Why are some firms more successful than others in commercial adoption of technologies licensed from Public Research Institutes in Singapore?

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Glossary

Abbreviations	Full Name
A*STAR	Agency for Science, Technology and Research
AUTM	Association of University Technology Managers
BCG	Boston Consulting Group
CA	Complementary Assets
CBT	Competence-based Theory
CDM model	Model by Crépon, Duguet and Mairesse (1998)
CSO	Corporate spin-off
DC	Dynamic Capabilities
ETPL	Exploit Technologies Pte Ltd
GDP	Gross Domestic Product
GERD	Gross expenditure on R&D
GET-Up	Growing Enterprises with Technology Upgrade (programme by Singapore government agency)
IP	Intellectual Property
ITIF	Information Technology and Innovation Foundation
ITL	Inward technology licensing
KBT	Knowledge-based Theory
KCC	Knowledge Conversion Capability
MAR	Marshall-Arrow-Romer (model)
MNC	Multi-national company
NIS	National Innovation System
NPD	New Product Development
OECD	The Organisation for Economic Co-operation and Development
PAET	Propensity to acquire external technologies
PFI	Profiting from innovation
PRI	Public research institute
R&D	Research and Development
RBT	Resource-based Theory
SME	Small and medium enterprise
TCE	Transaction Cost Economics
TRL	Technology Readiness Level
TTO	Technology Transfer Office
UITT	University-Industry Technology Transfer
USO	University spin-off
VIF	Variance Inflation Factor

Abstract

The role of public research institutes (PRIs) is fast growing in importance in the national innovation system (NIS) as external knowledge centres from which firms could acquire technologies to introduce new or improved products and processes for better market performance. However, there is a paucity of empirical research on innovation outcome and commercial adoption performance from firm-PRI relationship, as extant studies tend to focus on universities and their spin-offs as commercialisation avenues for university IP, or on firms that acquire IP from other firms rather than PRIs.

Building on the intersection of multiple theoretical lenses of Resource-based Theory (RBT), Knowledge-based Theory (KBT), profiting from innovation theory (PFI) and Transaction Cost Economics (TCE), as well as the perspectives of open innovation, absorptive capacity and Dynamic Capabilities theories, this research developed an integrated conceptual model to examine the determinants affecting a firm's propensity to acquire external technologies (PAET) from PRIs, innovation outcome and commercial adoption performance. This empirical study of 250 licensing agreements between firms and PRIs in Singapore conducted in 2010 using binary logistic regression and moderated hierarchical regression analysis makes several theoretical contributions.

Firstly, the results of this study show that a firm's reliance on basic R&D and readiness level of PRIs' technologies significantly affect a firm's PAET with PRIs. While the current TCE theory adequately explains the opportunistic behaviour of profit-driven firms that engage in technology licensing contracts with other firms, this study establishes two new dimensions (basic R&D reliance and external technology readiness level) that should be considered in the context of PRIs, thereby making important contributions to TCE theory. Secondly, the findings indicate that a firm's internal resources (IP and technologies) and external resources (commercial officer, researchers, technologies and IP) are critical in converting external knowledge to new or improved products or services, and in generating related sales. This study therefore contributes empirical evidence to RBT, PFI and the open innovation model in the emerging literature on PRI research

commercialisation. Thirdly, the findings support Dynamic Capabilities and absorptive capacity theories by confirming that having resources and knowledge (as postulated by RBT and KBT) is inadequate to guarantee superior commercial adoption performance. To successfully exploit external knowledge acquired from PRIs (as recommended by open innovation), a firm's dynamic capabilities (communication capability and absorptive capacity) are found to positively affect innovative outcome and performance. Finally, this research contributes to absorptive capacity theory and Crépon, Duguet and Mairesse's (CDM) model in the context of PRIs rather than private firms as licensors by establishing that communication capability is more significant in innovative outcome stage of CDM, while absorptive capacity more important in commercial adoption performance stage of CDM.

The key findings of this research have several important implications for policy and practice. Government agencies may consider formulating policies and programmes to encourage firms to (a) co-develop PRI technologies in early stage but with strong commercial potential to enhance their PAET and (b) build up New Product Development (NPD) dynamic capabilities (communication and absorptive capacity) to facilitate more effective assimilation of knowledge from PRIs. It is also essential for firms to be aware of the importance of NPD dynamic capabilities and put in place training processes, systems and tools to enhance their ability to identify, assimilate and apply new knowledge for commercial adoption.

Signed Declaration

I declare that:

- this thesis presents work carried out by myself and does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university;
- to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text; and all substantive contributions by others to the work presented, including jointly authored publications, is clearly acknowledged.



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Sarah Cheah
9 November 2012

1 Introduction

1.1 Research Background

As the entrepreneurial university and public research institutes (PRIs) emerge as part of the national innovation systems (NIS) (Etzkowitz, Mello and Almeida, 2005), their ability to effectively commercialise new knowledge by licensing or generating spin-offs has been an area of increasing interest among universities, PRIs, policy makers and academic researchers (Markman, Gianiodis, Phan and Balkin, 2005; Rothaermel, Agung and Jiang, 2007). According to the Association of University Technology Managers (AUTM, 2010), the number of patents granted to US universities has increased from less than 300 in 1980 to more than 4,400 in 2010. Revenues from licensing university IP have risen from approximately $160 million in 1991 to $2.3 billion in 2010 in the US. The exponential growth in technology commercialisation activities, such as licensing and spin-off companies, is observed not only in the US, but also across other regions such as Europe (Wright, Clarysse, Lockett and Knockaert, 2008) and Singapore (Wong, Ho and Singh, 2007).

This research aims to investigate the determinants affecting the propensity of firms from a range of industries to license technologies developed by PRIs in Singapore, and influencing their innovative outcomes and firm performance. The literature areas that pertain to this research comprise NIS, national innovative capacity, Triple Helix, knowledge production, university-industry collaboration, external technology acquisition, open innovation, new product development and performance. Existing studies tend to focus on universities rather than on PRIs as the sources of knowledge production (Rothaermel et al., 2007), on the antecedents and performance of university spin-offs rather than IP licensing to existing firms as a means of commercialisation (Walter, Auer and Ritter, 2006; Powers and McDougall, 2005), or on the conditions and performance of firms that license technologies from other firms rather than from PRIs (Tsai and Wang, 2008; Ettlie and Pavlou, 2006). The current literature has little focus on firms that license

technologies from PRIs (Link, Siegel and van Fleet, 2011; Mazzoleni and Nelson, 2007), possibly due to the lack of data available on licensees.

This study aims to address the above gaps in the current literature. The Resource-based Theory (RBT) (Wernerfelt, 1984; Barney, 1991) and the Knowledge-based Theory (KBT) (Grant, 1996) have typically been used in prior studies on university spin-offs, while Transaction Cost Economics (TCE) (Williamson, 1985) and absorptive capacity (Cohen and Levinthal, 1990) have been drawn upon as theoretical frameworks for previous research on external technology acquisition by firms or inter-firm New Product Development (NPD). This study contributes to theory by combining the erstwhile disparate studies to develop a conceptual model based on the multiple theoretical lenses of RBT, KBT, TCE and absorptive capacity to examine how a firm's resources can affect its propensity to license technologies from PRIs, and how its resources and NPD collaboration capabilities can influence its innovative outcome and performance. The results of this research are of value not only to policy makers of economies that are pursuing commercialisation of publicly-funded research as part of their NIS, but also to PRIs, technology transfer offices (TTOs), and the firms that have licensed or are interested in licensing research by PRIs.

Innovation in Singapore

Singapore is a country with a population of only 4.8 million with a per capita GDP of US$43,117 in 2010 (Schwab, 2011). Despite her small size and lack of natural resources, she was ranked first in terms of innovation and ease of doing business globally by three separate studies in 2009. The first study was conducted by the Boston Consulting Group[1] (BCG) (Andrew, DeRocco and Taylor, 2009) which ranked 110 countries in their International Innovation Index based on a variety of

[1] The report attributed Singapore's success to the role of the government in providing an excellent climate for innovation by pursuing a policy-driven cluster strategy, investing in local infrastructure, developing workforce quality by building both local skills and attracting foreign talent, as well as reducing the cost of doing business. These Singapore initiatives have created favourable conditions for developing manufacturing clusters, from electronics and petrochemicals in the 1970s, to computers, disk drives, TVs and VCRs in the 1980s, to semiconductors and telecommunications in the 1990s, to biotechnology and other high-tech sectors in the current decade. On the other hand, the US lagged behind in the eighth position due to workforce quality and its policies on immigration, infrastructure and economics, as well as lagging behind in the quality of its workforce. Nevertheless, the US is still regarded as innovation leader with its unique innovative culture, and has scored second among the 20 largest countries (measured by GDP).

inputs (comprising innovation environment, fiscal and other policies) and innovation performance factors (including R&D results, business performance and public impact). Singapore was ranked first[2], well ahead of other innovation leaders such as the US, Japan and Germany, as shown in Table A-1 of Appendix A. The second study was part of an annual series of reports published by The World Bank (2012) to compare the ease of doing business across 183 economies. For the sixth year running, Singapore topped the other economies in ease of doing business[3], as depicted in Table A-2 of Appendix A. The third study was performed by the Information Technology and Innovation Foundation (ITIF)[4] (Atkinson and Andes, 2011). 36 nations were evaluated based on innovation capacity, economic policy, information technology infrastructure, economic performance, entrepreneurship and human capital. Singapore was ranked the most competitively innovative nation by having in place policies that promoted technological innovation and economic competition, while the US came in fourth, as illustrated in Table A-3 of Appendix A.

Singapore's NIS and Economic Development

The above ranking came as no surprise, as the Singaporean government has been very aggressive in its pursuit of the NIS in four distinct phases, since its establishment in 1960s (Wong and Singh, 2008)[5]. Throughout the historical developments, one of the greatest strengths of Singapore's NIS has been its policies focusing on (a) technological adoption, (b) foreign trade and investment, and (c) foreign talent flow. These efforts have earned her top positions in innovation by the

[2] Singapore was ranked first globally, well ahead of other innovation leaders such as the US (ranked eighth), Japan (ranked ninth) and Germany (ranked nineteenth).

[3] For the sixth year running, Singapore topped the other economies in ease of doing business (versus United States ranking fourth), trading across borders (versus United States ranking twentieth).

[4] The report disclosed that the US policymakers had done less, partly with the belief that the US was neither competing with other economies nor would they remain a leading player.

[5] The Singapore government has been very aggressive in its pursuit of national innovation system in four distinct phases, since its establishment in 1960s (Wong and Singh, 2008):

- Phase 1 (mid-1960s to mid-1970s): development of operating capabilities – heavy reliance on foreign multi-national companies (MNCs) for technology transfer to develop Singapore as manufacturing hub in Southeast Asia.
- Phase 2 (mid-1970s to late 1980s): development of adaptive capabilities – transfer of process technologies from MNCs to develop a base of local supporting industries.
- Phase 3 (late 1980s to late 1990s): development of innovative capabilities – set up of PRIs to emphasise on applied R&D to support MNC in their innovation activities.
- Phase 4 (late 1990s onwards): development of pioneering capabilities – to focus on indigenous technological capabilities on basic research, creation of local technology-based new ventures and development of biotechnology sectors.

BCG (Andrew et al., 2009), the ITIF (Atkinson and Andes, 2011), and The World Bank (2012). Nevertheless, Singapore's NIS is not without its weaknesses, particularly in the areas of publicly-funded R&D system and technology entrepreneurship.

Mazzoleni and Nelson (2007) emphasise the significant role of publicly-funded R&D systems for countries as part of their NIS for economic catch up. They cite Singapore as a latecomer in this regard, focusing on publicly-funded R&D only in the late 1990s and establishing the TTO in 2002. Although Singapore has increased her gross expenditure on R&D (GERD) from 1.88% in 2000 to 2.61% in 2007, which is well above the OECD average (2.26% in 2006) and following closely that of the US (2.68% in 2007) (A*STAR, 2008), there is still a need to continue with investment in public R&D as well as to review the effectiveness of technology transfer from PRIs to the existing industry or new ventures (Wong and Singh, 2008).

In Singapore, a relatively low propensity for technology entrepreneurship has been found among the population (Wong, Lee, Ho and Wong, 2005). The small percentage of Singaporean entrepreneurs could be attributed in part to fear of failure culturally regarded as a social stigma and in part to the high employment rate from successful economic growth, both of which have resulted in the perception of high opportunity costs for entrepreneurs (Wong and Singh, 2008).

Given the significance of the weaknesses (Mazzoleni and Nelson[6], 2007; Wong et al.[7], 2005) and the imperative need to address them, there has been increasing interest among the public and private sectors on how technology transfers from PRIs to enterprises have impacted the latter's innovation and performance (Ho, Wong and Toh, 2009). According to Mr Lee Yi Shyan, Singapore's Senior Minister of State for Trade and Industry,

> One of the key strategic thrusts of our National R&D Agenda is to strengthen the nexus between R&D and businesses. A*STAR is a strategic partner to

[6] Mazzoleni and Nelson's (2007) study cite that Korea and Taiwan started their indigenous research in 1975 and 1973, respectively, which accounted for their remarkable economic performance from the late 1960s to 1990s. However, Singapore is a latecomer in this regard.
[7] Wong et al.'s (2005) study in the period from 2000 to 2005 found that only 4-7% of the population engaged in start-up, which paled in comparison to the 11-17% in the US.

> transfer public research expertise to SMEs through programmes such as the GET-Up programme[8]. (MTI, 2009)

A*STAR is Agency for Science, Technology and Research, which oversees 14 PRIs in Singapore (A*STAR, 2012). During the five-year Science and Technology Plan from 2006 to 2010, the Singapore government committed S$13.5 billion, of which S$ 5.4 billion went to A*STAR for mission-oriented R&D. More than 3,000 researchers, scientists and engineers coming from more than 50 countries work in A*STAR to contribute to technological innovation. A*STAR has a technology commercialisation and marketing arm, Exploit Technologies (ETPL), to manage a portfolio of close to 3,000 active patents and applications. By the end of 2009, A*STAR ETPL has granted about 300 licenses to multi-national corporations (MNCs), SMEs and new ventures via technology licensing (A*STAR, 2009).

As highlighted earlier, although the Singapore government continues to step up its investment in public R&D and pushes for more intensive commercialisation, there is still a need to address the current weakness of the publicly-funded R&D system by reviewing the effectiveness of technology transfer from PRIs to the existing industry or new ventures (Wong and Singh, 2008). Currently, there are no studies in Singapore and internationally which focus on how the recipients of technology transfer have been impacted by the transfer, and the challenges they face in their commercialisation pursuits.

1.2 Research Problem and Issues

Research Questions

This research aims to investigate the determinants affecting firms' propensity to license technologies developed by PRIs, and the factors influencing their innovative outcomes and firm performance. Thus, the three research questions are:

- What are the determinants of a firm's propensity to acquire external technology (PAET)? Prior studies have focused on a firm's propensity to out-license technologies, such as Fosfuri's research (2006) on large

[8] The GET-Up programme is one of the many programmes that the Singapore government has put in place to improve the technological capabilities of SMEs to enhance their competitiveness.

chemical firms in the US, Canada, Japan and Europe, or a firm's propensity to in-license from MNCs such as Lopez's study (2008) on manufacturing plants in Chile. The research question of the current study examines a firm's propensity to in-license from PRIs in Singapore. On studies that pertain to in-licensing, Ceccagnoli, Graham, Higgins and Lee (2010) report that firms in the pharmaceutical industry with strong R&D productivity or co-specialised complementary assets (such as resources to manufacture, market, sell and distribute) have a lower PAET. Transaction Cost Economics (TCE) (Williamson, 1985) explains that the more specific the nature of these assets, the greater is the corresponding increase in the risks of hold-up and opportunitism, thereby increasing contractual hazards and reducing PAET. Cassiman and Veugelers' (2006) study of Belgian manufacturing firms suggests that the complementarity between internal R&D and external knowledge is significant in their decision to acquire external technology from both the public and private sectors. This research builds on these earlier studies to explain the variation in propensity among the firm to in-license technologies from PRIs.

