]	.	.	.	.
		II	.405[a,c]	.303	.184	-.196	1.006
		PRO	-.123[a,c]	.183	.504	-.485	.240
	H	FBF	.[c,e]	.	.	.	.
		II	.[c,e]	.	.	.	.
		PRO	.[c,e]	.	.	.	.
	II	FBF	-.405[a,c]	.303	.184	-1.006	.196
		H	.[a,b]	.	.	.	.
		PRO	-.528[a,c]	.342	.126	-1.206	.151
	PRO	FBF	.123[a,c]	.183	.504	-.240	.485
		H	.[a,b]	.	.	.	.
		II	.528[a,c]	.342	.126	-.151	1.206
yes	FBF	H	-.171[a,c]	.139	.222	-.446	.105
		II	.252[a,c,*]	.099	.012	.055	.448
		PRO	-.103[a,c]	.099	.299	-.299	.093
	H	FBF	.171[a,c]	.139	.222	-.105	.446
		II	.422[a,c,*]	.141	.003	.144	.701
		PRO	.067[a,c]	.141	.633	-.211	.346
	II	FBF	-.252[a,c,*]	.099	.012	-.448	-.055
		H	-.422[a,c,*]	.141	.003	-.701	-.144
		PRO	-.355[a,c,*]	.102	.001	-.556	-.154
	PRO	FBF	.103[a,c]	.099	.299	-.093	.299
		H	-.067[a,c]	.141	.633	-.346	.211
		II	.355[a,c,*]	.102	.001	.154	.556

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. An estimate of the modified population marginal mean (I).

b. The level combination of factors in (J) is not observed.

c. An estimate of the modified population marginal mean (J).

e. The level combination of factors in (I) is not observed.

f. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table A3-6 Comparing knowledge diversity of actors with different size within each group of isolated and collaborative

Pairwise Comparisons

Dependent Variable: KHetero

Collaborative	(I) size	(J) size	Mean Difference (I-J)	Std. Error	Sig.[d]	95% Confidence Interval for Difference[d] Lower Bound	Upper Bound
no- since it is isolated	II	Large	-.440[a,b]	.337	.195	-1.107	.228
		SME	-.493[a,b]	.309	.114	-1.106	.120
	Large	II	.440[a,b]	.337	.195	-.228	1.107
		SME	-.053[a,b]	.183	.771	-.416	.309
	SME	II	.493[a,b]	.309	.114	-.120	1.106
		Large	.053[a,b]	.183	.771	-.309	.416
yes	II	Large	-.400[a,b,*]	.097	.000	-.591	-.208
		SME	-.219[a,b,*]	.097	.025	-.410	-.027
	Large	II	.400[a,b,*]	.097	.000	.208	.591
		SME	.181[a,b,*]	.091	.049	.001	.361
	SME	II	.219[a,b,*]	.097	.025	.027	.410
		Large	-.181[a,b,*]	.091	.049	-.361	-.001

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. An estimate of the modified population marginal mean (I).

b. An estimate of the modified population marginal mean (J).

d. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table A3-7 Comparing knowledge diversity of actors with different collaboration style within each actor type

Pairwise Comparisons

Dependent Variable: KHetero

OrgType	(I) Collaborative	(J) Collaborative	Mean Difference (I-J)	Std. Error	Sig.[e]	95% Confidence Interval for Difference[e]	
						Lower Bound	Upper Bound
FBF	no- since it is isolated	yes	-.134[a,b]	.094	.155	-.320	.052
	yes	no- since it is isolated	.134[a,b]	.094	.155	-.052	.320
H	no- since it is isolated	yes	.[b,c]	.	.	.	.
	yes	no- since it is isolated	.[a,d]	.	.	.	.
II	no- since it is isolated	yes	-.288[a,b]	.305	.348	-.892	.317
	yes	no- since it is isolated	.288[a,b]	.305	.348	-.317	.892
PRO	no- since it is isolated	yes	-.115[a,b]	.186	.537	-.483	.253
	yes	no- since it is isolated	.115[a,b]	.186	.537	-.253	.483

Based on estimated marginal means

a. An estimate of the modified population marginal mean (I).

b. An estimate of the modified population marginal mean (J).

c. The level combination of factors in (I) is not observed.

d. The level combination of factors in (J) is not observed.

e. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table A3-8 Comparing knowledge diversity of actors with different collaboration style within each actor size

Pairwise Comparisons

Dependent Variable: KHetero

size	(I) Collaborative	(J) Collaborative	Mean Difference (I-J)	Std. Error	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
II	no- since it is isolated	yes	-.288[a,b]	.305	.348	-.892	.317
	yes	no- since it is isolated	.288[a,b]	.305	.348	-.317	.892
Large	no- since it is isolated	yes	-.248[a,b]	.173	.154	-.589	.094
	yes	no- since it is isolated	.248[a,b]	.173	.154	-.094	.589
SME	no- since it is isolated	yes	-.013[a,b]	.109	.906	-.229	.204
	yes	no- since it is isolated	.013[a,b]	.109	.906	-.204	.229

Based on estimated marginal means

a. An estimate of the modified population marginal mean (I).

b. An estimate of the modified population marginal mean (J).

c. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table A3-8 Comparing knowledge diversity of collaborative and isolated actors with different size within each actor type