- For firms that acquire external technologies from PRIs, what factors influence their innovation outcome? In this study, a firm's Innovation Outcome measures whether the firm has embodied externally licensed technology from PRIs into any of its product or processes. Previous studies have analysed the impact of licensing foreign technology, rather than licensing publicly-funded indigenous technology, on the innovation outcome of the firms in Chile (Lopez, 2008) and Japan (Kiyota and Okazaki, 2005). Other studies have analysed both firms and research institutes as external sources of technologies, whose availability and quality of human capital are pivotal for the innovation outcome of the firms that license from PRIs (Hemmert, 2004). This research question draws attention to PRIs as sources of external knowledge. It further investigates why some firms that license technologies from PRIs are more successful than others in applying this external knowledge to develop product or process innovations.
- For firms that acquire external technologies, what factors influence their commercial adoption performance? In this study, commercial adoption

performance refers to the sales related to the exploitation of the technology that the firm licenses from PRIs. It comprises three items measured as a percentage of the total annual sales: (a) actual sales of new/improved products embodying the licensed technology in the latest fiscal year, (b) actual production volume using new/improved processes from the licensed technology in the latest fiscal year, and (c) the projected annual growth rate of sales revenue of the product(s) embodying the licensed technology in the next three years. Earlier studies have focused on the role of absorptive capacity in enhancing the firm's ability to benefit from technology licensing (Tsai and Wang, 2008). Apart from absorptive capacity, the significance of other capabilities, such as NPD and collaboration capabilities (Ettlie and Pavlou, 2006), have not been carefully examined in the commercialisation process of publicly-funded research. This research question addresses why some firms that introduce product and/or process innovations are more successful than others in commercial adoption performance.

1.3 Contributions of Research

Research

The areas of current literature that pertain to the study are: (a) NIS and national innovative capacity, (b) Triple Helix, (c) knowledge production, (d) university-industry collaboration, (e) external technology acquisition and (f) open innovation, new product development and performance. Existing literature in these areas tends to focus on universities, TTOs, new ventures, the external environments, including incubators, science parks and venture capitalists (Rothaermel et al., 2007), as well as firms that acquire technology from foreign firms or large local firms (Liu and Buck, 2007). There has been little research done on the firms that license indigenous technologies from the publicly-funded research centres (Link et al., 2011; Mazzoleni and Nelson, 2007). This could possibly be due to the lack of empirical data available on licensees of indigenous technologies. This study aims to address the above gaps in the current literature.

Theory

In the literature on NIS and national innovative capacity, there has been a proliferation of studies from diverse disciplines, including economics (Romer, 1990; Freeman, 1988; Nelson, 1993), strategic management (Porter, 2001) and science and technology (Pavitt, 1984). Some economists build on Romer's (1990) R&D-endogenous growth theories to develop the second-generation endogenous growth theories to explain the R&D effect on national economic growth: Schumpeterian growth theory (Schumpeter, 1934, 1954; Young, 1998) and semi-endogenous growth models (Kortum, 1997; Ang and Madsen, 2011). Strategic management scholars postulate the cluster theory (Porter, 1990; Mowery and Nelson, 1999) to establish the linkage among technological innovation, industrial clusters and a nation's comparative advantage. Others refer to the evolutionary economic theory (Nelson and Winter, 1982; Metcalfe, 1998) and institutional economic theory (Langlois, 1989; North, 1990) to develop the NIS framework (Nelson, 1988, 1993; Lundvall, 1988). Furman, Porter and Stern (2002) integrate the earlier works on NIS, cluster theory and endogenous growth theories to construct the national innovative capacity framework. Our review of the above studies and their underlying theories indicates that there is a paucity of empirical research on how firms as important actors have been impacted by the NIS components. This research addresses the gap by examining the knowledge exchange interaction between firms and PRIs as part of NIS. Building on the concept of Triple Helix (Etzkowitz and Leydesdorff, 1996) and its underlying coevolutionary theory (Lewin and Volberda, 1999), this research is developed based on their arguments of the growing significance of academia and extension of the academia sphere to include PRIs as an increasingly important source of technological knowledge. As an empirical study, this research contributes to the Triple Helix theory which has erstwhile been lacking in rigorous quantitative research methodology.

In the literature on university-industry collaboration, the prevalent theories used are Resource-based Theory (RBT) (Wernerfelt, 1984; Barney, 1991), the Knowledge-based Theory (KBT) (Grant, 1996) and Competence-based Theory (CBT) (Prahalad and Hamel, 1990). These theories have been insightful in understanding the role of resources, knowledge and competencies in sustaining a firm's competitive

advantage. However, the current review of these theories shows their limitation in explaining the dynamic linkage between a firm's input (resources, knowledge and competence) and its output (innovation outcome and performance).This research contributes to these theories by enriching their dimensions of organisational learning and innovation processes with insight from the other literature areas such as external technology acquisition, open innovation and NPD.

The existing literature on external technology acquisition and open innovation (Chesbrough, 2007a, 2007b) refers extensively to the postulates of Transaction Cost Economics (TCE) theory (Williamson, 1985) to address the various contractual hazards that firms could typically encounter with transaction exchange. Absorptive capacity theory (Cohen and Levinthal, 1990) has also been frequently drawn upon in the research of external technology acquisition to emphasise the significance of a firm's ability to innovate by identifying, assimilating and applying new knowledge for commercialisation.

The current literature review of these areas and their theoretical frameworks reveals that much attention has been paid to the transaction of transferring knowledge to or from other firms, rather than PRIs. Unlike the profit-oriented private firms, PRIs have social and economic agenda in spearheading and promoting industry adoption of technology research that is of national interest and at the early stage of technology S-curves (Rogers, 1983). The socio-economic and technological factors in the emerging trend of PRI-firm technology transaction need to be considered in the current TCE and absorptive capacity theories that have been developed. This research focus on PRI-firm dimension contributes to the current TCE and absorptive capacity theories that originated in avoidance of market failure (Coase, 1937) and absorption of external resources (Adler, 1965), respectively, and subsequently adapted to explain inter-firm knowledge transfer in the literature on external technology acquisition and open innovation.

In the literature on NPD, the Dynamic Capabilities Theory (Teece, Pisano and Shuen, 1997) and the CDM model (Crépon, Duguet and Mairesse, 1998) based on Cobb-Douglas production function (Pakes and Griliches, 1984) have been used extensively to predict a firm's performance and to develop inter-firm NPD models

to examine a firm's success in NPD collaboration. The current review of the Dynamic Capabilities Theory in the NPD literature shows the focus on the international established companies in high-technology industries rather than on young ventures or SMEs. The CDM model, on the other hand, focuses on the linkages among decision to innovate, innovation output and performance in terms of productivity rather than commercial adoption performance from publicly-funded research. By drawing on the perspectives of Dynamic Capabilities Theory and the CDM model, this research examines the linkage between a firm's propensity to in-license external technology from PRIs and its innovation outcome, and the association between its innovation outcome and its performance in terms of sales attributable to the innovation. The results of this research contribute to the Dynamic Capabilities Theory and the CDM model by enriching their dimensions and extending their relevance to PRI-firm relationship.

By building on the intersection of multiple theoretical lenses of the RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996), TCE (Williamson, 1985), PFI (Teece, 1986), absorptive capacity theory (Cohen and Levinthal, 1990), as well as Dynamic Capabilities Theory (Teece et al., 1997), this research develops an integrated conceptual model. Based on empirical data of firms that license technologies from PRIs of Singapore, this model demonstrates the moderating effects of internal resources (built on RBT, PFI and TCE), external resources (with reference to RBT and KBT) and NPD collaboration capability (based on absorptive capacity theory and Dynamic Capabilities Theory) on the research, innovation and enterprise value chain. These theories are discussed in detail in Chapter 2. Section 3.2 provides an overview of the variables and hypotheses that develop the conceptual model, while Section 5.4.8 summarises the regression analysis results for all the hypotheses. The results of the integrated conceptual model are presented below in Figure 1.1.

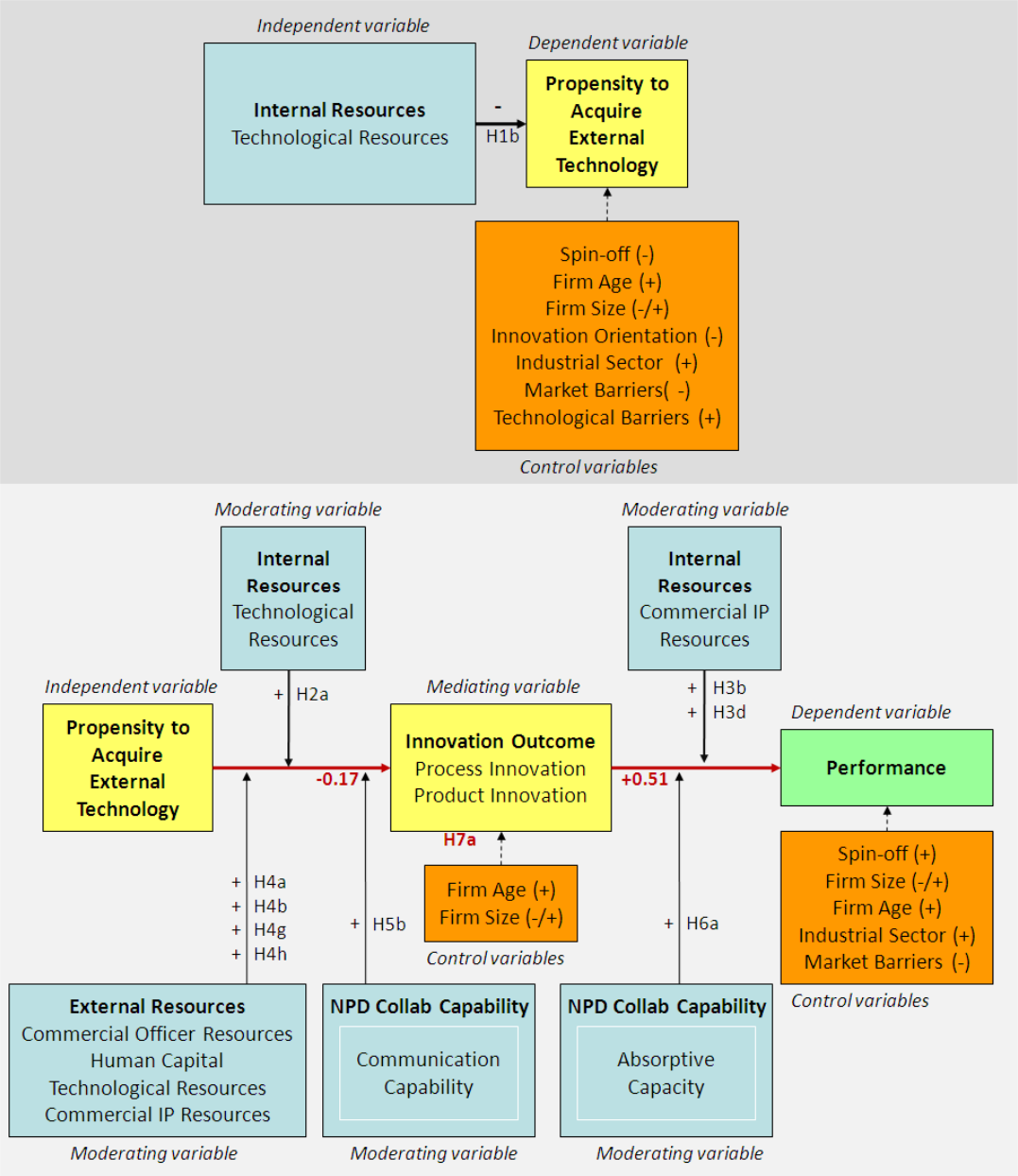

Figure 1-1: Intergrated Conceptual Model based on the regression results of this research

Practice and Policy

Unlike industry firms, PRIs are neither product designers nor product developers: this means that the technology that they offer for out-licensing tends to have a relatively lower readiness level than that of the industry firms, which would imply higher expected development costs and longer time-to-market that are borne by the firms. Moreover, there is high uncertainty of the technology itself as it is unproven. According to a study by Intellectual Ventures in 2008, although 60% of the patents were developed by academia, PRIs and individual inventors, they contributed to

less than 1% of the licensing revenue. On the other hand, large enterprises which were the originators of 40% of the patents received more than 99% of the licensing revenue (Hagiu, Yoffie and Wagonfeld, 2011). The distribution of licensing revenue between these groups that is disproportionate to that in patent origination signals a critical issue that public policy makers will have to address if they are committed to encouraging more firms to license and commercialise indigenous technologies from PRIs to the industry.

The answers to the above research questions help PRIs and TTOs gain even deeper understanding into a range of factors contributing to the relatively low level of licensing volume from PRIs compared to that from the industrial research laboratories. The results of this study reveal implications for policies and practices, as well as the necessary reviews and changes that should be effected to encourage industry adoption of technologies developed by PRIs.

The findings serve as valuable insights for the private firms on how they could organise their internal resources and processes to work with PRIs and government agencies to participate in technology development programmes to co-develop technologies and maximise gains from the collaboration.

Given that PRIs and firms in Singapore may face similar challenges to those in the other innovating economies in developing their national innovation systems, the results of this study should generally be relevant to policy makers and the private sector, thereby making a significant contribution to the body of knowledge in commercial adoption of research by PRIs, as part of NIS.

1.4 Research Methodology

A quantitative research methodology is used to investigate the correlations among the variables using licensing agreements as units of analysis in non-contrived settings. This study aims to investigate: (a) factors impacting propensity to license, and (b) factors affecting commercial adoption of licensed technology. With respect to (a), a survey is conducted on companies which have signed evaluation IP

licenses[9] and companies which have signed commercial IP licenses[10]. Of the former companies, some may decide to convert to full commercial licenses to acquire the external technology upon completion of evaluation, while others may decide not to proceed with the acquisition. This survey attempts to determine the factors impacting firms' propensity to license. To answer the research questions pertaining to (b), only companies that have signed full licenses to acquire external technology are surveyed. More details of the research methodology are provided in Chapter 4.

1.5 Definitions of Key Concepts

This research aims to investigate the determinants affecting firms' propensity to in-license the external technologies developed by PRIs as part of their open innovation strategy. These PRIs constitute one sphere of the Triple Helix in the larger context of Singapore's NIS. The firms' access to external and internal resources, knowledge, competencies as well as dynamic capabilities may influence their innovative outcomes and firm performance. This section provides definitions of the key concepts employed in this research.

According to the Resource-based Theory (RBT) (Wernerfelt, 1984; Barney, 1991), the firm's performance is determined by its resources. Barney defined resources as assets that are specific to the firm, *'valuable, rare, imperfectly imitable, and non-substitutable'* (Barney, 1991, p. 117). Grant (1996) builds on the RBT to develop the Knowledge-based Theory (KBT), asserting that the most valuable strategic resource of the firm is knowledge. Zahra, van de Velde and Larraneta (2007, p. 574) build on the KBT to define knowledge as '*intellectual capital and property as well as the organisational skills used to capture and exploit them'*. Prahalad and Hamel (1990) posit the Competence-based Theory, arguing that a firm needs to develop core competencies to sustain its competitive advantage. The authors define core competencies as '*the collective learning in the organisation, especially how to*

[9] Firms may sign evaluation IP licenses with technology transfer offices to evaluate the technologies developed by PRIs for a stipulated period of time. By the end of the evaluation period, the firms will decide if they will proceed to sign commercial IP license to adopt the technology as part of their product or process innovation for commercialisation.

[10] Firms may sign commercial IP licenses with technology transfer offices to adopt the technology as part of their product or process innovation for commercialisation under terms and conditions that typically cover four clusters: subject, scope of rights, financial terms and rights to future releases (WIPO, 2003).

coordinate diverse production skills and integrate multiple streams of technologies' and '*communication, involvement, and a deep commitment working across organisation boundaries*' (Prahalad and Hamel, 1990, p. 81). Teece et al. (1997, p. 516), draw on the RBT (Wernerfelt, 1984) and Competence-based Theory to propose the concept of dynamic capabilities and their significance in enabling a firm to 'achieve new and innovative forms of competitive advantage'. Teece et al. (1997, p. 516) define dynamic capabilities as '*the firms' ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments'.*

Although innovation could have different meanings in different literature streams, this research shall refer to the definition used by Crossan and Apaydin (2010), who adapted the following definition from the European Commission's Green Paper on Innovation, as listed in Table 1-1. Their definition is fairly broad with an emphasis on novelty that is applicable at an organisational level. Based on this definition, the innovative outcomes could be product innovation or process innovation (Hall, Lotti and Mairesse, 2009). According to the Community Innovation Survey[11] conducted by Eurostat (2012), product innovation and process innovation have been defined as possible innovative outcomes in the Community Innovation Surveys by the European community (Griffith, Huergo, Mairesse and Peters, 2006; Parisi, Schiantarelli and Sembenelli, 2006) and other countries, such as Canada using the conceptual framework known as the CDM model. Adopting the definition of the Community Innovation Survey conducted by Eurostat (2012), product innovation is '*new or significantly improved product (good or service) introduced to the market',* while process innovation is *'the introduction within an enterprise of a new or significantly improved process, as well as organisational and marketing innovations, including new logistics or distribution methods'* (Eurostat, 2012).

The CDM model, developed by Crépon, Duguet and Mairesse (1998), addresses some researchers' concern that although R&D is a significant factor, it is just an innovation input that should not directly affect a firm's performance. These authors

[11] The Community Innovation Surveys are a series of surveys conducted since 1993 in the member states of the European Union. These surveys are harmonised in terms of methodology and design for the purpose of measuring and comparing innovative activities across the region. The data cover product and process innovation. As of 2010, six CIS surveys have been performed (Eurostat, 2012).

argue that the latter is influenced by innovation output, such as process innovation, product innovation or both. The CDM model *depicts two key relationships pursuant to a firm's decision to invest in innovation.* The first relationship describes the link between innovation input (comprising primarily R&D) and innovation output (in the form of product innovation or process innovation) as accepted in the knowledge production function (Pakes and Griliches 1984). The second relationship establishes the connection between the innovation output and productivity based on Cobb-Douglas production function.

As firms strive to improve their business performance through increase in market share and profitability, they constantly seek to enhance their range of products and/or service offerings through product or process innovation. To accelerate their NPD process, the firms are likely to adopt the concept of open innovation defined by Chesbrough (2006b) as presented in Table 1-1.

'Openness' refers to acquisition of external knowledge (Lichtenthaler, 2011, p. 76). In this research, the firms under examination are those that have demonstrated a varying degree of propensity to acquire external technologies, which is also synonymous with terms of 'inward technology licensing' or 'in-licensing of external technology' commonly used by scholars (Atuahene-Gima, 1993, p. 230; Tsai and Wang, 2008, p. 91; Agrawal, 2006, p.65). This research refers to Atuahene-Gima's (1993) definition of 'propensity to adopt inward technology licensing' to define propensity to acquire external technologies as a '*firm's attitudinal orientation or intention toward future use of inward technology licensing as an alternative to internal R&D*' as part of its open innovation strategy (Atuahene-Gima, 1993, p. 233).

Before firms decide to engage in technology licensing transactions, they will consider the make-versus-buy options and the various types of transaction costs and their effects. This research uses the lenses of the Transaction Cost Economics Theory (Williamson, 1985), Profit For Innovation (PFI) (Teece, 1986) and RBT (Wernerfelt, 1984; Barney, 1991) to focus on the transaction costs of IP appropriability and complementary assets as important resources for the firms in sustaining competitive advantage.

The term, NPD, refers to the process of developing new products or services for the market. For successful launch of new products or services that embody external knowledge from PRIs, this research studies the dynamic capabilities (Teece et al., 1997) that the firms require for inter-organisation collaborative product development, which are referred to as NPD collaboration capability (Ettlie and Pavlou, 2006).

Although there are multiple definitions of the absorptive capacity construct, this research utilises its original definition by Cohen and Levinthal (1990, p. 128): *'the firm's ability to recognise the value of new, external information, assimilate it, and apply it to commercial ends'*. Their definition is selected because it provides a strong emphasis on R&D-based innovation and commercial adoption, which is also the focus of this research.

With the growing significance of the role of PRIs in knowledge generation for the industry to develop a knowledge-driven economy, firms are beginning to look towards PRIs as centres of knowledge production and distribution. In this research, PRIs are centres that are funded by the public sector to perform research and development (R&D). According to OECD's glossary of statistical terms (OECD, 2002), R&D comprises basic research, applied research and experimental development, which are defined in Table 1-1.

This research builds on the concept of the NIS with PRIs as one of the primary institutions in promoting innovation to both the public and private sectors. This research uses the definition of NIS by Metcalfe (1997), who refers to it as:

> A set of distinct institutions which jointly or individually contribute to the development and diffusion of new technologies and which provide the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts, which define new technologies. (Metcalfe, 1997, p. 289)

Based on this definition, PRIs is one of the 'interconnected institutes to create, store and transfer the knowledge, skills and artefacts, which define new technologies' (Metcalfe, 1997, p. 289). As the R&D efforts and innovation capabilities are home-grown and cultivated by the domestic PRIs, the term 'indigenous' is frequently used to describe such knowledge, skills and artefacts by the scholars (Guan, Chiu, Yam,

Chin and Pun, 2006, p. 667; Liu and Buck, 2007, p. 355; Mazzoleni and Nelson, 2007, p. 1514). Further, this research adopts the framework of the Triple Helix III to explain the role of PRIs by using Etzkowitz and Leydesdorff's definition found in Table 1-1.

According to this definition, PRIs represent one of the three institutional spheres, overlapping with the other government and industry spheres. It follows that the TTOs play the role of 'hybrid organisations emerging at the interfaces' to facilitate the transfer of technology and knowledge from PRIs to firms (Etzkowitz and Leydesdorff, 2000, p. 111). A summary of the definitions of all the key concepts used in this research is provided in Table 1-1.

Key Concepts	**Definitions**
Resources	Assets that are specific to the firm*, 'valuable, rare, imperfectly imitable, and non-substitutable'* (Barney, 1991, p. 117).
Knowledge	'intellectual capital and property as well as the organisational skills used to capture and exploit them' (Zahra, van de Velde and Larraneta, 2007, p. 574).
Core competencies	'the collective learning in the organisation, especially how to coordinate diverse production skills and integrate multiple streams of technologies' and 'communication, involvement, and a deep commitment working across organisation boundaries' (Prahalad and Hamel, 1990, p.81).
Dynamic Capabilities	'the firms' ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments' (Teece et al., 1997, p. 516).
Innovation	'Innovation is production or adoption, assimilation, and exploitation of a value-added novelty in economic and social spheres; renewal and enlargement of products, services, and markets; development of new methods of production; and establishment of new management systems. It is both a process and an outcome' (European Commission's Green Paper on Innovation, 1995, pp. 1-2; Crossan and Apaydin, 2010, p. 1155).
	'An innovation is defined as a new or significantly improved product (good or service) introduced to the market, or the introduction within an enterprise of a new or significantly improved process, as well as organisational and marketing innovations, including new logistics or distribution methods' (Eurostat, 2012).

Key Concepts	Definitions
Product Innovation	'new or significantly improved product (good or service) introduced to the market' (Eurostat, 2012).
Process Innovation	'the introduction within an enterprise of a new or significantly improved process, as well as organisational and marketing innovations, including new logistics or distribution methods' (Eurostat, 2012).
CDM Model	The CDM model depicts two key relationships pursuant to a firm's decision to invest in innovation. The first relationship describes the link between innovation input (comprising primarily R&D) and innovation output (in the form of product innovation or process innovation) as accepted in the knowledge production function (Pakes and Griliches 1984). The second relationship establishes the connection between the innovation output and productivity based on Cobb-Douglas production function (Crépon, Duguet and Mairesse, 1998).
Open Innovation	'The use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively' (Chesbrough, 2006b, p1).
Propensity to acquire external technologies	'firm's attitudinal orientation or intention toward future use of inward technology licensing as an alternative to internal R&D' as part of its open innovation strategy (Atuahene-Gima, 1993, p. 233).
Absorptive capacity	'the firm's ability to recognise the value of new, external information, assimilate it, and apply it to commercial ends' (Cohen and Levinthal, 1990, p. 128).
Basic research	'Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view' (OECD, 2002).
Applied Research	'Applied Research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective' (OECD, 2002).
Experimental development	'Experimental development is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed' (OECD, 2002).

Key Concepts	Definitions
National Innovation System (NIS)	'A set of distinct institutions which jointly or individually contribute to the development and diffusion of new technologies and which provide the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts, which define new technologies' (Metcalfe, 1997, p. 289).
Triple Helix III	'Triple Helix III is generating a knowledge infrastructure in terms of overlapping institutional spheres, with each taking the role of the other and with hybrid organisations emerging at the interfaces' (Etzkowitz and Leydesdorff, 2000, p. 111).

Table 1-1: Definitions of Key Concepts

1.6 Structure of the Thesis

This thesis comprises six chapters.

Chapter 1 Introduction outlines the research topic and prior research on the propensity of firms to acquire external technologies from PRIs, their innovation outcome and commercial adoption performance. This chapter highlights the significance of the research, drawing upon the emerging role of PRIs as part of NIS and Triple Helix. It summarises the research gaps identified in the literature review. In addition, it provides an overview of the research problem and issues, as well as highlights the contributions of this research to theory, policy and practice. This chapter also introduces the research methodology, outlines the thesis structure, and defines the key concepts, scope, assumptions and justifications of the research.

Chapter 2 Research Literature Review examines the current literature to review prior studies that are related to the key research questions of the thesis: NIS, national innovative capacity, Triple Helix, Mode-2 knowledge production, university-industry collaboration, external technology acquisition, as well as open innovation, NPD and performance at firm level. The underlying theories, development and relevance to this research for each of the literature streams are highlighted in the chapter.

Chapter 3 Research Questions, Conceptual Framework and Hypotheses discusses the main research questions, the conceptual model and hypotheses. To address the literature gaps highlighted in Chapter 2, this chapter aims to address the following three research questions and the seven related hypotheses.

- Research Question 1: What are the determinants of a firm's PAET?
- Research Question 2: For firms that acquire external technologies from PRIs, what factors influence their innovation outcome?
- Research Question 3: For firms that acquire external technologies, what factors influence their commercial adoption performance?

Chapter 4 Methodology and Research Design presents the methodology and research design used to collect the data analysed to answer the research questions and the hypotheses. This chapter provides justification for the paradigm and the quantitative research methodology that has been adopted. It elaborates on the research measures and measurements, the sampling strategy, as well as the designed questionnaire based on the literature review in Chapter 2. The chapter discusses the data collection and concludes with the procedure for sound ethical practices.

Chapter 5 Analysis of Data presents an overview of the respondents' profile and analyses the data for their reliability and validity using both descriptive and inferential statistics. This chapter presents the binary logistic regression analysis results to validate Hypothesis 1. It analyses the moderated hierarchical regression results that validate Hypotheses 2 to 6 and examines mediation analysis to confirm Hypothesis 7. Finally, this chapter provides a detailed discussion of all the regression analysis results in response to each of the three research questions that are defined and elaborated upon in Chapter 3.

Chapter 6 Conclusions, Contributions and Implications concludes the study with a summary of the findings for each hypothesis, forming conclusions about the research problem and providing implications of the study for theory, policy and practice. It also highlights the contributions of this study and outlines the limitations. Finally, the chapter recommends areas that warrant more attention and suggests directions for future research.

Figure 1-2 provides an illustration of the thesis structure.

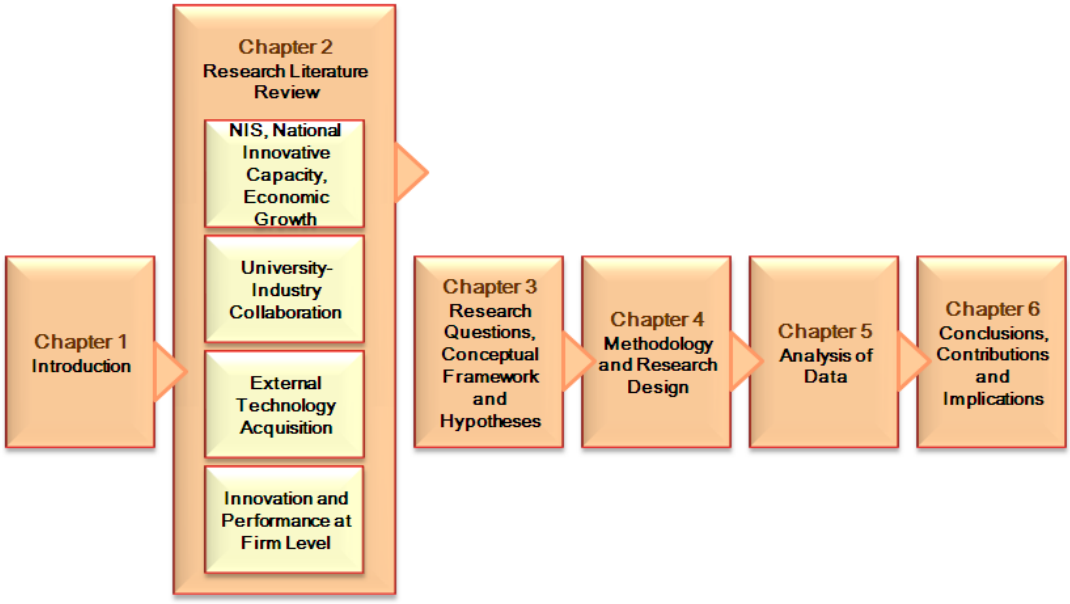

Figure 1-2: Structure of Thesis

2 Research Literature Review

2.1 Introduction

The prosperity of an economy depends on its capacity for innovation and its ability to achieve sustainable growth in national income (Belitz, Clemens, Sch midt-Ehmcke and Jens Werwatz, 2008). The importance of science and technology in raising the productivity level and improving the living standard of a nation has been well acknowledged by policymakers[12] (OECD, 1963; OECD, 1972; Godin, 2009). The centrality of R&D-based innovation as a driver of competitive advantage for a nation has been supported by a proliferation of empirical literature from a range of disciplines, including economics (Romer, 1990; Madsen, 2008; Freeman, 1988; Nelson, 1993; Kim, Kim and Yang, 2012), strategic management (Mowery and Nelson, 1999; Porter, 2001), science and technology (Pavitt, 1984; Kline and Rosenberg, 1986), and entrepreneurship (O'Shea, Allen, Chevalier and Roche, 2005; Powers and McDougall, 2005).

Some economists have used the R&D-based ***endogenous growth theories*** to explain the effect of R&D on the economic performance of the industrialised OECD economies (Romer, 1990; Coe and Helpman, 1995; Zachariadis, 2004; Ha and Howitt, 2007; Madsen, 2008). Others have postulated the ***NIS*** framework to highlight the crucial roles of a system of inter-connected distinct institutions in the innovation process (Freeman, 1988; Lundvall, 1988; Nelson, 1988, 1993). The scholars in the discipline of strategic management, on the other hand, have articulated the linkage among technological innovation, industrial clusters and a nation's comparative advantage, advancing theories such as ***cluster theory*** (Porter, 1990; Mowery and Nelson, 1999; Porter, 2001) and ***coevolutionary theory*** (Lewin and Volberda, 1999). While Porter's (1990) cluster theory is cited to argue that

[12] List (1841), a German economist, exhorted the central role of science to economic progress. He advocated the need for the government to take ownership in stimulating the economy by developing the basic infrastructure, such as railways and institutions, and protect infant industries to nurture growth. Bush (1945) postulated a causal relationship between basic research ('science') and socio-economic growth ('public welfare'), and underscored some fundamental principles for the government to uphold basic research through development of scientific talent and revision of the income tax and patent laws to intensify industrial research.

inter-firm rivalry operating within industrial clusters spurs innovation and develops national or regional industrial competitive advantage, Lewin and Volberda's (1999) coevolutionary theory is used to explain the complex and reciprocal interaction between the business entities and their operating environments, as well as their coevolution in shaping the larger innovation system. Although these perspectives have their distinct characteristics in their respective fields of application, they share a common theme: countries that do not build up their intellectual, industrial or human capital are likely to be left behind. The development of these theories and models in both economics and strategic management have spawned the development of other concepts, such as ***national innovative capacity*** framework (Porter and Stern, 1999; Stern, Porter and Furman, 200l; Furman et al., 2002; Hu and Mathews, 2008; Huang, Shih and Wu, 2011), the ***Triple Helix*** characterising the government-university-industry interaction and emphasising the critical role of the entrepreneurial university (Etzkowitz and Leydesdorff, 1999; Kim et al., 2012) and the global cluster of innovation framework (Freeman and Engel, 2007; Engel and del-Palacio, 2011).

At the firm level, there has also been burgeoning research literature to focus on how a firm's competitive advantage might be driven by its ***resources*** (Wernerfelt, 1984; Barney, 1991), ***knowledge*** (Grant, 1996), ***competencies*** (Hamel and Prahalad, 1994), ***dynamic capabilities*** (Teece et al., 1997; Eisenhardt and Martin, 2000), ***complementary assets*** (Teece, 1986), ***absorptive capacity*** (Cohen and Levinthal, 1990), and its process for ***open innovation*** (Chesbrough, 2003). These authors from industrial economics, innovation, organisational science and strategic management have researched extensively to advocate theories such as the ***Resource-based Theory*** (Wernerfelt, 1984; Barney, 1991), ***Knowledge-based Theory*** (Grant, 1996), ***Transaction Cost Economics Theory*** (Williamson, 1985; Teece, 1986), ***Dynamic Capabilities Theory*** (Teece et al., 1997), ***absorptive capacity theory*** (Cohen and Levinthal, 1990), ***Competence-based Theory*** (Hamel and Prahalad, 1994; Freiling, Gersch and Goeke, 2008), and ***open innovation*** model (Chesbrough, 2007b).