Pairwise Comparisons

Dependent Variable: KHetero

OrgType	Collaborative	(I) size	(J) size	Mean Difference (I-J)	Std. Error	Sig.[c]	95% Confidence Interval for Difference[c] Lower Bound	Upper Bound
FBF	no- since it is isolated	II	Large	.[a]	.	.	.	.
			SME	.[a]	.	.	.	.
		Large	II	.[b]	.	.	.	.
			SME	-.051	.129	.690	-.306	.204
		SME	II	.[b]	.	.	.	.
			Large	.051	.129	.690	-.204	.306
	yes	II	Large	.[a]	.	.	.	.
			SME	.[a]	.	.	.	.
		Large	II	.[b]	.	.	.	.
			SME	.063	.137	.645	-.208	.334
		SME	II	.[b]	.	.	.	.
			Large	-.063	.137	.645	-.334	.208
H	no- since it is isolated	II	Large	.[a,b]	.	.	.	.
			SME	.[a,b]	.	.	.	.
		Large	II	.[a,b]	.	.	.	.
			SME	.[a,b]	.	.	.	.
		SME	II	.[a,b]	.	.	.	.
			Large	.[a,b]	.	.	.	.
	yes	II	Large	.[a]	.	.	.	.
			SME	.[a,b]	.	.	.	.
		Large	II	.[b]	.	.	.	.
			SME	.[b]	.	.	.	.
		SME	II	.[a,b]	.	.	.	.
			Large	.[a]	.	.	.	.
II	no- since it is isolated	II	Large	.[b]	.	.	.	.
			SME	.[b]	.	.	.	.
		Large	II	.[a]	.	.	.	.
			SME	.[a,b]	.	.	.	.
		SME	II	.[a]	.	.	.	.
			Large	.[a,b]	.	.	.	.
	yes	II	Large	.[b]	.	.	.	.
			SME	.[b]	.	.	.	.
		Large	II	.[a]	.	.	.	.
			SME	.[a,b]	.	.	.	.
		SME	II	.[a]	.	.	.	.
			Large	.[a,b]	.	.	.	.
PRO	no- since it is isolated	II	Large	.[a]	.	.	.	.
			SME	.[a]	.	.	.	.
		Large	II	.[b]	.	.	.	.
			SME	-.056	.342	.871	-.734	.623
		SME	II	.[b]	.	.	.	.
			Large	.056	.342	.871	-.623	.734
	yes	II	Large	.[a]	.	.	.	.
			SME	.[a]	.	.	.	.
		Large	II	.[b]	.	.	.	.
			SME	.276	.143	.056	-.008	.560
		SME	II	.[b]	.	.	.	.
			Large	-.276	.143	.056	-.560	.008

Based on estimated marginal means

a. The level combination of factors in (I) is not observed.

b. The level combination of factors in (J) is not observed.

c. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table A3-9 Comparing knowledge diversity of collaborative and isolated actors with different type within each actor size

Pairwise Comparisons

Dependent Variable: KHetero

size	Collaborative	(I) OrgType	(J) OrgType	Mean Difference (I-J)	Std. Error	Sig.[c]	95% Confidence Interval for Difference[c] Lower Bound	Upper Bound
II	no- since it is isolated	FBF	H	.[a,b]	.	.	.	.
			II	.[a]	.	.	.	.
			PRO	.[a,b]	.	.	.	.
		H	FBF	.[a,b]	.	.	.	.
			II	.[a]	.	.	.	.
			PRO	.[a,b]	.	.	.	.
		II	FBF	.[b]	.	.	.	.
			H	.[b]	.	.	.	.
			PRO	.[b]	.	.	.	.
		PRO	FBF	.[a,b]	.	.	.	.
			H	.[a,b]	.	.	.	.
			II	.[a]	.	.	.	.
	yes	FBF	H	.[a,b]	.	.	.	.
			II	.[a]	.	.	.	.
			PRO	.[a,b]	.	.	.	.
		H	FBF	.[a,b]	.	.	.	.
			II	.[a]	.	.	.	.
			PRO	.[a,b]	.	.	.	.
		II	FBF	.[b]	.	.	.	.
			H	.[b]	.	.	.	.
			PRO	.[b]	.	.	.	.
		PRO	FBF	.[a,b]	.	.	.	.
			H	.[a,b]	.	.	.	.
			II	.[a]	.	.	.	.
Large	no- since it is isolated	FBF	H	.[b]	.	.	.	.
			II	.[b]	.	.	.	.
			PRO	-.120	.320	.707	-.755	.514
		H	FBF	.[a]	.	.	.	.
			II	.[a,b]	.	.	.	.
			PRO	.[a]	.	.	.	.
		II	FBF	.[a]	.	.	.	.
			H	.[a,b]	.	.	.	.
			PRO	.[a]	.	.	.	.
		PRO	FBF	.120	.320	.707	-.514	.755
			H	.[b]	.	.	.	.
			II	.[b]	.	.	.	.
	yes	FBF	H	-.139	.171	.418	-.478	.200
			II	.[b]	.	.	.	.
			PRO	-.210	.151	.166	-.508	.088
		H	FBF	.139	.171	.418	-.200	.478
			II	.[b]	.	.	.	.
			PRO	-.071	.151	.639	-.369	.227
		II	FBF	.[a]	.	.	.	.
			H	.[a]	.	.	.	.
			PRO	.[a]	.	.	.	.
		PRO	FBF	.210	.151	.166	-.088	.508
			H	.071	.151	.639	-.227	.369
			II	.[b]	.	.	.	.
SME	no- since it is isolated	FBF	H	.[b]	.	.	.	.
			II	.[b]	.	.	.	.
			PRO	-.125	.177	.482	-.475	.225
		H	FBF	.[a]	.	.	.	.
			II	.[a,b]	.	.	.	.
			PRO	.[a]	.	.	.	.
		II	FBF	.[a]	.	.	.	.
			H	.[a,b]	.	.	.	.
			PRO	.[a]	.	.	.	.
		PRO	FBF	.125	.177	.482	-.225	.475
			H	.[b]	.	.	.	.
			II	.[b]	.	.	.	.
	yes	FBF	H	.[b]	.	.	.	.
			II	.[b]	.	.	.	.
			PRO	.003	.129	.978	-.251	.258
		H	FBF	.[a]	.	.	.	.
			II	.[a,b]	.	.	.	.
			PRO	.[a]	.	.	.	.
		II	FBF	.[a]	.	.	.	.
			H	.[a,b]	.	.	.	.
			PRO	.[a]	.	.	.	.
		PRO	FBF	-.003	.129	.978	-.258	.251
			H	.[b]	.	.	.	.
			II	.[b]	.	.	.	.