Section 2.2 reviews the recent development of ***NIS*** (Nelson, 1993) and ***national innovative capacity*** framework (Furman et al., 2002), with reference to the ***endogenous growth theory*** (Romer, 1990) and ***cluster theory*** (Porter, 1990, 2001),

in examining the factors that influence a nation's ability to generate and commercialise technological innovation over time for wealth creation.

Given the growing interest in the role of entrepreneurial university in contributing to national economic development, Etzkowitz and Leydesdorff drew upon ***evolutionary theories*** (Nelson and Winter, 1982) to herald the ***Triple Helix*** concept to advocate the significance of the three institutional spheres: (a) the government, (b) industry and (c) university, and their relationships for the development of innovation systems in the increasingly knowledge-based societies (Etzkowitz and Leydesdorff, 1996; Leydesdorff and Etzkowitz, 1998). Since then, four strands have emerged in the ***university-industry collaboration*** literature since the 1980s, with each revolving around one group of factors (Rothaermel et al., 2007; O'Shea et al., 2005). Section 2.3 reviews the development of research literature on the four groups of factors affecting university-industry technology collaboration: (a) university and PRI-related organisation factors, (b) technological transfer office organisation factors, (c) entrepreneur and new venture-related factors, and (d) environmental factors. The section also discusses the (a) ***Resource-based Theory*** (Wernerfelt, 1984; Barney, 1991), (b) ***Knowledge-based Theory*** (Grant, 1996), (c) ***Competence-based Theory*** (Hamel and Prahalad, 1994) and (d) ***Dynamic Capabilities Theory*** (Teece et al., 1997) that have been drawn upon by researchers of this literature area (O'Shea et al., 2005; Powers and McDougall, 2005; Zahra et al., 2007).

Section 2.4 provides a scan of the ***external technology acquisition*** literature and reviews three strands: (a) the significance of the institutional factors on the firm's technology acquisition performance, (b) the factors affecting a firms' decision to acquire external technology and (c) how external technology affects firm's performance (Tsai and Wang, 2008). The development of the ***Transaction Cost Economics Theory*** (Williamson, 1985) and ***absorptive capacity theory*** (Cohen and Levinthal, 1990) in these literature strands is also highlighted.

To ensure a comprehensive review of the relevant literature areas, Section 2.5 examines the other research streams of ***innovation and performance*** to review the extent of research conducted on firms acquiring publicly-funded technological innovation from PRIs. In this section, two literature streams are discussed: (a) open

innovation and intermediation, (b) firm innovation and its relationship with NPD and firm performance. The theoretical lenses of ***open innovation*** (Chesbrough, 2003) and ***CDM*** models (Crépon et al., 1998) are discussed.

2.2 National Innovation System, National Innovative Capacity and Economic Growth

Why do countries have different rates of economic growth? For the past century, economists have proposed different theories to explain the differences in economic development across countries. Before World War II, the post-Keynesian growth theories were popular among economists who shared the belief that 'market forces were not sufficient to secure growth with full employment' (Fagerberg, 1994, p. 1148; Harrod, 1939; Domar, 1946; Eichner and Kregel, 1975). In the 1950s, Robert Solow proposed the neoclassical growth model, also known as exogenous growth model (Solow, 1956), which attributed productivity to the capital per worker, with the standard assumption of perfect competition, diminishing returns to capital and labour, etc. These classical growth theories, however, mainly focused on the capital and labour, not on technological progress, with the prediction that 'in the long run, GDP per capita in all countries will grow at the same, exogenously determined rate of technological progress' (Fagerberg, 1994, pp.1148-1149).

From the 1960s to the 1980s, there was increasing interest among the economists to show that the technological progress was endogenous rather than exogenous to economic growth, and that it was the cause rather than the result of the growth (Romer, 1986; Lucas, 1988), leading to the development of the first-generation *endogenous growth theory* (Romer, 1990, Grossman and Helpman, 1991) and subsequent evolution into second-generation endogenous growth theory (Jones, 1995b; Kortum, 1997; Segerstrom, 1998). Appendix B1 traces the development of endogenous growth models in the recent decade.

Between 1980s and 1990s, as regional and national economies faced increasing competition from globalization, there was intense interest among researchers in the disciplines of economics, innovation, science and technology management, to look

at alternative models based on agglomeration economics[13] concept (Marshall, [1890]1910) to spur economic growth and sustain comparative advantage for nations (Nakamura, 1985; Porter, 1990). While Nakamura (1985) found significant influence of industry size on productivity, Porter (1990) advocated the importance of industrial clusters in enhancing the competitiveness of a region or country. Porter's cluster theory (Porter, 1990, 2000) heralded a proliferation of publications about knowledge spillover (Malmberg and Maskell, 2002; Iammarino and McCann, 2006; Gilbert, McDougall and Audretsch, 2008; Desrochers and Leppälä, 2011), regional and global innovation cluster (Yu and Jackson, 2011; Engel and del-Palacio, 2011). The recent development of Porter's cluster theory is discussed in Appendix B2.

In the 1980s, there were also arguments that economic development might involve the dynamic interaction of technological and social factors, thus warranting a more holistic system approach (Nelson and Winter, 1982). These observations culminated in the formulation of the NIS concept, which was popularised by Freeman (1987) in his study of Japan. Since then, the NIS approach has been built upon (Lundvall, 1992; Nelson, 1993), giving birth to new concepts such as 'regional systems of innovation' (Maskell and Malmberg, 1997) and 'sectoral systems of innovation' (Breschi and Malerba, 1997). Section 2.2.1 discusses the more recent works on the NIS concept and its future directions (Carlsson, 2006; Fagerberg and Srholec, 2008).

Drawing upon the endogenous growth theory (Romer, 1990), cluster theory (Porter, 1990, 2000) and NIS (Nelson, 1993), Furman, Porter and Stern (2002) built on the concept of national innovative capacity (Suarez-Villa, 1990) to introduce a framework to examine its determinants and their relative significance in explaining the variation in innovation intensity across 17 OECD economies. Section 2.2.2 reviews the findings of their study and subsequent contributions by other authors in the same literature area (Gans and Stern, 2003; Hu and Mathews, 2008; Li, 2009; Huang et al., 2011).

[13] The concept of agglomeration economies (Marshall, 1890) used the notion of economies of scale to explain the benefits of localization of economies from the agglomeration of workforce with specialised skills, providers of specialised inputs and services, and knowledge spillovers.

2.2.1 NIS

2.2.1.1 Development of NIS Concept

In the 1980s, the NIS concept emerged with the groundbreaking work of Freeman (1987), Lundvall (1992) and Nelson (1993), in the literature on innovation, science and technology. Their concept of NIS went beyond the earlier innovation system models by Leontief (1941) and Dahmén (1970, 1989). Leontief (1941) depicted innovation system as a static input/output model made up of inputs and outputs of goods and services that flow across the industries and sectors of an economy, with unidirectional linkages among the system components. Dahmén (1989, p. 109), on the other hand, applied Schumpeterian ideas (1939) to construct a more dynamic model of 'development bloc' comprising technological innovation systems to show how innovation could create opportunities for economic activities under the favourable conditions of available relevant skills and resources, as well as a ready market.

The NIS concept developed by Freeman (1988), Lundvall (1992) and Nelson (1993) was broader than those of Leontief (1941) and Dahmén (1970, 1989) in that they included not only their respective input/output and technological systems, but also the institutions and organisations with significant roles in science and technology policies at a country level, encompassing the policies and practices of universities, PRIs and government agencies in promoting R&D and nurturing the talent required to carry out R&D activities. While Freeman (1988) and Nelson (1988) expounded on their studies of technology progress and economy growth rate in Japan and the US respectively, Lundvall (1988) published a paper on *Innovation as an interactive process: from user-producer interaction to the national system of innovation*.

In the past two decades, new concepts on innovation systems have emerged with Cooke (1996), Maskell and Malmberg (1997, p. 25) postulating 'regional' systems of innovation. While Carlsson and Stankiewitz (1991, p. 93) championed the idea of 'technological systems' in Sweden, Breschi and Malerba (1997, p. 131) advanced the notion of 'sectoral innovation systems' in Italy. The regional innovation system bore the most similarity to NIS in that it acknowledged that the

innovation systems pertained to a particular locality. As for the other concepts, technological systems and sectoral innovation systems were more concerned with the process of innovation in respect of particular technologies or sectors.

While the critics of innovation studies observed that there seemed to be four definitions of innovation systems, the concept of innovation systems has gathered even greater momentum in spawning interest in other disciplines such as economics, science and technology management, and in moving analysis from system level to firm level. With multiple definitions of innovation system - be it national, regional, sectoral or technological - Carlsson, Jacobsson, Holmen and Rickne (2002) highlighted the methodological and analytical issues that these various concepts could bring about. One issue would be to ascertain the suitable level of analysis, that is, whether the analysis should be performed at the level of: product, technology, firm or region. Other issues would be identifying the appropriate population, the relevant system components, the key relationships among them and the suitable proxy of system performance to measure.

In particular, Carlsson (2006) took stock of literature on innovation systems and found that there were 750 publications in this area in the 1982-2002 period (Carlsson, 2006, p.58). These publications include internal comparison of innovation systems at the technological, sectoral, regional or national levels and globalisation of corporate R&D. Half of the publications pertained to NIS, while one quarter referred to regional innovation systems and the rest to sectoral or technological systems. Although there was extensive literature on the globalisation of corporate R&D, only 36 studies out of 750 publications covered internationalisation of corporate R&D in the context of innovation systems. Of these 36 studies, 22 were journal articles while the remaining 14 were books and book chapters. After further screening, Carlsson (2006) found that only five journals published empirical studies on internationalisation of innovation systems, with the works of Niosi and Bellon (1994, 1996) as being the most rigorous.

Based on the multiple aspects of the NIS concept from his extensive literature review, Carlsson (2006, p. 58) summarised the definition of NIS by Metcalfe as follows:

> A set of distinct institutions which jointly or individually contribute to the development and diffusion of new technologies and which provide the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts, which define new technologies. (Metcalfe, 1997, p. 289)

2.2.1.2 Theoretical Foundations of NIS: Evolutionary and Institutional Theories

The theoretical foundation of the innovation system concept - be it local, sectoral, technological, regional or national - tends to be built on the evolutionary theory of economic growth (Freeman, 1988; Carlsson, 1995; Edquist, 1997; Mowery and Nelson, 1999). In their seminal work, *Technology, Institutions and Innovation Systems*, Nelson and Nelson (2002) integrated the evolutionary economic theory (Nelson and Winter, 1982; Metcalfe, 1998) with the institutional economic theory (Langlois, 1989; North, 1990). According to Nelson and Nelson, institutional economics is oriented 'toward the set of factors that mould and define human interaction, both within organisations, and between them' (Nelson and Nelson, 2002, p. 266).

Nelson and Nelson (2002, p. 266) postulated that 'much of modern evolutionary economic theorizing is focused on the processes of technological advance'. By fitting institutions in the evolutionary theory of economic growth, the authors articulated the concept of NIS as the various institutions that have interdependencies and are required to support the development of distinct clusters of technologies and innovation, which, in turn, will drive economic growth (Nelson and Nelson, 2002, p. 271). This is consistent with McKelvey's (1997, p. 418) reference to the principles of evolutionary theory to define three functions of innovation system: (a) 'retention and transmission of information', (b) 'generation of novelty leading to diversity' and (c) 'selection among alternatives'. Edquist and Lundvall (1993, p. 267), on the other hand, draw upon the neo-Schumpeterian theory of innovation, tacit knowledge and bounded rationality of agents to define 'the national system of innovation' as being 'constituted by the institutions and economic structure affecting the rate and direction of technological change in the society'.

2.2.1.3 Recent Literature Strands of NIS

In the NIS literature, some authors develop the NIS concept further by examining the dynamics of interaction among the development of institutions, industries, businesses and organisations at the micro- and macro-levels (Fagerberg, Mowery and Verspagen, 2009). Other scholars research the processes and capabilities of NIS that significantly influence innovative or economic performance (Hekkert, Suurs, Negro, Kuhlmann and Smits, 2007; Fagerberg and Srohlec, 2008; Buesa, Heijs and Baumert, 2011; Herrmann and Peine, 2011). More recent strands of NIS literature involve the mitigating effect of NIS structural factors on crisis (Filippetti and Archibugi, 2011), efficiency of NIS (Guan and Chen, 2012) and the relevance of NIS in the internationalisation of innovation system (Niosi and Bellon, 1996, pp. 153–154; Filippetti, Frenz and Ietto-Gillies, 2009; Frenz and Ietto-Gillies, 2009). Table 2-1 presents an overview of the key development of the NIS concept from 1993 to 2012.

Author	Significant Contributions to NIS Concept
Edquist and Lundvall, 1993.	Applied neo-Schumpeterian theory of innovation, tacit knowledge and bounded rationality of agents to define 'the national system of innovation' as being 'constituted by the institutions and economic structure affecting the rate and direction of technological change in the society' (p. 267).
McKelvey, 1997	Applied the principles of evolutionary theory to define three functions of innovation system: (a) 'retention and transmission of information', (b) 'generation of novelty leading to diversity' and (c) 'selection among alternatives' (p. 418).
Nelson and Nelson, 2002	Applied the evolutionary economics theory and institutional theory to explain the concept of NIS, as a system comprising the various institutions that have interdependencies and are required to support the development of distinct clusters of technologies and innovation, which, in turn, will drive economic growth.
Carlsson, Jacobsson, Holmen and Rickne, 2002	Highlighted methodological and analytical issues that the NIS concept could bring about. One issue would be to ascertain the suitable level of analysis: whether the analysis should be performed at the product, technology, firm or regional levels. Other issues would be identifying the appropriate population, the relevant system components, the key relationships among them and the suitable proxy of system performance to measure.

Author	Significant Contributions to NIS Concept
Carlsson, 2006	Took stock of literature on innovation systems and found that there were 750 publications on this area by the close of 2002. These publications included internal comparison of innovation systems at the technological, sectoral, regional or national levels and globalisation of corporate R&D. Half of the publications pertained to NIS, while one quarter referred to regional innovation systems and the rest to the sectoral or technological systems.
Hekkert, Suurs, Negro, Kuhlmann and Smits, 2007	Analysed the processes, also defined as functions that operate within a high-performance innovation system from the cluster of Sustainable Technology Development.
Fagerberg and Srohlec, 2008	Established the capabilities that have significant effect on economic development: 'innovation system' development, 'governance' quality, 'political system' characteristics, and economy 'openness' (p. 1417).
Fagerberg, Mowery and Verspagen, 2009	Postulated that the dynamics of interaction among the development of institutions, industries, businesses and organisations over a period of time contributed to the distinct NIS configuration of a country.
Frenz and Ietto-Gillies, 2009	Examined how different knowledge sources impact innovation performance in the UK. Frenz and Ietto-Gillies postulated two primary sources of knowledge: internal knowledge and external knowledge, which are similar to the inbound and outbound innovation concepts discussed in the earlier works by Chesbrough (2003).
Godin, 2009	Reviewed the publications of OECD since 1960s to argue that the 'system approach' according to the NIS concept arose from the strong influence that the OECD had on the key authors who popularised the concept: Freeman, Nelson and Lundvall (p. 476). The NIS model was criticised to be more of a label than theoretical contribution used by policy makers to promote technology, science and innovation policies.
Buesa, Heijs and Baumert, 2011	Applied evolutionary theory to posit that innovative performance, operationally defined as patent registered, is multi-dimensional. Used factor analysis to establish that 'the five main aspects of innovation system: the National environment, the Regional environment, Innovating firms, Universities and the R&D done by Public Administration' are significant determinants of 'regional innovation' represented by patents registered (p. 723).
Filippetti and Archibugi, 2011	Found that human capital, high-technology cluster specialisation and a financial system are significant structural aspects of NIS that could reduce the impact of crisis on European firms'

Author	Significant Contributions to NIS Concept
	investment in innovation.
Yam, Lo, Tang and Lau, 2011	Argued that the link between regional innovation system and firm innovation system was lacking.
Herrmann and Peine, 2011	Exhorted that the need for firms to be 'aware of the compatibility and complementarities of the NIS and VoC [varieties of capitalism] arguments and seek both to hire scientists with adequate knowledge backgrounds and to train their workforce in the required skills as this dramatically increases their innovative potential' (p. 699).
Hung and Whittington, 2011	Applied institutional theory to argue 'institutional entrepreneurship as a form of internal agency within national innovation systems' in their study of Taiwanese Information Technology companies over the period from 1980 to 2007 (p. 526).
Guan and Chen, 2012	Used relational network two-stage data envelopment analysis (DEA) to model the NIS efficiency in two stages: 'an upstream knowledge production process (KPP) and a downstream knowledge commercialisation process (KCP)' (p. 102). Found that KCP had significant impact on the NIS efficiency, based on data of 22 OECD countries.

Table 2-1: Summary of significant contributions to NIS

From the above literature review, there was general consensus that more research on NIS should be directed towards the process of learning and developing competencies, analysis of the impact of NIS on economic performance, as well as how environmental and social factors affect knowledge production (Lundvall, 2010). While Yam et al. (2011) argued that the link between the regional innovation system and firm innovation system was lacking, Hung and Whittington (2011, p. 526) maintained that 'institutional entrepreneurship as a form of internal agency within national innovation systems' in their study of Taiwanese Information Technology companies over the period from 1980 to 2007. Herrmann and Peine (2011) exhorted that the need for firms to be:

> …aware of the compatibility and complementarities of the NIS and VoC [varieties of capitalism] arguments and seek both to hire scientists with adequate knowledge backgrounds and to train their workforce in the required skills as this dramatically increases their innovative potential. (Herrmann and Peine, 2011, p. 699)

Despite the extant volume of literature pertaining to the NIS and the related concepts of regional, technological and sectoral innovation systems, there has been little research done on how firms as important actors in the systems are impacted by the other actors and related components of the innovation systems, as well as the innovation process (Yam et al., 2011; Herrmann and Peine, 2011).

Although there seem to be multiple definitions of the NIS, this research and dissertation use Metcalfe's (1997, p. 289) definition of NIS for the innovating firms, as introduced in Section 1.5. This broad definition emphasises the system approach and highlights the interdependencies among the various institutions for the fostering of an innovative environment for innovating firms. It provides a framework that supports the assumption that the university, PRIs, TTOs and government agencies that promote economic development in Singapore are part of a 'set of distinct institutions which jointly or individually contribute to the development of diffusion of new technologies' through facilitating the adoption by the firms (important actors of Singapore innovation system) of the new technologies developed by PRIs 'to influence the innovation process' (Metcalfe, 1997, p.289; Carlsson, 2006, p.58).

This research assumes that this Singaporean 'system of interconnected institutions' designed to 'create, store and transfer the knowledge, skills and artefacts, which define new technologies' and 'condition the innovative environment' would positively influence the firms' propensity to license as a means of adopting the new technological innovation developed by the PRIs funded by government R&D grants and supported by government policies that encourage technological innovation among the firms in Singapore (Metcalfe, 1997, p.289; Motohashi, 2005; Carlsson, 2006, p. 58).

2.2.2 National Innovative Capacity

2.2.2.1 Development of National Innovative Capacity

The concept of national innovative capacity was first introduced by Suarez-Villa and Hasnath (1993, p. 296) as 'the successful outcomes of all corporate and individual invention'. Furman, Porter and Stern further developed the concept of national innovative capacity as follows:

> The ability of a country — as both a political and economic entity — to produce and commercialise a flow of new-to-the world technologies over the long term. (Furman, Porter and Stern, 2002, p. 900)

Furman et al. (2002) drew upon the endogenous growth theory (Romer, 1990), cluster theory (Porter, 1990, 2000) and NIS (Nelson, 1993) that were explained in detail in the previous sections to posit a framework to examine the determinants and their relative significance in explaining the variation in innovation intensity across 17 OECD economies.

2.2.2.2 Theoretical Foundations of National Innovative Capacity: Endogenous Growth Theory, Cluster Theory and NIS

In Furman et al.'s (2002) framework, the national innovative capacity depends on three groups of factors. The first group pertains to the nation's 'common innovation infrastructure' (Furman et al., 2002, p. 899), comprising the size of human capital dedicated to R&D and the knowledge stock available to the R&D workers, which Romer (1990) highlighted as being significant for fuelling technological progress in his endogenous growth theory. In addition, the first group of factors includes national policies supporting education and training, IP protection, international exchange of goods and services and tax incentives to promote R&D. These policies are consistent with the NIS concept of having 'the national focus of other policies, laws and regulations which condition the innovative environment' with the intent 'to create, store and transfer the knowledge, skills and artefacts, which define new technologies' (Metcalfe, 1997, p.289).

While the first group of factors describes the macroeconomic environment, the second group of factors captures the elements of microeconomic environment in the form of Porterian industrial clusters with their respective diamond frameworks and their four elements, as asserted by Porter's cluster theory (Porter, 1990): (a) 'factor (input) conditions', (b) 'demand conditions', (c) 'related and supporting industries', and (d) 'context for firm strategy and rivalry' (Porter, 2000, p. 20).

The third group of factors measures the strengths of relationships between the first and second groups. Furman et al. (2002, p. 907) argued that the reciprocal nature of 'the relationship between the common innovation infrastructure and industrial

clusters' could influence the innovative output. They cited the high-performance Swedish cluster on sustaining technology innovations as an example of high quality of linkages between the national investment in education and training of scientists and engineers in environmental technology and the local cluster, with the former increasing the value of factor (input) conditions for the development of the latter. On the other hand, the absence of the linkage facilitation by the relevant institutions could mean the spillover of knowledge to, and its exploitation by, other countries, as in the case of the Japanese commercialisation of US-invented VCR technology (Rosenbloom and Cusumano, 1987; Furman et al., 2002).

2.2.2.3 Recent Literature Strands of National Innovative Capacity

Building on the national innovative capacity framework of Furman et al. (2002) and the concept of innovation index[14] developed by Porter and Stern (1999), Gans and Stern (2003) assessed the innovative capacity of Australia between 1980 and 2000. Gans and Stern (2003, p. 32) found that from 1980 to the early 1990s Australia's innovative capacity, as represented by her innovation index, improved from being an 'imitator economy' to a 'second-tier innovator economy' due to increasing public sector investment in R&D and tertiary education. The accumulation of cutting-edge knowledge within the nation allowed Australia not only to reduce her reliance on imported technologies, but also to increase her contribution to innovation in the global marketplace, as consistent with Romer's (1990) endogenous growth theory of the significance of the size of R&D talent pool and technology knowledge stock on a country's rate of technological progress.

Between 1991 and 2000, however, Gans and Stern (2003) observed that the innovation index of Australia stagnated and attributed this to the weak linkage between her common innovation infrastructure and clusters. During this period, the increase in Australia's public funding for R&D and tertiary education in life sciences was a mismatch with the private sector's rising investment in engineering and software in their specific industrial clusters, thereby impinging on Australia's

[14] The Innovation Index was developed by Porter and Stern to assess the intensity of the national innovation systems using regression analysis and quantitative modeling to determine the factors and their relative signifnance in contributing to the innovative output of the countries. The Index enables comparison of the performance of the national innovation systems across countries for benchmarking and improvement (Porter and Stern, 1999, p.3).

innovative output, as predicted by the national innovative capacity model of Furman et al. (2002). Since then, Gans and Hayes have been using Furman et al. (2002) to track Australia's national innovative capacity (Gans and Hayes, 2004; 2005; 2006; 2007; 2008; 2009; 2010) and her relative national innovative performance with the rest of the 28 OECD countries (Gans and Hayes, 2010). The most recent report showed a rise in Australia's Innovation Index from the 13th position in 2009 to 12th in 2010, attributing the improvement to sustained R&D investment between 2000 and 2006, as well as significant surge in technology cluster specialisation.

To examine the factors that contributed to the national innovative capacity of emerging innovator economies, Furman and Hayes (2004, pp. 1344-1345) attempted to categorise[15] the countries by their innovative capacities using the 'per capita international patenting' data of 29 OECD countries from 1978 to 1999: 'leading innovators, middle tier innovators, third tier innovator and emerging innovator countries'. In particular, Furman and Hayes (2004) found that both innovation-enhancing policy commitments and sustained investment in frontier technological innovations are significant drivers of national innovative capacity that enable the emerging innovator economies such as South Korea and Finland, to catch up with their innovative output.

In the last decade, several studies have contributed significantly to the development of the national innovative capacity concept. One area of contribution is related to the firm characteristics at microeconomic level and their relationship with innovative capacity at both national and firm level (Suarez-Villa, 2003a, 2003b). Suarez-Villa (2003b, p. 400) investigated the relationship between innovative capacity and the inter-firm network, reporting the significance of the 'experimental firm' as a new form of organisation. Experimental firms are enterprises that are committed to research and innovative output, connected to external networks for

[15] The categories were leading innovator countries (e.g., Germany, US), middle tier innovator countries (e.g., Australia and a few countries of West Europe), third tier innovator countries (e.g., New Zealand and Spain) and emerging innovator countries (e.g., Finland and South Korea) (Furman and Hayes, 2004).

development of innovative capacity, as well as adopt multi-disciplinary dynamic organisation structures (Giaoutzi and Nijkamp, 2008).

Hu and Mathews (2005) examined how the innovative capacity of the East Asian economies[16] differed from that of the 17 OECD countries studied by Furman et al. (2002). Their conceptual model was a combination of the national innovative capacity framework of Furman et al. (2002) from the literature on NIS with the concept of latecomer catch-up innovation of Gerschenkron (1962) from the literature on East Asian development of industry and technology (Hu and Mathews, 2005, p. 1323). While the discussion of NIS seems to lean towards developed economies and 'new-to-the-world' innovation, research on East Asian industrial and technological development squarely focuses on the East Asian economies catching up with the economic race by transitioning from being an 'imitator' to an 'innovator' (Hu and Mathews, 2005, p. 1323). From their study, Hu and Mathews (2005) found general agreement with the results of Furman et al. (2002) although there were some key differences between the East Asian and the US or OECD countries. In addition to being impacted by smaller group of significant factors, the East Asian economies had an increasing 'ratio of the number of patented inventions to real R&D expenditure' (Hu and Mathews, 2005, p. 1323), compared to the US or OECD economies, which were experiencing declining ratios. The key factors that the East Asian latecomers focused on were R&D workforce, patent stocks, and R&D expenditure by both public and private sectors (Hu and Mathews, 2005, p. 1348).

In a more recent study on the innovative capacity of Taiwan, Mathews and Hu (2007) found the shift in the role of the public universities from focusing on tertiary education as part of the national common infrastructure to serving as a technology licensing and incubation agency as part of the linkage between national common infrastructure and clusters (Furman et al., 2002), similar to that role of universities in the developed countries. PRIs, on the other hand, served as the R&D organisations for Taiwan's SMEs, fostering a high quality of linkages between public R&D and the industry.

[16] The East Asian countries studied by Hu and Mathews (2005) were China, Hong Kong, Korea, Singapore and Taiwan.

In a separate study of China, Hu and Mathews (2008) observed a striking difference in the role of universities and PRIs between China and the other developing countries. While universities had 'not only been a critical source of innovative activity but also been a practitioner by means of forward engineering and spin-offs', many PRIs 'transformed themselves into private technology service enterprises or were affiliated with corporate groups as the means for their survival' (Hu and Mathews, 2008, p. 1476). The study concluded that China was still in the early phase of the national innovative capacity life cycle, and it would take some time before the role of her public sector would evolve into similar to that of the East Asian Tigers (Korea, Singapore and Taiwan).

Apart from Hu and Mathews (2005, 2008), many scholars have observed the differences in the determinants of national innovative capacity between developed and developing economies (Liu and White, 2001; Radiosevic, 2002; Gu and Lundvall, 2006). Concerned about the relevance of the concept of national innovation system to a transitional economy such as China with wide disparity in the level of industrial and technological development across different regions (Tylecote, 2006), Li did not use the national innovative capacity framework of Furman et al. (2002), which was regarded as biased towards the developed economies. Instead, Li (2009) drew upon the literature streams on regional innovation system (Asheim and Isaksen, 1997) and integrated transitional economies with Tylecote's (2006) dual technology system to develop a framework for analysing the regional innovative capacity of a transitional economy. Li (2009) employed a stochastic frontier model first used by Aigner, Lovell and Schmidt (1977), as well as Meeusen and van den Broeck (1977) to investigate the factors contributing to the variation in innovative capacity across 30 regions in China during the 1998-2005 period. Li's (2009) results show that there is a distinction between invention patents and utility model patents as proxy for innovative output. While the former is primarily contributed by universities and PRIs, and is significantly affected by accumulated R&D stock, the latter tends to be generated by firms and is influenced by R&D expenditure.

More recent discussion in the literature on national innovative capacity pertains to its relationship with the 'network contagion effects' by Huang et al. (2011, p. 244). Building on the concept of 'international diffusion of embodied[17] and disembodied technology' (Rogers, 1983) and 'social network analysis' (Burt, 1987), Huang et al. (2011, p. 247-248) examined 42 countries between 1997 and 2002 and found the network position of the countries to be more significant than international interaction in explaining the variation in national innovative performance across the countries. The authors' results also show that 'disembodied technology diffusion influences national innovation capacity more significantly than does embodied technology diffusion' (Huang et al., 2011, p. 270).

Archibugi and Coco (2005) performed a comprehensive comparison of the different methods of measuring national technological capabilities adopted by World Economic Forum, UN Development Program, UN Industrial Development Organisation, and RAND Corporation. In particular, they questioned the reliability of using patent data at US Patent Trademark Office to measure national innovative capacity (Furman et al., 2002), as this could over-estimate the innovative capacity of the US since most countries would file their patents both in their home countries and in the US. They further highlighted the differences in patenting legislation among countries might mean that the current use of patent statistics to measure innovative capacity would favour those countries with restrictions on grouping multiple priorities in a single patent registration, and these countries would have to file more applications (such as Japan and South Korea) than would other countries without such restrictions (Archibugi and Coco, 2005, p. 183). The other issue is that 'patenting is itself a strategic choice' by a firm, so it is not a reliable measure of innovation (Spender and Grant, 1996, p. 7).

In the study of the regional innovative capacity of China, Li (2009) concurred with the findings of Archibugi and Coco (2005) on the weakness of using patents as indicators of innovation output. Li (2009) emphasised the significance of measuring innovation efficiency and analysing their determinants, bearing in mind that the

[17] Embodied technology refers to technology that is embodied in a particular product and capital good such that knowledge about its algorithms or processes may be acquired through reverse engineering. Disembodied technology refers to technology that is tacit in the minds of the personnel with experience and expertise (Shih and Chang, 2009).

interaction among different stakeholders of the innovation system is multi-dimensional and depends on the productive use of resources committed to R&D and the knowledge creation process. In the same vein, Wonglimpiyarat (2010), who conducted a separate study on the innovative capacity of Thailand, suggested finding alternative measures of innovation output and efficiency antecedents for future research.

According to Furman and Hayes (2004, p. 1351), the data on the national innovative capacities of the 29 OECD countries show that 'there is no universal recipe that enables follower countries to catch-up to leading innovator economies' and that it is essential to understand the 'unique circumstances that have led these countries to make substantial commitments to innovative capacity' as well as 'the common relationships that allow these countries' investments to bear fruit'. It is therefore important to investigate in depth the characteristics of a country - Singapore in this research- to identify both distinct and common conditions that would contribute to the current literature on innovative capacity.

To conclude, Section 2.2 has reviewed the recent development of the NIS (Nelson, 1993), endogenous growth theories (Romer, 1990), cluster theory (Porter, 1990, 2001) and national innovative capacity (Furman et al., 2002) in investigating the determinants that affect the innovative capacity, productivity growth rate and competitiveness at a national, sectoral, technological and cluster level. It has also reviewed the relevance and influence of the earlier theories of: Schumpeterian growth theory (Schumpeter, 1949), agglomeration theory (Marshall, 1890), evolutionary theory (Nelson and Winter, 1982; Metcalfe, 1998) and institutional theory (Langlois, 1989; North, 1990) across a range of disciplines covering industrial economics, science and technology management, business strategy and policy.

Although much research has been conducted in the literature streams of NIS and national innovative capacity, these streams have been criticised for assuming the centrality of the firm's role in performing innovation (Etzkowitz and Leydesdorff, 1996). In the late 1990s, Etzkowitz and Leydesdorff heralded the Triple Helix concept to emphasise the increasingly prominent role of the university in innovation.

An overview of the Triple Helix is provided in Appendix B3. Section 2.3 discusses its relevance in the literature on university-industry collaboration.