Based on estimated marginal means

a. The level combination of factors in (I) is not observed.

b. The level combination of factors in (J) is not observed.

c. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Appendix 4: Process

This appendix provides more details for the analysis reported in Chapter 7 in relation to the process of k-networks.

Descriptive analysis

As mentioned in Chapter 5, the concept of partner diversity was used to calculate collaborative process in terms of structural exploration/exploitation process of actors in k-networks. The range of the exploration/exploitation measure (exploration index) was between 0 to 1. As shown in Figure A4-1, there are 10 actors with zero score of the exploration index.

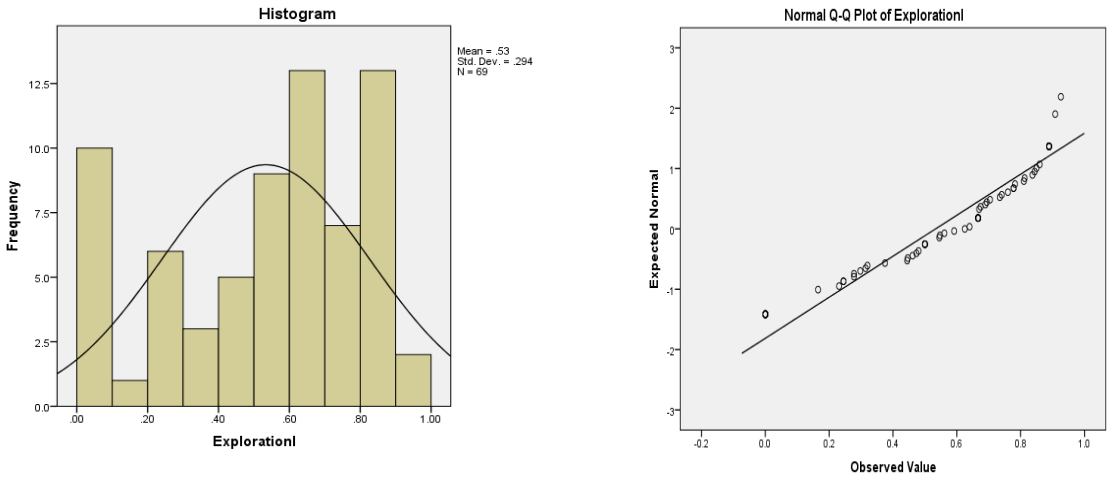


Figure A4-1 Histogram and normal Q-Q plot for exploration/exploitation index

Factorial ANOVA to test H6

Table A4-1 Normality test for process based on Kolmogorov-Smirnov and Shapiro-Wilk

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
ExplorationI	.153	69	.000	.902	69	.000

a. Lilliefors Significance Correction

Regarding the homogeneity of variances, as done in subQ1, I used a non-parametric Levene's Test (Nordstokke et al. 2011) by calculating the difference of heterogeneity ranks from the mean of the corresponded group (e.g. size). As illustrated in Table A4-2, it is strongly possible to assume the variances among three groups of large, SME and individuals are significantly the same ($F = .769$, and $\alpha = .468 > .05$).

Table A4-2 Variances among three groups of large, SME and individuals

ANOVA

Exlrak_diff

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	105.605	2	52.802	.769	.468
Within Groups	4531.554	66	68.660		
Total	4637.159	68			

So although the distribution of data is not a perfect normal, the data has passed the non-parametric Levene's Test (Nordstokke et al. 2011), so there is a good condition to assume the ANOVA is a valid test in this context.

Table A4-3 Comparing exploration/exploitation process of actors with different size within each actor type

Pairwise Comparisons

Dependent Variable: ExplorationI

OrgType	(I) size	(J) size	Mean Difference (I-J)	Std. Error	Sig.[d]	95% Confidence Interval for Difference[d]	
						Lower Bound	Upper Bound
FBF	II	Large	.[a]	.	.	.	.
		SME	.[a]	.	.	.	.
	Large	II	.[b]	.	.	.	.
		SME	.079	.111	.481	-.143	.301
	SME	II	.[b]	.	.	.	.
		Large	-.079	.111	.481	-.301	.143
H	II	Large	.[a]	.	.	.	.
		SME	.[a,b]	.	.	.	.
	Large	II	.[b]	.	.	.	.
		SME	.[b]	.	.	.	.
	SME	II	.[a,b]	.	.	.	.
		Large	.[a]	.	.	.	.
II	II	Large	.[b]	.	.	.	.
		SME	.[b]	.	.	.	.
	Large	II	.[a]	.	.	.	.
		SME	.[a,b]	.	.	.	.
	SME	II	.[a]	.	.	.	.
		Large	.[a,b]	.	.	.	.
PRO	II	Large	.[a]	.	.	.	.
		SME	.[a]	.	.	.	.
	Large	II	.[b]	.	.	.	.
		SME	.285*	.117	.018	.051	.518
	SME	II	.[b]	.	.	.	.
		Large	-.285*	.117	.018	-.518	-.051

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. The level combination of factors in (I) is not observed.

b. The level combination of factors in (J) is not observed.

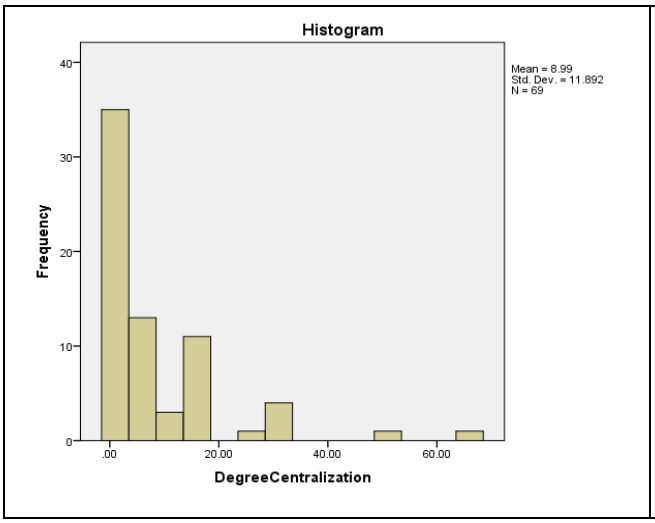
d. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Appendix 5: Structure

This appendix provides more details for the analysis reported in Chapter 8 in relation to the structure of k-networks.

Descriptive analysis of centrality

Degree of centrality is counted by using UCINET6 – a SNA package (Borgatti et al. 2002) – for all 69 collaborative firms. The measure here is called centrality and the higher value of an actor's centrality represents a more central position in the network. The lowest degree of centrality is one for actors who have only one patent partnership during 2001–2010.The largest figure is 68 again for the University of Melbourne. The descriptive analysis of centrality is shown in the Figure A5-1.



DegreeCentralization

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	14	20.3	20.3	20.3
	2.00	10	14.5	14.5	34.8
	3.00	11	15.9	15.9	50.7
	4.00	1	1.4	1.4	52.2
	5.00	3	4.3	4.3	56.5
	6.00	2	2.9	2.9	59.4
	7.00	4	5.8	5.8	65.2
	8.00	3	4.3	4.3	69.6
	12.00	3	4.3	4.3	73.9
	14.00	2	2.9	2.9	76.8
	15.00	2	2.9	2.9	79.7
	16.00	6	8.7	8.7	88.4
	17.00	1	1.4	1.4	89.9
	26.00	1	1.4	1.4	91.3
	29.00	3	4.3	4.3	95.7
	31.00	1	1.4	1.4	97.1
	51.00	1	1.4	1.4	98.6
	68.00	1	1.4	1.4	100.0
	Total	69	100.0	100.0	

Figure A5-1 Description for centrality

Factorial ANOVA to test H10

Based on the histogram (Figure A5-1) and the normality test, it is not possible to consider the distribution of the exploration index as normal.

Table A5-1 Normality test for centrality based on Kolmogorov-Smirnov and Shapiro-Wilk

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DegreeCentralization	.251	69	.000	.671	69	.000

a. Lilliefors Significance Correction

Regarding the homogeneity of variances, like I have done in subQ1 and subQ4, I used a non-parametric Levene's Test (Nordstokke et al. 2011) by calculating the difference of heterogeneity ranks from the mean of the corresponded group (e.g. size). As illustrated in Figure 15-1 it is strongly possible to assume the variances among three groups of large, SME and individuals are significantly the same (F = 1.679, and α = .194 > .05).

Table A5-2 Variances among three groups of large, SME and individuals

ANOVA

DegrRank_diff

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	274.444	2	137.222	1.679	.194
Within Groups	5393.456	66	81.719		
Total	5667.900	68			

So although the distribution of data is not a perfect normal, the data has passed the non-parametric Levene's Test (Nordstokke et al. 2011), so there is a good condition to assume the ANOVA is a valid test in this context.

Descriptive analysis of density

By using the concept of geometric mean to calculate density in a valued network or clustering in weighted networks network by Opsahl and Panzarasa (2009), density is calculated for all 69 collaborative firms. The higher value of an actor's density represents more closed partnerships in the ego-network of that actor. In the same way the value of one represents an actor who is strongly focused on a constant set of partners. The lowest degree of density is zero for actors who have no closed patent partnership during 2001–2010. The largest figure is one for several actors. The descriptive analysis of density is shown in Figure A5-2. There are about the same number of actors with zero or 1 score of density.

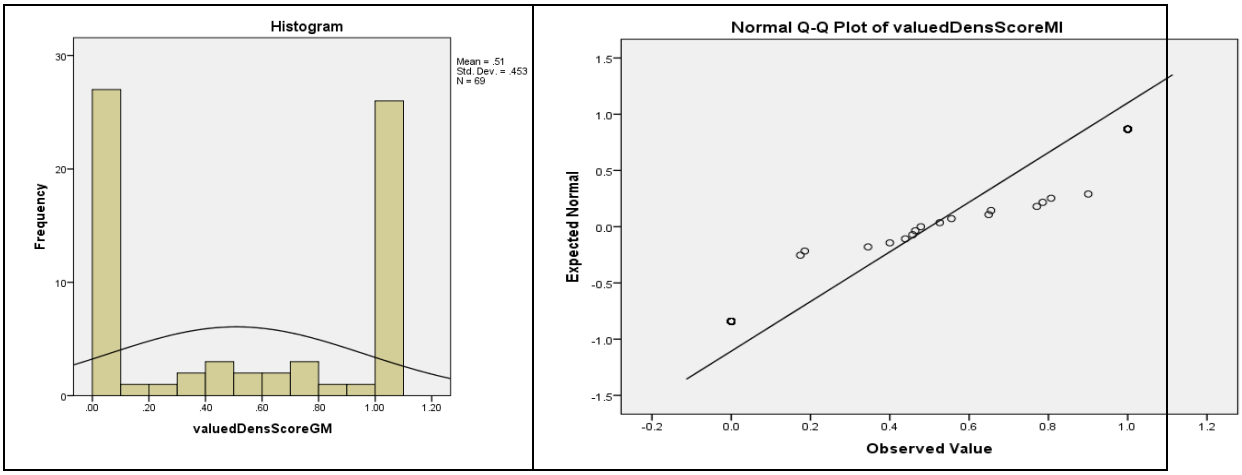


Figure A5-2 Description for density

Factorial ANOVA to test H13

Based on the histogram (Figure A5-2) and the normality test, it is not possible to consider the distribution of the density as normal.

Table A5-3 Normality test for centrality based on Kolmogorov-Smirnov and Shapiro-Wilk

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
valuedDensScoreMI	.257	69	.000	.752	69	.000

a. Lilliefors Significance Correction

Regarding the homogeneity of variances, this concept is often tested by Levene's Test by using one-way-ANOVA on the absolute value (or sometimes the square) of the residuals (e.g. Čudanov et al. (2009). Because the data are distributed far from a normal shape, to check the equality of variances I used normalised-rank transformation (Wood et al. 2009; Del Vecchio et al. 2012) and then I tried a non-parametric Levene's Test (Nordstokke et al. 2011) by calculating the difference of heterogeneity ranks from the mean of the corresponded group (e.g. size). As illustrated in Table A5-4?, it is possible to assume the variances among three groups of large, SME and individuals are significantly the same ($F = 1.343$, and $\rho = .268 > .05$).