2.3 University-Industry Collaboration

2.3.1 Introduction

During the period from 1953 to 1963, the US government R&D fund swelled by 250%, and their accompanying budget for university research surged by 455%. In subsequent years, more changes continued to take place: funding was allocated to universities and government research institutes for basic research, particularly in life sciences by NIH (Graham and Diamond, 1997, p.34; Carlsson, Acs, Audretsch and Braunerhjelm, 2009). The Bayh-Dole Act was enacted to encourage US universities and PRIs to engage in commercialisation of federally funded research (Mowery, Nelson, Sampat and Ziedonis, 2004). The Small Business Innovation Research Programme was set up in the US to encourage technology-based entrepreneurship.

These considerable changes in national science and technology policies and programmes have brought about an increase in patenting of inventions by universities and PRIs, out-licensing of IP and transfer of technological knowledge to the industry (AUTM, 2010). Figure B-6 of Appendix B illustrates the growth in disclosures and patent filing activities in US universities, hospitals and research from 2000 to 2010. Figure B-7 of Appendix B depicts the rising trend in the gross license income that they have received for the same period (AUTM, 2010). According to Wong's (2011) study that was commissioned by the IP Academy of Singapore, the contribution to global patent output by Asia Pacific economies has increased from 29% in 2005 to 33% in 2009. Among the Asia Pacific economies, Singapore's share of patenting increased from 0.30 (at 8th rank) in 2005 to 0.32 (at 7th rank) in 2009, with patent output growth rate of 8%, particularly in the areas of infocommunication technologies and electronics. In recent years (2007-2009), A*STAR ranks as Singapore's top patent assignee organisation (Wong, 2011).

2.3.2 Growing Importance of the Entrepreneurial University

Apart from the US, a similar increase in the rate of technology commercialisation is observed in the universities and PRIs of other countries, such as Australia, Canada and Europe (Wright, Clarysse, Mustar and Lockett, 2007; Siegel, Veugelers and Wright, 2007). Figure B-8 of Appendix B illustrates the growth in patent filings by these countries between 2003 and 2007. The trend of growing government and business expenditure for academic R&D may be seen in the other developed and developing countries as well, as shown in the report from National Science Board, 2010, presented in Figure B-1 of Appendix B. Building on the coevolutionary theory, Etzkowitz and Leydesdorff (1996) heralded the Triple Helix concept to emphasise the increasingly prominent role of the university as 'equal partner' (Etzkowitz, 2011, p. 550) with the industry and government institutional spheres and fostering strong interaction among the spheres through 'circulation' (Etzkowitz and Zhou, 2007, p. 1) of intellectual capital among the spheres.

2.3.2.1 Triple Helix Concept

The role of the university is more pivotal than ever in the innovation process as it contributes to the industry as a source of intellectual and human capital for economic development. One of the many regional policy implications of the Triple Helix model is the rise of 'hybrid organisations' such as technology transfer offices (TTOs), academic and public research institutes, incubators, science parks and venture capitalists that facilitate the interaction of the three institutional spheres in generating technological innovations from the laboratories, and commercialising them into products and services (Etzkowitz and Zhou, 2007, p. 10)[18]. Apart from the Triple Helix model, the Mode-2 Knowledge Production model introduced by Michael Gibbons, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott, and Martin Trow in the publication *The New Production of Knowledge* (1994) has gained much attention in the literature on knowledge production.

[18] More details of the recent development and implications of the Triple Helix concept may be found in Appendix B3.

2.3.2.2 Mode-2 Knowledge Production Model

Michael et al. (1994) noted that the mode of knowledge production was changing rapidly from the current set of discipline-based research practices, which they referred to as Mode-1, to a new form of context-driven and multi-disciplinary research practice, described as Mode-2. Mode-1 describes the current research practices of universities and research institutes that are structured by *areas of technical specialisation or disciplines*, with the academic faculty members organised in *hierarchical forms* by their *areas of expertise,* and research *problems defined according to the interests of academics.* Mode-2 is distinguished from Mode-1 by *trans-disciplinary structures*, *flatter organisation forms* by projects with a greater sense of social responsibility, research problems defined according to *practical applications*, research teams of *heterogeneous* technical knowledge and review teams with more *diverse* interests and a *wider range* of considerations[19].

Scholars in these literature streams have argued that various factors point to the more prominent role that universities and PRIs are expected to play in transferring technology to the industry and creating economic impact. These factors include changes in national science and technology policies to promote academia as one of the three spheres in the triple academia-government-industry helix (Etzkowitz and Leydesdorff, 2000), and the development of educational and research institutions that become part of NIS to promote economic development (Mowery and Sampat, 2005a; Sharin, 2006; Lundvall, 2007). The shift from investigator-led research with autonomy in Mode-1 to context-driven research with social responsibility and reflexivity in Mode-2 Production of Knowledge tightened the linkage between public research and the industry (Michael et al., 1994). The industry, on the other hand, has increasingly turned to external knowledge including public research as they transition from a closed to an open form of innovation in response to competitive pressure and rapid technological changes (Chesbrough, 2006a; Vanhaverbeke, 2012).

[19] Please refer to Appendix B4 for detailed discussion on the various models of Knowledge Production, including the Linear Model (Bush, 1945), the Chain-Linked Model (Kline and Rosenberg, 1986) and Mode-2 Knowledge Production Model (Michael et al., 1994).

Rothaermel et al.'s (2007) review of the literature on university-industry collaboration found that 173 academic articles were published from 1981 to 2005. Although the authors found more than 70% of the publications atheoretical, they noted that one of the prevalent theories used by the remaining articles was the RBT (Wernerfelt, 1984; Barney, 1991). They categorised the literature into four strands: (a) entrepreneurial university, (b) TTO productivity, (c) new venture creation and (d) environment including innovation networks. In a similar vein, O'Shea et al. (2005) identified three research streams: (a) entrepreneur, (b) university and TTO, and (c) environment. Adapting from the works of Rothaermel et al. (2007) and O'Shea et al. (2005), the rest of this chapter delves into the four groups of factors affecting university-industry technology collaboration: (a) university and PRI-related organisation factors, (b) TTO organisation-related factors, (c) entrepreneur and new venture-related factors, and (d) environmental factors. However, before discussing these factors, the next section reviews the development of the RBT (Wernerfelt, 1984; Barney, 1991) and extends its examination of the other theories from strategic management (Knowledge-based Theory, Competence-based Theory and Dynamic Capabilities Theory) in order to enrich the understanding to build a robust conceptual model for this research.

2.3.3 Resource-based Theory

The RBT was introduced in the strategic management literature and seeks to explain why firms differ from one another and how their deployment of resources could contribute to the differences (Penrose, 1959). The theory operates based on the following principles that were empirically derived: (a) firms may be regarded as a bundle of productive resources, (b) firms differ in the extent to which they manage their resources in pursuing their business strategies and (c) these differences found among the firms are relatively stable over time (Foss, 1996). Drawing on the assumptions primarily from the economics literature that: (a) differences in firm performance are attributable to the differences in the resources that they possess and (b) firms engage in performance-enhancement behaviour, Foss asserted that these principles and assumptions provided the framework for the RBT. Wernerfelt (1984), on the other hand, used the analogy of the portfolio theory (Henderson, 1979):

> …where strong products in a firm's growth-share matrix supply weak ones with cash, again underscores the duality between the product and the resource perspectives on the firm (Wernerfelt, 1984, p. 178).

Wernerfelt contended that the firm performance required 'balance between exploitation of existing resources and development of new ones' (Wernerfelt, 1984, p. 178). Barney (1991, p. 101) built upon the framework of Wernerfelt (1984) and Penrose (1959) to argue that the strength of a firm is determined by the resources it has at its disposal. Barney further defined these resources as:

> …firm resources include all assets, capabilities, organisational processes, firm attributes, information, knowledge, etc., controlled by a firm that enable the firm to conceive of and implement strategies that improve its efficiency and effectiveness (Barney, 1991, p. 101).

While Barney uses resources and capabilities interchangeably in his definition, Grant (1991) makes a distinction between these two terms. Grant considers resources as inputs to the production process, such as machinery, employee skill set, budgets, IP, etc. A firm's capability, on the other hand, refers to its 'capacity for a team of resources to perform some task or activity' (Grant, 1991, p.119). Grant argues that 'while resources are the source of a firm's capabilities', it is not the resources, but the firm's capabilities that form the basis for the firm's competitive advantage (Grant, 1991, p. 119). Nevertheless, Grant concludes that both the resources and capabilities are central to a firm's strategy formulation and profitability.

In general, a firm's resources may be categorised into tangible and intangible resources (Grant, 1991). Tangible resources may include physical assets such as machinery, financial assets, budgets and IP. Intangible resources comprise organisational routines, employee skill set, creativity, knowledge and goodwill of the firm. Firms are endowed with different types of resources that could be deployed to allow them to implement their strategy and gain a competitive advantage in their market place. The RBT (Wernerfelt, 1984; Barney, 1991) states that in order to sustain competitive advantage, a firm's resources must be 'valuable, rare, imperfectly imitable and non-substitutable' (Barney, 1991, p. 117).

According to Barney (1991), resources are valuable when they enable the firms to maximise external opportunities, and minimise the threats that the firms face.

However, if the valuable resources are found in many competitors, then these resources may not be an effective source of competitive advantage. On the other hand, if the valuable resources are rare, the firms which possess these resources are more likely to create a competitive advantage over those which do not have any. As a rule of thumb, Barney (1991) postulates that when the number of companies that are endowed with one or more resources reaches the number required for a perfectly competitive market to exist, the valuable resources are no longer considered to be rare, and therefore are unlikely to sustain a competitive advantage.

Resources may be imperfectly imitable for various reasons. Barney explains that one possible reason may be due to the past events that may have taken place in the firm, such as the endowment of certain resources of prized locations or operating licenses by the regulating authorities that may make it difficult for the competitors to replicate the resources. He offers another reason as the lack of clarity about a resource that contributes to competitive advantage, resulting in poor imitation of this resource by the competitors. Finally, Barney articulates that there are resources that have a relatively high level of social complexity that make them hard to be duplicated by competitors, such as the organisational culture of strong teamwork and fostering innovation, or deeply-entrenched relationships with the suppliers, distributors or customers. Non-substitutable resources are those that have no equivalent in terms of strategic value in enabling a firm to achieve competitive advantage. If substitutes are easily available to competitors, then it is likely the firms owning the 'valuable, rare, imperfectly imitable and non-substitutable' resources will not be able to sustain their competitive advantage (Barney, 1991, p. 117).

Wernerfelt (1984, p. 173) highlights that the resources that enable their holders to enjoy the cost or revenue advantages over the other aspiring holders could create 'resource position barriers' that the current holders could enjoy. Despite the similarity with the entry barriers in traditional competitive strategy (Porter, 1980), Wernerfelt argues that the resource position barriers are distinct from entry barriers. While entry barriers describe the dynamics between incumbents and new entrants, resource position barriers depict the context among incumbents (Wernerfelt, 1984, p. 173).

In this review of the development of RBT literature, six main strands are found (Barney, Ketchen and Wright, 2011). The first strand pertains to links with the other concepts such as:

- Organisational capabilities, organisational learning and competitiveness to develop the Knowledge-based Theory (KBT) (Grant, 1996);
- 'Rivalry restraint, information asymmetry and commitment timing' as other sources of competitive advantage (Makadok, 2011, p. 1316);
- Schumpeter's endogenous growth theory (Schumpeter, 1934), Transaction Cost Economics (TCE) Theory (Williamson, 1985), Strategic Factors Market (Barney, 1986), Competence-based Theory (CBT) (Prahalad and Hamel, 1990), evolutionary theory of economics (Nelson and Winter, 1988) to develop the concept of dynamic capabilities (Teece, Pisano and Shuen, 1997; Teece, 2007).

We shall discuss in greater detail the development of KBT (Grant, 1996), CBT (Prahalad and Hamel, 1990), Dynamic Capabilities Theory (Teece et al., 1997) and TCE (Williamson, 1985) in Sections 2.3.4, 2.3.5, 2.3.6 and 2.4.1, respectively.

The second strand relates to the organisational routines of buying and building resources (Maritan and Peteraf, 2011; Sirmon, Hitt and Ireland, 2007). The third theme revolves around the theoretical micro-foundations of RBT (Kraaijenbrink, Spender and Groen, 2010; Foss, 2011; Coff and Kryscynski, 2011). The link between RBT and corporate social responsibility form the fourth theme (Hart, 1995; Hart and Dowell, 2011). The fifth theme involves the investigation of research methods used and their issues in the extant studies on RBT (Armstrong and Shimizu, 2007; Molloy, Chadwick, Ployhart and Golden, 2011). The final strand focuses on the link between firms' resources and financial performance (Rumelt, 1991; Combs and Ketchen, 1999; Crook, Ketchen, Combs and Todd, 2008). Although it is huge, it is largely inconclusive. Table 2-2 provides a summary of the significant contributions to, and recent development of, RBT.

Author	**Significant contributions to the Resource-based Theory**
Penrose, 1959	Introduced the concept that a firm's growth is dependent on its resources.

Author	Significant contributions to the Resource-based Theory
Wernerfelt, 1984	Asserted the importance of developing a firm's resources rather than its products and introduced the term, Resource-based View (RBV).
Barney, 1991	Defined the essential principles of RBV, defined resources as 'all assets, capabilities, organisational processes, firm attributes, information, knowledge, etc. controlled by a firm that enable the firm to conceive of and implement strategies that improve its efficiency and effectiveness' (p. 101). Presented that resources with the characteristics of being 'valuable, rare, imperfectly imitable and non-substitutable' have potential of competitive advantage (p. 117).
Grant, 1991	Distinguished between resources and capabilities. Defined resources as inputs to the production process, including tangible resources (e.g., machinery, budgets and IP) and intangible resources (e.g., employee skill set, organisational routines and creativity). Described capabilities as the capacity of resources for performance. Resources form the basis for capabilities, which, in turn, become the source for the firm's competitive advantage, and provide foundation for strategy.
Rumelt, 1991	Provided empirical findings to establish a direct relationship between the firm's resources and its performance.
Hart, 1995	Presented the natural-resource-based view (NRBV) of the firm as an offshoot of the RBT, to extend the model to include the natural environment in which the firm operates. The model argues the need for firm to develop 'strategic capabilities' in the form of 'pollution prevention, product stewardship, and sustainable development' to respond to environmental challenges (p. 992).
Grant, 1996	Integrated the concepts from RBT, organisational capabilities, organisational learning and competitive advantage to argue that knowledge was the most valuable strategic resource of the firm. Presented the Knowledge-based Theory as an offshoot of the RBT.
Teece, Pisano and Shuen, 1997	Built on the perspectives of RBT, Schumpeter's endogenous growth theory (Schumpeter, 1934), TCE theory (Williamson, 1985), strategic factors market (Barney, 1986) and evolutionary theory of economics (Nelson and Winter, 1988) to develop the concept of dynamic capabilities. Articulated the concept of dynamic capabilities as spin-off of the RBT and argued that the competitive advantage is the result of combining resources (also known as specific assets), organisational routines, as well as market and technological opportunities.

Author	Significant contributions to the Resource-based Theory
Oliver, 1997	Combined the concept of RBT with the institutional theory from the organisational theory to incorporate the institutional factors comprising both internal organisational cultural factors and external sociological conditions to explain variation in competitive advantage at firm level.
Combs and Ketchen, 1999	Conducted empirical research on 94 restaurant groups to reconcile the conflicting perspectives of minimising organisational costs (organisational economics) and developing organisational resources (RBV) and their impact on inter-organisation collaboration (franchises or joint-ventures) and performance (financial return and growth).
Lippman and Rumelt, 2003	Applied the perspectives of payment (also synonymous with firm revenue) and economic rent from economics to consider the scarcity of resources and provide the micro-foundations for the RBT in the field of strategy.
Winter, 2003	Defined the basic capabilities that allow a firm to survive for a short-term horizon with 'zero-order' enhanced capabilities as dynamic capabilities, and strategic capabilities with costly investment as higher-order capabilities (e.g., in NPD activity) (p. 992).
Foss and Ishikawa, 2007	Observed that the RBV was static, as it lacked explanation on processes for acquiring and building a firm's resources to enhance its competitive advantage. Linked the perspectives from entrepreneurship and capital theory (Simon, 1962) to develop a dynamic RBT.
Teece, 2007	Provided the micro-foundations for dynamic capabilities characterised by the capacity (e.g., entrepreneurial judgement of management) that the firm must possess to sense and seize opportunities before transitioning to sustain its competitive advantage and improve performance in an open economy.
Armstrong and Shimizu, 2007	Applied Bacharach's (1989) concept of 'utility' and 'falisifiability' to review the methodologies of 125 research studies on RBT (Armstrong and Shimizu, 2007, p. 963). Recommended the need for empirical research to consider and control for the moderating effect of external factors such as market timing and demand.
Sirmon, Hitt and Ireland, 2007	Proposed to integrate the management of firm resource in RBT with the perspective of value creation so as to develop an integrated resource management model to address the extant issue of lack of dynamism of RBT.

Author	Significant contributions to the Resource-based Theory
Crook, Ketchen, Combs and Todd, 2008.	Examined 125 studies covering 29,000 organisations to establish a significantly positive relationship between a firm's strategic resources and performance.
Kraaijenbrink, Spender and Groen, 2010	Reviewed and categorised the criticism of RBT into eight areas. Suggested future research to address some of the critical areas that pertain to the 'indeterminate nature of two of the RBV's basic concepts—resource and value—and the narrow conceptualisation of a firm's competitive advantage' (p. 349).
Barney, Ketchen and Wight, 2011	Reviewed the key publications on RBT from 1991 to 2011 and identified five literature strands: relationships with other theoretical concepts, organisational routines of resource building, theoretical micro-foundation, link with corporate social responsibility and research methods.
Hart and Dowell, 2011	Reviewed the development of environmental challenges, progress made in NRBV and sustainable enterprise for the past 15 years.
Makadok, 2011	Noted limitation of using only RBT to explain inter-firm variation in competitive advantage and suggested as future direction the integration with three other related perspectives: 'rivalry restraint, information asymmetry, and commitment timing' (p. 1316).
Wernerfelt, 2011	Articulated that the availability of current resources could contribute to unequal opportunities in the race for new resources. Proposed that firms should augment their portfolios of resources by leveraging their currently available resources.
Maritan and Peteraf, 2011	Suggested future research direction of RBT to reconcile the debate between Strategic Factor Markets theory (Barney, 1986) on resource acquisition and asset accumulation (Dierickx and Cool, 1989) to explain the development of heterogeneous resource portfolio at firm level.
Foss, N. 2011	Reviewed the development of the RBT micro-foundations and observed the use of disparate models ranging from the game theory to behavioural models with some level of abstraction. Recommended clear problem definition prior to future research projects on micro-foundation.
Molloy, Chadwick, Ployhart and Golden, 2011	Observed the issues of the measurement of 186 intangible resources in the recent RBT studies. Proposed 'a theory-driven multidisciplinary assessment process' to link RBT and the intangible resources (p. 1311).

Author	Significant contributions to the Resource-based Theory
Coff and Kryscynski, 2011	Highlighted that characteristics of resources as 'valuable, rare, imperfectly imitable and non-substitutable' in RBT (Barney, 1991, p. 117) make human resource management a challenge. Introduced the concept of strategic human resource management to provide the micro-foundation for recruiting, motivating and retaining the high-performing staff to maintain human capital as a source of competitive advantage.
Priem, Li and Carr, 2012	Highlighted the limitation of RBT and dynamic capabilities in determining the value of a firm's resources as the factors are exogenous to the firm. Proposed the application of demand-side research on consumer heterogeneity to address the issue and to complement RBT's focus on resource heterogeneity and dynamic capabilities.

Table 2-2: Summary of significant contributions to the Resource-based Theory

Since the publication by Penrose, there was general consensus among the research scholars in the management literature that the tacit and complex nature of organisational knowledge posed challenges in transferring knowledge outside the organisation (Penrose, 1959; Kogut and Zander, 1992, 1996). Drawing upon the RBT (Wernerfelt, 1984; Barney, 1991), Grant (1996) integrated the perspectives of organisational capabilities, organisational learning and competitive advantage to assert that knowledge is the most strategic and significant resource of the firm (Kogut and Zander, 1992). The next section reviews the development of the KBT and its contributions to research on innovation, management of technology, organisational learning and entrepreneurship.

2.3.4 Knowledge-based Theory

Knowledge is a critical resource for a firm's survival and growth (Prahalad and Hamel, 1990; Drucker, 1998), as it plays a significant role in introducing incremental or radical innovation to its products, processes and services in a timely manner to a market that is marked with growing uncertainty and competition (Nonaka, Toyama and Nagata, 2000). Knowledge is also essential for a firm's attempt to continuously review, re-organise itself and its capabilities, and re-invent its business model for strategic innovative responses to the changing business environment in which it operates (van Daal, de Haas and Weggeman, 1998; Chesbrough, 2007a).

Concept of Knowledge

Knowledge is different from data and information. While data may be in the form of characters and words, numerical values, images or sounds that are captured from some measurement process, information is the organisation of data into meaningful semantics for interpretation and inferences with the application of the relevant analysis tools and techniques (Hislop, 2005; Mitchell, 2000). Knowledge, on the other hand, involves the use of experience, cognitive reasoning, perspectives, comparison and analogies in the appreciation of information, pushing the frontier of understanding and awareness against the unknown (Nooteboom, 1996; Nonaka et al., 2000). As Nooteboom (1996) aptly put it,

> People possess cognitive structures for perception, interpretation and evaluation. Perception produces data for interpretation. Interpretation entails the production of meaning, which transforms data into information, by fitting it into a stock of knowledge. Understanding connects and transforms information into beliefs or claims of causal or deductive insight. Knowledge is a meaningfully ordered stock of information (interpreted data), and understanding, plus the ability to transform it into actions (skill), which yields performance. (Nooteboom, 1996, p. 8)

This implies that the same set of data and information may be perceived, interpreted and evaluated differently by individuals or collection of individuals who have their distinct patterns of thinking coloured by their prior experiences, training and mental models to produce diverse knowledge structures and content (Frappaolo, 1997; Davenport, De Long and Beers, 1998; Jorna, 2006).

At the individual level, knowledge is gained through the process of 'perception, interpretation and evaluation' (Nooteboom, 1996, p. 8). This can be illustrated by a staff member who learns on his or her job by observing the steps of a particular process, making sense of their significance, following the steps and deriving new insight on ways to enhance the effectiveness of the current process. At the organisational level, the collective knowledge of all the individuals forms the organisational knowledge (Nelson and Winter, 1982).

Types of Organisational Knowledge

In the literature on organisational knowledge, there have been many studies that postulate the different types of organisational knowledge and their characteristics.

The concept of organisational knowledge as scientific or practical was first highlighted by Hayek (1945) in Austrian Economics (Oguz, 2010). Subsequent typologies of organisational knowledge were postulated as objective versus experiential (Penrose, 1959), tacit versus explicit (Polanyi, 1966), un-codified versus codified (Boisot, 1995; Blacker, 1995), and concrete versus abstract forms of theoretical knowledge (Cijsouw and Jorna, 2003). Among these typologies, Polanyi's works of tacit and explicit knowledge have been most frequently cited by other researchers. According to Polanyi (1966) and Blacker (1995), organisational knowledge may be explicit or codified in the form of organisational policies, procedures, routines or work instructions.

However, there is another form of organisational knowledge that is implicit or tacit, residing in the minds of individual employees. As tacit knowledge is based on personal experience in a particular context, it is difficult to articulate and document formally for transmission from one individual to another within the same organisation, and even much more so from one organisation to another in the event of external technology acquisition (Grant, 1996). Nelson and Winter (1982) further developed the concept of tacit knowledge within the framework of organisation theory, drawing upon the concept of bounded rationality (Simon, 1947, 1991; March and Simon, 1993) to explain organisational behaviour (Oguz, 2011). Subsequent contributions to the literature on organisational knowledge involve the linkage of the concept of knowledge to the notion of organisational strategy (Itami, 1987; Nonaka and Takeuchi, 1995; Hussi, 2004). Itami (1987) highlighted tacit organisational knowledge as an invisible asset that is a source of competitive advantage. Nonaka and Takeuchi (1995) emphasised the imperative to convert tacit knowledge to explicit knowledge to develop new knowledge. Their work was a significant contribution to the management literature in postulating four mechanisms for conversion: (a) 'socialisation (from tacit knowledge to tacit knowledge)', (b) 'externalization (from tacit knowledge to explicit knowledge)', (3) 'combination (from explicit knowledge to explicit knowledge)' and (4) 'internalisation (from explicit knowledge to tacit knowledge)' (Nonaka, Toyama and Konno, 2000, p. 9).

Based on the works of earlier authors (Polanyi, 1966; Boisot, 1995; Cijsouw and Jorna, 2003; Nonaka and Takeuchi, 1995), Jorna (2006) developed a useful knowledge space (K-Space) model comprising three dimensions: tacit knowledge[20] (ranging from rough to detailed forms, theoretical knowledge[21] (ranging from abstract to concrete forms), and codified knowledge[22] (ranging from weak to strong forms). The author suggested the use of the K-Space model to take stock of the existing knowledge types within an organisation to identify its knowledge strengths and gaps for active conversion of its existing knowledge to useful and relevant forms (detailed, concrete and strong forms) along any of its three knowledge dimensions. The model may also be used to identify the need for external sources of knowledge to be acquired and assimilated into the organisation (Boisot, 1998; Jorna, 2006).

While the organisational knowledge literature focuses on the different knowledge types and how their characteristics impact organisational capabilities as critical resource, the literature on organisational learning sheds light on the capacity and process of an organisation to learn, in order to solve problems and make improvements (Argyris and Schon, 1978; Wheelwright and Clark, 1992; Argyris, 1999; Michael and Palandjian, 2004; Goffin and Koners, 2011). For example, Argyris (1999) highlighted the notions of espoused theory and theory-in-use to emphasise the advantages of double-loop learning over single-loop learning for more effective changes and improvements to take place in organisations. In the 1990s, there was growing interest among the researchers of organisational learning literature to look at how innovation could be enhanced (Bartoletti, Corso, Marine and Pellegrini, 2002), while the significance of knowledge and its management has gained increasing attention in the literature on product innovation (Corso, Martini, Paolucci and Pellegrini, 2001, p. 348; Hussi, 2004; Frenz and Ietto-Gillies, 2009).

Hussi (2004) purported that it was the dynamics between explicit and tacit knowledge that generated knowledge and fuelled innovation. Frenz and Ietto-Gillies

[20] Rough tacit knowledge refers to limited knowledge possessed by the source and makes it stickier or relatively harder for the recipient to comprehend than detailed knowledge.
[21] Theoretical knowledge varies according to the complexity of the causality relationship. The more complex is the causality relationship, the more abstract is the theoretical knowledge.
[22] Codified knowledge pertains to the ambiguity of the representation by symbols. The more ambiguous is the codified knowledge, the more weakly-coded is the knowledge.

(2009), on the other hand, examined how different knowledge sources impact innovation performance in the UK. In their study, Frenz and Ietto-Gillies postulated two primary sources of knowledge: internal knowledge and external knowledge, which are similar to the inbound and outbound innovation concepts discussed in the earlier works by Chesbrough (2003). They asserted that internal knowledge is generated by R&D performed within the business unit of an organisation. As for external knowledge, they expanded the possible range of sources to include knowledge being transferred from outside the business unit, such as the R&D of another unit within the same organisation, the R&D of another organisation through possible mechanisms of inward licensing of external technology or contract R&D services of another organisation, or the R&D collaboration with another organisation. They compared the impact on innovation performance of the recipient organisation along three dimensions: (a) orientation from the transfer (internal versus external), (b) specificity of the knowledge transferred (full versus limited appropriability of underlying IP), and (c) degree of ease of knowledge transfer determined by three other sub-dimensions: the characteristics of the knowledge (tacit versus explicit) (Polanyi, 1966), characteristics of the knowledge recipient (Foss and Pedersen, 2002), and characteristics of the knowledge source (Cohen and Levinthal, 1990; Hedlund and Rolander, 1990; Zanfei, 2000; Forsgren et al., 2005).

Based on the data of 679 firms collected from the UK Community Innovation Survey, Frenz and Ietto-Gillies (2009) found that, except for joint R&D collaboration, all sources of knowledge had significant impact on the innovation performance of the recipient organisation, measured by the revenue from sale of products or services embodying the innovation. Their results indicated that the collaborative effort involved in joint R&D was not as effective as the other sources of knowledge in improving innovation performance. On the other hand, international knowledge transfer within the same firm was positively associated with the innovation performance. This could be attributed to a high degree of transferability and appropriability that was found within the same organisation, leading to a high level of cooperative effort in transferring innovative knowledge and insight from different NIS (Frenz and Ietto-Gillies, 2009). Other studies examined the relationship among knowledge, innovation and performance. For example, firm knowledge was reported to interact with industry dynamism and

firm-level innovation to influence performance, based on a survey of 845 Canadian manufacturing firms by Thornhill (2006).

Organisational Knowledge for Fuelling Innovation as a Business Strategy

Deriving similar insights from the TCE theory (Coase, 1937; Williamson, 1975, 1985), the KBT postulates that the existence of a firm arises from its ability to organise and execute its knowledge-intensive routines more cost-effectively than market transactions (Conner and Prahalad, 1996; Foss, 1996; Grant, 1996; Madhok, 1996; Nickerson and Zenger, 2004). According to KBT, firms that are able to integrate diverse areas of knowledge are well-positioned to exploit their competitive advantage.

Although the KBT has a relatively narrow focus on knowledge as a strategic resource compared to the RBT from which it originated, the current literature review of KBT shows that it has diverse strands. Some authors dwell on the efficiency of knowledge transfer (Winter and Szulanski, 2001; Zahra, van de Velde and Larraneta, 2007). In particular, Zahra et al. (2007, p. 574) defined knowledge as 'intellectual capital and property as well as the organisational skills used to capture and exploit them'. The authors applied KBT in the field of entrepreneurship to define the concept of 'knowledge conversion capability' (KCC) and its three components: 'conceptualisation and visioning of applications of that knowledge', 'configuration and design of potential products and other applications', as well as 'embodiment and integration of knowledge into products' (Zahra et al., 2007, p. 569). Their study of 78 university spin-offs (USO) and 91 corporate spin-offs (CSO) indicated that KCC was significant in explaining the variation in performance between USO and CSO in creating value from the commercialisation of their inventions into products and services.

Other contributions to KBT focus on the firms' ability to develop new knowledge (Kogut and Zander, 1992; Nahapiet and Ghoshal, 1998). Kogut and Zander (1992, p. 384) posited that 'combinative capabilities' as the firm's ability to exploit knowledge of diverse types and sources that are significant for creating value for the firm. Nahapiet and Ghoshal (1998), on the other hand, extended the KBT by integrating it with the theory of social capital (Bourdieu, 1986; Coleman, 1988).

Building on the structural, cognitive and relational dimensions of a firm's social capital, Nahapiet and Ghoshal (1998) proposed four conditions for the creation of knowledge, also referred to as intellectual capital: (a) ability to access the parties for knowledge, (b) expectation of value from knowledge, (c) incentives for knowledge synthesis and (d) ability of knowledge synthesis.

There was discussion on the expertise and experience of the knowledge workers participating in the creation and exchange of knowledge (Kogut and Zander, 1992; Nickerson and Zenger, 2004). Some authors (Kogut and Zander, 1992) are of the view that firms provide expedient mechanisms for knowledge-intensive processes among professionals of similar functional experience and expertise. Others (Nickerson and Zenger, 2004) argue that firms provide an efficient environment for the creation of combinative knowledge from knowledge workers of diverse disciplines and expertise.

In the KBT literature, there was debate over why, how and when individuals could be more efficient in organising and coordinating knowledge exchanges within the setting of a firm than in the context of a market. Kogut and Zander (1992, p. 390) attributed the superior coordination performance of firms over the market to the characteristics of firms of being 'communities within which varieties of functional expertise can be communicated and combined by a common language and organising principles'. However, some critics (Foss, 1996) disputed that such coordination of knowledge-intensive processes could well take place in the marketplace and demanded further clarity on the characteristics of the knowledge, knowledge workers and knowledge processes for KBT to be meaningful and relevant. Other critics imputed the dispute to the ambiguity over the concepts of knowledge, capabilities, competences and the units of analysis (Felin and Foss, 2005; Felin and Hesterly, 2007; Nahapiet and Ghoshal, 1998). While Felin and Foss (2005) adopted analysis at an individual level, Nahapiet and Ghoshal (1998) employed a firm-level approach.

The conflicting views of KBT and lack of empirical studies have attracted much criticism and been likened to 'a theoretical patchwork' rather than 'a solid body of theoretical knowledge' (Kaplan, Schenkel, von Krogh and Weber, 2001, p. 3). To

reconcile the conflicting views, Hakanson (2010) helped set directions for future research by extending KBT with Holzner's (1968) dimension of epistemic community:

> …groups of people mastering the theories, codes, and tools of a common practice regardless of their geographical location and the intensity of mutual contact that they may maintain. (Hakanson, 2010, p. 1809)

Hakanson (2010, p. 1801) argued that the new dimension of a firm as an 'epistemic community' in KBT will enrich the theory by considering the significance of intellectual background of knowledge workers, in addition to the tacit nature of their knowledge (Polanyi, 1966; Nelson and Winter, 1982).