Table A5-4 Variances among three groups of large, SME and individuals

Test of Homogeneity of Variances

DenGMRank_diff

Levene Statistic	df1	df2	Sig.
1.343	2	66	.268

So although the distribution of data is not a perfect normal, the data has passed the non-parametric Levene's Test (Nordstokke et al. 2011), so there is a good condition to assume the ANOVA is a valid test in this context.

Given the analysis of validity of using ANOVA, I ran factorial ANOVA as a method to check the impact of collaboration in network, size and type of actors. In Table A5-4, the description of all the control variables and the number of actors are shown.

Table A5-5 Description of actor's density with different type within each group of actor size

Descriptive Statistics

Dependent Variable: ValueDensity_RAN

Size	OrgType	Mean	Std. Deviation	N
II	II	54.00000	10.307764	17
	Total	54.00000	10.307764	17
Large	FBF	27.91667	17.579581	6
	H	42.41667	7.364894	6
	PRO	25.50000	13.332292	11
	Total	30.54348	14.710782	23
SME	FBF	28.68182	19.105313	22
	PRO	23.35714	16.942831	7
	Total	27.39655	18.456696	29
Total	FBF	28.51786	18.472443	28
	H	42.41667	7.364894	6
	II	54.00000	10.307764	17
	PRO	24.66667	14.388517	18
	Total	35.00000	18.891914	69

Interaction of size and type-centrality and density

Table A5-6 Comparing centrality of actors with different size within each actor type

Pairwise Comparisons

Dependent Variable: DegreeCentralization

OrgType	(I) size	(J) size	Mean Difference (I-J)	Std. Error	Sig.[d]	95% Confidence Interval for Difference[d]	
						Lower Bound	Upper Bound
FBF	II	Large	.[a]	.	.	.	.
		SME	.[a]	.	.	.	.
	Large	II	.[b]	.	.	.	.
		SME	6.106	4.914	.219	-3.714	15.926
	SME	II	.[b]	.	.	.	.
		Large	-6.106	4.914	.219	-15.926	3.714
H	II	Large	.[a]	.	.	.	.
		SME	.[a,b]	.	.	.	.
	Large	II	.[b]	.	.	.	.
		SME	.[b]	.	.	.	.
	SME	II	.[a,b]	.	.	.	.
		Large	.[a]	.	.	.	.
II	II	Large	.[b]	.	.	.	.
		SME	.[b]	.	.	.	.
	Large	II	.[a]	.	.	.	.
		SME	.[a,b]	.	.	.	.
	SME	II	.[a]	.	.	.	.
		Large	.[a,b]	.	.	.	.
PRO	II	Large	.[a]	.	.	.	.
		SME	.[a]	.	.	.	.
	Large	II	.[b]	.	.	.	.
		SME	12.935*	5.159	.015	2.626	23.244
	SME	II	.[b]	.	.	.	.
		Large	-12.935*	5.159	.015	-23.244	-2.626

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. The level combination of factors in (I) is not observed.

b. The level combination of factors in (J) is not observed.

d. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table A5-7 Comparing centrality of actors with different type within each actor size

Pairwise Comparisons

Dependent Variable: DegreeCentralization

size	(I) OrgType	(J) OrgType	Mean Difference (I-J)	Std. Error	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
II	FBF	H	.[a,b]	.	.	.	.
		II	.[a]	.	.	.	.
		PRO	.[a,b]	.	.	.	.
	H	FBF	.[a,b]	.	.	.	.
		II	.[a]	.	.	.	.
		PRO	.[a,b]	.	.	.	.
	II	FBF	.[b]	.	.	.	.
		H	.[b]	.	.	.	.
		PRO	.[b]	.	.	.	.
	PRO	FBF	.[a,b]	.	.	.	.
		H	.[a,b]	.	.	.	.
		II	.[a]	.	.	.	.
Large	FBF	H	-11.167	6.160	.075	-23.477	1.144
		II	.[b]	.	.	.	.
		PRO	-8.030	5.415	.143	-18.852	2.791
	H	FBF	11.167	6.160	.075	-1.144	23.477
		II	.[b]	.	.	.	.
		PRO	3.136	5.415	.565	-7.685	13.958
	II	FBF	.[a]	.	.	.	.
		H	.[a]	.	.	.	.
		PRO	.[a]	.	.	.	.
	PRO	FBF	8.030	5.415	.143	-2.791	18.852
		H	-3.136	5.415	.565	-13.958	7.685
		II	.[b]	.	.	.	.
SME	FBF	H	.[b]	.	.	.	.
		II	.[b]	.	.	.	.
		PRO	-1.201	4.630	.796	-10.454	8.051
	H	FBF	.[a]	.	.	.	.
		II	.[a,b]	.	.	.	.
		PRO	.[a]	.	.	.	.
	II	FBF	.[a]	.	.	.	.
		H	.[a,b]	.	.	.	.
		PRO	.[a]	.	.	.	.
	PRO	FBF	1.201	4.630	.796	-8.051	10.454
		H	.[b]	.	.	.	.
		II	.[b]	.	.	.	.

Based on estimated marginal means

a. The level combination of factors in (I) is not observed.

b. The level combination of factors in (J) is not observed.

c. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table A5-8 Comparing density of actors with different type within each actor size

Pairwise Comparisons

Dependent Variable: ValueDensity_RAN

Size	(I) OrgType	(J) OrgType	Mean Difference (I-J)	Std. Error	Sig.[d]	95% Confidence Interval for Difference[d]	
						Lower Bound	Upper Bound
II	FBF	H	.[a,b]	.	.	.	.
		II	.[a]	.	.	.	.
		PRO	.[a,b]	.	.	.	.
	H	FBF	.[a,b]	.	.	.	.
		II	.[a]	.	.	.	.
		PRO	.[a,b]	.	.	.	.
	II	FBF	.[b]	.	.	.	.
		H	.[b]	.	.	.	.
		PRO	.[b]	.	.	.	.
	PRO	FBF	.[a,b]	.	.	.	.
		H	.[a,b]	.	.	.	.
		II	.[a]	.	.	.	.
Large	FBF	H	-14.500	8.814	.105	-32.113	3.113
		II	.[b]	.	.	.	.
		PRO	2.417	7.748	.756	-13.066	17.899
	H	FBF	14.500	8.814	.105	-3.113	32.113
		II	.[b]	.	.	.	.
		PRO	16.917*	7.748	.033	1.434	32.399
	II	FBF	.[a]	.	.	.	.
		H	.[a]	.	.	.	.
		PRO	.[a]	.	.	.	.
	PRO	FBF	-2.417	7.748	.756	-17.899	13.066
		H	-16.917*	7.748	.033	-32.399	-1.434
		II	.[b]	.	.	.	.
SME	FBF	H	.[b]	.	.	.	.
		II	.[b]	.	.	.	.
		PRO	5.325	6.625	.425	-7.913	18.563
	H	FBF	.[a]	.	.	.	.
		II	.[a,b]	.	.	.	.
		PRO	.[a]	.	.	.	.
	II	FBF	.[a]	.	.	.	.
		H	.[a,b]	.	.	.	.
		PRO	.[a]	.	.	.	.
	PRO	FBF	-5.325	6.625	.425	-18.563	7.913
		H	.[b]	.	.	.	.
		II	.[b]	.	.	.	.

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. The level combination of factors in (I) is not observed.

b. The level combination of factors in (J) is not observed.

d. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Appendix 6: Interactions

Heteroscedasticity

The Koenker test rejected the homoscedasticity (Chi-square = 14.361, significance level of Chi-square .0062 < .05). This is also reflected in the histogram of residuals and the scatter plot standardised residuals vs. predicted value, since there is a funnel pattern in plot i.e. for the higher predicted values there are more fragmented variance (residuals).

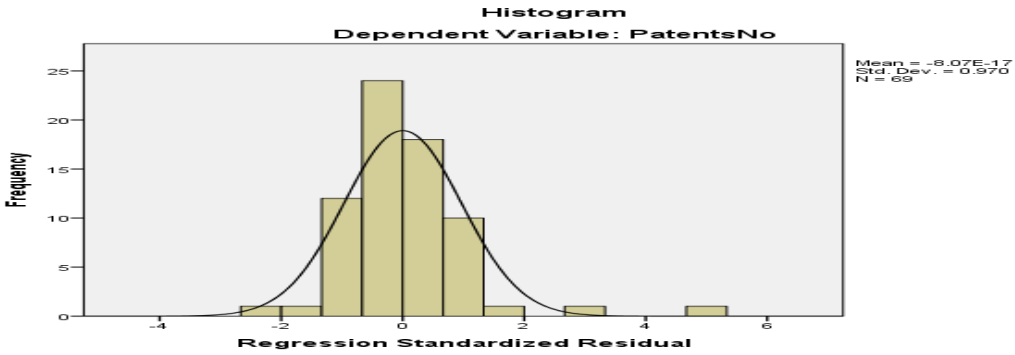


Figure A6-1 The histogram of residuals to monitor Heteroscedasticity

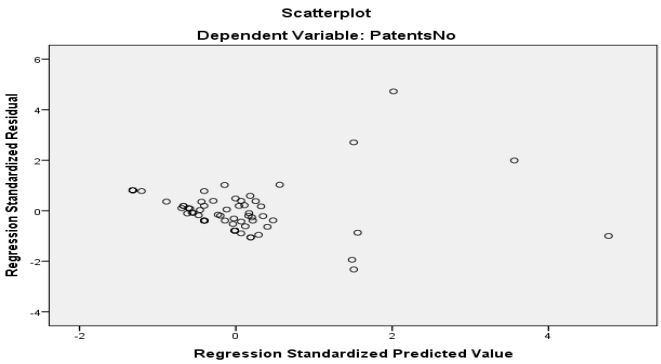


Figure A6-2 A funnel pattern in the scatter plot of standardised residuals vs. predicted value

Multicollinearity

Table A6-1 The common test of Tolerance or Variance Inflation Factors (VIF)

Coefficients[a]

Model		Collinearity Statistics	
		Tolerance	VIF
1	valuedDensScoreGM	.445	2.247
	ExplorationI	.412	2.427
	PatentsNo	.715	1.398
	KHetero	.555	1.800

a. Dependent Variable: DegreeCentralization

Role of size and type to examine H15

Table A6-2 Role of size and type on knowledge diversity and centrality

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	.422	.4740	-.507	1.351	.794	1	.373
[Size=II]	-.936	.4963	-1.909	.037	3.554	1	.059
[Size=Large]	-.015	.3866	-.772	.743	.001	1	.969
[Size=SME]	0[a]	.	.	.	.	.	.
[OrgType=FBF]	-.017	.3423	-.688	.654	.003	1	.960
[OrgType=H]	-.921	.5356	-1.971	.129	2.957	1	.086
[OrgType=II]	0[a]	.	.	.	.	.	.
[OrgType=PRO]	0[a]	.	.	.	.	.	.
KHetero	2.249	.6241	1.026	3.472	12.992	1	.000
DegreeCentralization	.035	.0153	.005	.065	5.262	1	.022
(Scale)	1[b]						
(Negative binomial)	1[b]						

Dependent Variable: PatentsNo
Model: (Intercept), Size, OrgType, KHetero, DegreeCentralization

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

Table A6-3 Role of size and type on the interaction of knowledge diversity and centrality

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	.225	.6136	-.977	1.428	.135	1	.714
[Size=II]	-.776	.5868	-1.926	.375	1.747	1	.186
[Size=Large]	-.019	.3849	-.773	.735	.002	1	.961
[Size=SME]	0[a]	.	.	.	.	.	.
[OrgType=FBF]	.013	.3448	-.662	.689	.001	1	.969
[OrgType=H]	-.833	.5649	-1.940	.274	2.176	1	.140
[OrgType=II]	0[a]	.	.	.	.	.	.
[OrgType=PRO]	0[a]	.	.	.	.	.	.
KHetero	2.666	1.0427	.622	4.710	6.537	1	.011
DegreeCentralization	.018	.0368	-.054	.090	.243	1	.622
DegreeCentrality_KHetro_Normalized	.177	.3559	-.520	.875	.248	1	.619
(Scale)	1[b]						
(Negative binomial)	1[b]						

Dependent Variable: PatentsNo
Model: (Intercept), Size, OrgType, KHetero, DegreeCentralization, DegreeCentrality_KHetro_Normalized

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

Table A6-4 Role of size and type on the interaction of process and density

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.517	.5250	.488	2.546	8.351	1	.004
ExplorationI	2.032	.8617	.343	3.721	5.560	1	.018
valuedDensScoreGM	-.742	.4943	-1.710	.227	2.252	1	.133
Exploration_Density_normal	-.138	.2800	-.686	.411	.242	1	.623
[Size=II]	-1.653	.7101	-3.045	-.261	5.420	1	.020
[Size=Large]	.466	.3948	-.308	1.239	1.391	1	.238
[Size=SME]	0[a]	.	.	.	.	.	.
[OrgType=FBF]	-.082	.3725	-.812	.648	.048	1	.827
[OrgType=H]	-1.079	.6333	-2.320	.162	2.902	1	.088
[OrgType=II]	0[a]	.	.	.	.	.	.
[OrgType=PRO]	0[a]	.	.	.	.	.	.
(Scale)	1[b]						
(Negative binomial)	1[b]						

Dependent Variable: PatentsNo
Model: (Intercept), ExplorationI, valuedDensScoreGM, Exploration_Density_normal, Size, OrgType

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

Appendix 7: Case study research documents

21th February 2012

Explanatory Statement

Title: Knowledge networks of SMEs in innovation-driven collaborations

This information sheet is for you to keep.

My name is Adel Moslehi and I am conducting a research project with Dr. Henry Linger and Dr. Kerry Tanner, senior lecturers in the Caulfield School of Information Technology (IT), and Prof. Ian Cooke from Asia Pacific Centre for Science and Wealth Creation at Monash University, towards a PhD degree at Monash University. This means that I will be writing a thesis which is the equivalent of a 300 page book. You are invited to take part in this study. Please read this explanatory statement in full before making a decision.

Why were you chosen for this research?

You have been selected as a potential participant because your company has filed at least one patent within the period of 2001-2010 in Melbourne. I have contacted you by using your company's details provided publicly on your corporation's website.

The aim of the research and possible benefits

The primary purpose of this study is to understand the role of inter-firm knowledge sharing related to innovation. This research examines knowledge networks (k-networks) of small and medium sized enterprises (SMEs). A k-network refers to a collection of individuals with whom SMEs interact to acquire or access needed information to accomplish tasks in their new product development projects. This research aims at developing more understanding about how to manage the networking practices to acquire knowledge. Participating in a network, as a source for knowledge integration has been considered as one of the most important challenges which an entrepreneur faces from the beginning of their business. Your participation will help us with this research effort.

What does the research involve? And how much time will the research take?

The study involves semi-structured interviews about issues of knowledge sharing and inter-organisational interactions during the patent project(s). Length of interview is expected to be about 60 minutes.

Inconvenience/discomfort and confidentiality

There are no foreseeable risks associated with this research project and I respect the privacy of all participants. A report of the study may be submitted for publication however individual participants and companies will not be identifiable in such a report.

Storage of data

Storage of the data collected will adhere to the University regulations and kept on University premises, in a locked filing cabinet for five years.

You can withdraw from the research

Being in this study is voluntary and you are under no obligation to consent to participation. However, if you do consent to participate, you may only withdraw prior to analysing the interview transcript.

Results

If you would like to be informed of the aggregate research finding, please contact [redacted]

Have a concern about any aspect of this study OR complaint

If you would like to contact the researchers about any aspect of this study, please contact the Chief Investigator:	If you have a complaint concerning the manner in which this research (project number: 2012000243) is being conducted, please contact:
Dr. Henry Linger [redacted] [redacted]	Executive Officer Monash University Human Research Ethics Committee (MUHREC) Building 3e Room 111 Research Office Monash University VIC 3800 [redacted] [redacted] [redacted]

Thank you in advance for your valuable participation.

Sincerely

Adel Moslehi

PhD Candidate

Caulfield School of Information Technology, Monash University

Consent Form – Participant

Title: Knowledge Networks in innovation projects

NOTE: This consent form will remain with the Monash University researcher for their records

I agree to take part in the above named PhD research project conducted by Adel Moslehi. I have read the Explanatory Statement and understand that the aim and purpose of the research is to investigate his research question:

What is the role of inter-organisational knowledge networks in innovation-driven collaborations?

I understand that agreeing to take part means that:

I agree to participate in the interview ☐ Yes ☐ No

I agree to allow the interview to be audio-taped ☐ Yes ☐ No

I agree to make myself available for a follow-up interview if required ☐ Yes ☐ No

I understand that my participation is voluntary, that I can choose not to participate in part or all of the project, and that I can withdraw at any stage of the project without being penalised or disadvantaged in any way.

I understand that any data that the researcher extracts from the interview for use in reports or published findings will not, under any circumstances, contain names or identifying characteristics.

I understand that I will be given a transcript of data concerning me for my approval before it is included in the write up of the research.

I understand that any information I provide is confidential, and that no information that could lead to the identification of any individual will be disclosed in any reports on the project, or to any other party.

I understand that data from the interview transcript and audio-tape will be kept in a secure storage and accessible to the research team. I also understand that the data will be destroyed after a 5 year period unless I consent to it being used in future research.

Participant's name:…….....

Participant's email/phone: .....…….…….……

Signature: ……

Date: …….

Interview Protocol

Table A7-1 Summary of the interviewee roles and interview topics for each case

Position	Topics for interview	Expected length of interview
A: Senior manager/CEOs	Project(s) and company backgrounds, attitude to knowledge sharing and inter-organisational collaboration	1 hour
B: Project leaders and innovators involved in the projects	Issues and approaches of knowledge sharing and inter-organisational interactions during the project(s) mainly with focus on content, purpose and actions of knowledge sharing Interactions with external partners detailed practices of knowledge sharing and collaboration	2 hours
C: Informants from the SME's partners	Issues and approaches of knowledge sharing and inter-organisational interactions during the project(s) mainly with focus on content, purpose and actions of knowledge sharing	2 hours

A: Topic areas for senior manager/CEOs

A.1. Organisation's Business Environment

1. What are the main activities of the organisation

2. Number of staff

3. Organisation's revenue? Less than $25,000? Between $25,000 and $100,000? more than $100,000

4. What is the org chart?

A.2. Attitude inter-organisational collaboration

5. What are main purposes of the collaboration with other organisations in your patent projects?

6. Is it easy to identify organisations that can collaborate with you? How do you find them? Do you have a variety of organisations to choose from?

7. Is it easy to work with these organisations? What specific characteristics do you look for when you work with an organisation?

   Cost, Previous experience, Based locally, Size, Trust, have knowledge in common, Depend on your patent/innovation purpose? e.g. whether you explore a new product or commercialise an existing technology/product

8. Within your collaboration networks, what are the key attributes of successful linkages? Why? What do you need to do to have a better network?

   1. Do you prefer to make closed and frequent interactions (despite the cost of maintenance) in order to have long term trustworthy relations? Why?

   2. Or do you prefer to access to new companies with novel opportunities e.g, do you prefer to make loose connections and identifying and reaping the emergent opportunities? Why?

      - In general, how has these characteristics of network influenced on your innovation project?

A.3. Attitude to Knowledge sharing

9. Is there any formal procedure for managing the knowledge that can be acquired /shared through the collaboration? If yes In general, what objectives do you have?

10. How do you manage the acquired knowledge from a partner in the patent collaboration?

11. In general, how has the company benefitted from the use of knowledge sharing practices?

12. Why does your company create, share and use knowledge in the ways described earlier?

B: Topic areas for project leaders and innovators involved in the projects

B.1. KM practices during the innovation project

- Could you describe the ways in which your company actively acquired, created, shared and harnessed knowledge during the following project(s)?

    1. In a patent partnership, does your method to acquire the knowledge from your partner, depend on your partner characteristics? Which characteristics are important? How do these characteristics influence on your knowledge sharing practices?

        a. Whether the partner is frequent or new?

        b. Size?

        c. Income? less than $25,000? between $25,000 and $100,000? more than $100,000

    - Why does your company create, share and use knowledge in the ways described earlier?

    - In general, how has the company benefitted from the use of knowledge sharing practices?

B.2. Content of the knowledge during the innovation project

- What are the characteristics of the knowledge that is acquired from your partners? Is it possible to articulate/document such knowledge or it is gained only through experience?

- Which characteristics of knowledge are important? How do these characteristics influence your knowledge sharing practices? Probe by asking about

    i. Area of knowledge (technological, managerial or market knowledge), why?

    ii. Codifiability (whether the knowledge is documented/ or it is gained only through experience) why?

    iii. Complexity (whether the knowledge is stand-alone or part of a system/technology)

    iv. Availability (public vs. private knowledge)

- In general, how have these characteristics of knowledge influenced your innovation project?

C: Topic areas for informants from the SME's partners

C.1. Organisation's Business Environment

- What are the main activities of the organisation, Number of staff, Is the organisation's revenue less than $25,000? between $25,000 and $100,000? More than $100,000, What is the org chart?

C.2. Attitude inter-organisational collaboration

- What are main purposes of the collaboration with SMEs? e.g. collaboration with SME partners in your patent projects

- Is it easy to identify SMEs that can collaborate with you? How do you find them? Do you have a variety of SMEs to choose from?

- Is it easy to work with these SMEs? In general what specific characteristics do you look for when you work with an organisation?

Cost, Previous experience, Based locally, Size, Trust, have knowledge in common, Depend on your patent/innovation purpose? e.g. whether you explore a new product or commercialise an existing technology/product

Within your collaboration networks with SMEs, what are the key attributes of successful linkages? Why?Do you prefer to make closed and frequent relations (robust and iterative two way communication) and pay for the cost of maintenance in order to have long term trustworthy relations with SMEs? Why? Or you prefer to access to new companies with novel opportunities e.g. do you prefer to make loose connections and identifying emergent opportunities? In general, how have these network characteristics influenced your innovation project?

C.3. Attitude to Knowledge sharing

- Is there any formal procedure for managing the knowledge that can be acquired /shared through the collaboration? Does the size of your partner make any change on this procedure? Why and how?

- In that particular partnership with aforementioned SME, could you describe how do you manage the knowledge exchange?

- Why did your company create, share and use knowledge in the ways described earlier?

- In general, how has the company benefitted from the use of knowledge sharing practices?

C.4. Content of the knowledge during the innovation project

- What are the characteristics of the knowledge that is acquired from your partners? Is it possible to articulate/document such knowledge or it is gained only through experience?

- Which characteristics of knowledge are important? How do these characteristics influence on your knowledge sharing practices? Probe for example

    1. Area of knowledge (technological, managerial or market knowledge), why?

    2. Codifiability (whether the knowledge is documented/ or it is gained only through experience) why?

    3. Complexity(whether the knowledge is stand-alone or part of a system/technology)

    4. availability public vs. private knowledge

- In general, how has these characteristics of knowledge influenced on your innovation project?