More recent contributions include linkages of KBT with other perspectives, such as cluster theory, to examine inter-firm performance variation within a cluster (McCann and Folta, 2011) and 'evolutionary anthropology, social psychology, and experimental economics' to introduce motivational and cognitive dimensions (Foss, 2011, p. 1422).

A summary of the current review of the KBT literature is provided in Table 2-3.

Author	**Significant contributions to the Knowledge-based Theory**
Kogut and Zander, 1992	Posited that '[c]omplex organisations exist as communities within which varieties of functional expertise can be communicated and combined by a common language and organising principles' (p. 390). Highlighted 'combinative capabilities' as the firm's ability to exploit knowledge of diverse types and sources that are significant for creating value for the firm (p. 384).
Kogut and Zander, 1996	Developed the perspective that firms are 'social community specialising in the speed and efficiency in the creation and transfer of knowledge' (p. 503). This perspective of value creation contrasted with that of value appropriation postulated by the predominant TCE theory (Williamson, 1975) of that time.
Grant, 1996	Integrated the concepts from RBT, organisational capabilities, organisational learning and competitive advantage to argue that knowledge as the most valuable strategic resource of the firm. Presented the KBT as an offshoot of the RBT.
Conner and Prahalad, 1996	Attempted to reconcile the perspectives of bounded rationality, TCE and opportunistic behaviour (Coase, 1937; Simon, 1951; Williamson, 1975) with KBT using the notion of employment

Author	Significant contributions to the Knowledge-based Theory
	contracts for the organisation.
Foss, 1996	Critiqued KBT by disputing Kogut and Zander's (1996) explanation of firms' efficiency in coordinating knowledge over market place as 'a distinctly non-economic mode of explanation' (p. 519). Observed Conner and Prahalad's (1996) inadequate characterisation of the firm.
Madhok, 1996	Highlighted the limitation of TCE theory and its opportunistic perspective (Williamson, 1985), as it ignored the firm as 'bundle of knowledge' (p.577). Applied the perspective of the organisational capability to highlight the applicability of KBT in organisational scholarship.
Nahapiet and Ghoshal, 1998	Extended the KBT by introducing the theory of social capital to lay down four conditions for the creation of knowledge, also referred to as intellectual capital: ability to access the parties for knowledge, expectation of value from knowledge, incentives for knowledge synthesis and ability of knowledge synthesis.
Kaplan, Schenkel, von Krogh and Weber, 2001	Integrated KBT with past contributions to set future research directions to explain inter-firm performance variation in the field of strategic management.
Winter and Szulanski, 2001	Presented the replication strategy as an efficient means of exploiting and transferring knowledge within an organisation.
Nickerson and Zenger, 2004	Argued that firms provide an efficient environment for creation of combinative knowledge from knowledge workers of diverse disciplines and expertise.
Felin and Foss, 2005	Reviewed the field of strategic organisation and highlighted issues (such as lack of clear definition of organisational routines and capabilities) that are relevant for practitioners, paucity of empirical research, and ambiguity in units of analysis.
Zahra, van de Velde, E. and Larraneta, 2007	Showed the relevance of KBT in the field of entrepreneurship. Based on the KBT, Zahra et al. (2007, p. 569) defined the concept of 'knowledge conversion capability' (KCC) and its three components: 'conceptualisation and visioning of applications of that knowledge', 'configuration and design of potential products and other applications', and 'embodiment and integration of knowledge into products'. Their study of 78 university spin-offs (USO) and 91 corporate spin-offs (CSO) indicated that KCC was significant in explaining the variation in performance between USO and CSO in creating value from the commercialisation of their inventions into products and services.

Author	Significant contributions to the Knowledge-based Theory
Felin and Hesterley, 2007	Posited that organisation knowledge resides with individual knowledge workers, and advocated using 'heterogeneous individuals as an alternative explanation in explaining new value and knowledge creation' (p. 214).
Ha°kanson, 2010	Set directions for future research by extending KBT with Holzner's (1968) dimension of epistemic community, 'groups of people mastering the theories, codes, and tools of a common practice regardless of their geographical location and the intensity of mutual contact that they may maintain' (p. 1809). Argued that the new dimension of a firm as an 'epistemic community' in KBT will enrich the theory by considering the significance of intellectual background of knowledge workers, in addition to the tacit nature of their knowledge (p. 1801).
McCann and Folta, 2011	Applied knowledge-based view (Grant, 1996) to examine the performance of biotechnology firms within a geographical cluster. Found that certain firm characteristics such as age and knowledge stocks could affect performance among the clustered firms.
Foss, 2011	Built on the perspectives from 'evolutionary anthropology, social psychology, and experimental economics' to introduce the dimensions of motivation and cognitive thinking to 'knowledge-based value creation' (p. 1422).

Table 2-3: Summary of significant contributions to the Knowledge-based Theory

From the above literature review, it is apparent that KBT has its current limitations in theoretical foundation and empirical support.

The literature on organisational knowledge, learning, and innovation tend to focus on the characteristics of knowledge, knowledge sources, knowledge recipients and the knowledge processes, as well as on how they impact the innovation performance of firms. However, there is limited coverage on academic and government-funded research centres as knowledge sources and how their knowledge characteristics and transfer process could influence organisational knowledge, learning and innovation. Thus far, most of the studies on the topic of academic and government-funded research centres as knowledge sources are found in the literature on NIS discussed in Section 2.2. For example, Agrawal (2006) argued that much knowledge associated with university research was neither codified nor tacit, but latent. As university inventors held the key to latent

knowledge, Agrawal's study of 124 license agreements associated with MIT inventions demonstrated that engaging inventors for knowledge acquisition would positively affect commercialisation performance. Given the scarcity of studies in this area in the extant literature on organisational knowledge and learning, this research contributes to the literature gap by focusing on how external knowledge source (in the form of R&D from government-funded research centres) and in-house R&D could moderate the relationship between a firm's PAET and its innovative outcome in the form of product or process innovation. Further, this research examines how internal R&D can moderate the relationship between innovative outcome and commercial adoption performance, drawing upon RBT (Wernerfelt, 1984; Barney, 1991) and KBT (Nonaka, 1994; Grant, 1996).

In addition to spinning off KBT, RBT has also emphasised the significance of competence in establishing the relationship between a firm's resources and its competitive advantage (Wernerfelt, 1984; Barney, 1991). The next section reviews the development of the Competence-based Theory.

2.3.5 Competence-based Theory

The origin of the Competence-based Theory (CBT) may be traced to the groundbreaking study by Chandler (1962) on Dupont[23] and the contingency theory, which postulated that there was no best approach for managing an organisation. The term 'distinctive competence' was also heralded by Andrews in the 1960s, which was later mentioned in his publication (Andrews, 1971) of *The Concept of Corporate Strategy*.

The optimal strategy that an organisation should choose would be contingent upon both internal factors (e.g., resources) and external circumstances (e.g., the product market). According to Penrose (1959) and Chandler (1977), firms concentrate on accumulating and exploiting resources, and gaining competences, which involve the ability to scrutinise the resources that should be acquired by the firm. Based on the core tenets of RBT, Prahalad and Hamel (1990) developed the concept of core

[23] Chandler (1962) established the relationship among ownership of certain resources, product/ market choices and organisational decisions.

competence, while Sanchez and Heene (1996) posited the competence-based strategy for competition. Prahalad and Hamel (1990, p. 81) defined core competencies as 'the collective learning in the organisation, especially how to coordinate diverse production skills and integrate multiple streams of technologies' and 'communication, involvement, and a deep commitment working across organisation boundaries'. They highlighted that, while core competencies are 'enhanced as they are applied and shared' unlike physical assets which depreciate in value with the passage of time, they must be cultivated and protected just like knowledge in order to be exploited into products and services for the delivery of value[24] (Prahalad and Hamel, 1990, p. 81).

Since the publication by Prahalad and Hamel (1990), there has been much development focusing on the following aspects:

- Market dynamics ranging from low degree of dynamism (Siggelkow, 2001) through moderate to high level of hypercompetitive markets (Bingham and Eisenhardt, 2010)
- Organisational boundaries (Gilbert, 2006; Martin and Eisenhardt, 2010)
- Comparison with TCE theory (Foss, 1993; Hodgson, 1998)

[24] Corporate strategy, which refers to the strategy of a firm with multiple strategic business units, arose from the concept of creating shareholder value. The central issue it addressed was how to justify the existence of a diversified firm, that is, how a firm could create shareholder value at the corporate level. Influenced by the Efficient Market Hypothesis (Fama, 1970), corporate managers regarded their firms as portfolios of strategic business units and performed efficient allocation of capital and resources to the needs of the business units to maximise shareholder value. However, there was much concern among the academics that many of these corporate strategies were destroying, rather than creating, shareholder value. In response to these observations, Prahalad and Hamel (1990) studied the business strategies of the Japanese enterprises which consistently outperformed the US enterprises in the 1970s and 1980s. Prahalad and Hamel (1990) found that the critical success factors of the Japanese firms were neither high R&D expenditures nor anti-trust laws in the US. Rather, the successes of the Japanese firms could be attributed to their concept of integrated corporation that was characterised by the ability of the top management to effectively coordinate production skills and enterprise-wide technologies, and seamlessly collaborate across organisational boundaries, thereby enabling the individual business units to offer new products and services to rapidly changing markets. On the other hand, they observed the portfolio approach of strategic business units that US firms adopted as corporate strategy was hindering cross-organisational collaboration with their underpinning processes of individual business autonomy. Prahalad and Hamel's (1990) new approach of 'core competence' to corporate strategy resonated with Porter's (1987) *From Competitive Advantage to Corporate Strategy,* where he delineates this approach as skill-transfer and activity-sharing among business units. Unfortunately, Prahalad and Hamel's (1990) concept of 'core competence' tends to be confused with Andrews' (1971) perspective of 'distinctive competence', thereby diluting the power of the insights of Prahalad and Hamel.

- Linkages with other concepts such as organisational learning and entrepreneurship (Freiling, Gersch and Goeke, 2008; Bingham, Eisenhardt and Davis, 2009)
- Integration with boundary research concepts (Santos and Eisenhardt, 2009) on efficiency (Jacobides and Hitt, 2005), power (Mayer and Nickerson, 2005) and identity (Weick, 1995; Bogner and Barr, 2000)

Table 2-4 provides a summary of the significant contributions to CBT.

Author	**Significant contributions to the Competence-based Theory**
Prahalad and Hamel, 1990	Drew upon the contingency theory to develop the Competence-based Theory that articulated that firms must gain core competence to successfully compete. Defined core competencies as 'the collective learning in the organisation, especially how to coordinate diverse production skills and integrate multiple streams of technologies' (p. 81).
Foss, 1993	Contrasted the transaction cost theory (Coase, 1937) and the competence-based model based on evolutionary theory. He observed that the competence-based model which regarded the firm as a centre of knowledge gave more insight to the sources of competitive advantage.
Weick, 1995	Postulated that organisation managers make sense of their environments through cognitive models which are abstract representations of events. These cognitive models are important for guiding managerial actions in formulating strategies in a competitive market.
Hodgson, 1997	Built on the research on organisational learning and cultural diffusion to emphasise the significance of CBT over the transaction cost theory in accounting for the existence and performance of the firm.
Sanchez and Heene, 1996	Developed a framework of open system to depict the nature of a firm comprising shared system of beliefs among individuals that is structured to question assumption and governed by management processes to identify new opportunities to create value in a competence-based competition.
Bogner and Barr, 2000	Built on the cognitive model of Weick (1995) and asserted that firms operating in hypercompetitive markets need adaptive sense making process to sustain their performance. The turbulent changes would make it difficult for resources or competencies that have been developed to spillover across the industry. Hence, to be successful in hypercompetitive markets,

Author	Significant contributions to the Competence-based Theory
	Bogner and Barr recommended that organisation managers should adopt the approach of experimental action (Huber, 1991).
Siggelkow, 2001	Posited firms as '*system* of interconnected choices: choices with respect to activities, policies and organisational structures, capabilities, and resource' and that firms with a good fit of internal choices could enhance competencies and competitive advantage (p. 838). However, the tight linkages could also reduce the responsiveness of the firms to external environmental choices.
Helfat and Peteraf, 2003	Asserted that the fundamental concept of dynamic capabilities was concerned about the change from one competency to another.
Sanchez, 2004	Proposed that ongoing opportunities and threats in the external environment would require the firm to consider five modes of competences that vary in flexibility of the firm's choices in its response to the changes.
Gilbert, 2006	Observed that firms should respond to discontinuous change by nurturing competencies that 'meet the requirements of multiple, simultaneously inconsistent contexts' (p. 164).
Freiling, Gersch and Goeke, 2008	Based on the framework of Lakatos (1970), the organisational theory and entrepreneurship research, Freiling et al. provided a re-conceptualisation of CBT, emphasising the 'role of entrepreneurship, dynamic capabilities and competences' (p. 1144).
Bingham, Eisenhardt and Davis, 2009	Studied six technology-based entrepreneurial firms from three countries of different cultural settings. Found support for the strategic value of competencies in the industry, and significant relationships between 'experience, cognition, and organisational action' (p. ii).
Bingham and Eisenhardt, 2010	Articulated that it is not only the resources, but the relationships among the resources and competences that are significant in sustaining competitive advantage.
Martin and Eisenhardt 2010	Contributed that collaboration across strategic business units in multi-business organisations had significant effect on firm performance.

Table 2-4: Summary of significant contributions to the Competence-based Theory

More recently, Freiling et al. (2008) provided a re-conceptualisation of CBT. Based on the framework of Lakatos (1970), the organisational theory and entrepreneurship

research, Freiling et al. reviewed the current issues of the CBT and provided guidance for future research directions.

Apart from CBT, the Dynamic Capabilities Theory is an important theory that was also developed on RBT. The next section reviews the development of the Dynamic Capabilities Theory.

2.3.6 Dynamic Capabilities Theory

The concept of dynamic capabilities was first introduced by Teece et al. (1997). Building on the perspectives of RBT (Wernerfelt, 1984), Schumpeter's endogenous growth theory (Schumpeter, 1934), TCE theory (Williamson, 1985), strategic factors market (Barney, 1986) and evolutionary theory of economics (Nelson and Winter, 1988), Teece et al. (1997, p. 516) defined dynamic capabilities as 'the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments'. Dynamic capabilities therefore could form the basis of a firm's competitive advantage.

Pursuant to the publication by Teece et al. (1997), more than 1,500 articles have been published with reference to the concept of dynamic capabilities across diverse disciplines such as strategic management (Teece, 2007), entrepreneurship (Newey and Zahra, 2009), human resource management (Thompson, 2007; Wang, Jaw and Tsai, 2012), information management (Lim, Stratopoulos and Wirjanto, 2011), international management (Fang and Zou, 2009; Chen, Lee and Lay, 2009), marketing management (Cao, 2011) and operation management (Fixson, 2005; O'Connor, 2008). Since the conceptualisation of dynamic capabilities, several authors have proposed alternative definitions emphasising different aspects such as the antecedents (Teece, Pisano and Shuen, 1997), role (Eisenhardt and Martin, 2000), learning processes (Zollo and Winter, 2002), characteristics (Winter, 2003), outcomes of dynamic capabilities (Zahra, Sapienza and Davidsson, 2006), intent (Helfat, Finkelstein, Mitchell, Peteraf, Singh, Teece and Winter, 2007) and the multiple dimensions (Barreto, 2010) of dynamic capabilities. Table 2-5 provides a summary of these definitions.

Authors	Alternative Definitions of Dynamic Capabilities
Teece, Pisano and Shuen, 1997	'The firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments' (p. 516).
Eisenhardt and Martin, 2000	'The firm's processes that use resources – specifically the processes to integrate, reconfigure, gain and release resources – to match or even create market change. Dynamic capabilities thus are the organisational and strategic routines by which firms achieve new resource configurations as market emerge, collide, split, evolve and die' (p. 1107).
Zollo and Winter, 2002	'A dynamic capability is a learned and stable pattern of collective activity through which the organisation systematically generates and modifies its operating routines in pursuit of improved effectiveness' (p. 340).
Winter, 2003	'Those (capabilities) that operate to extend, modify or create ordinary capabilities' (p. 991).
Zahra, Sapienza and Davidsson, 2006	'The abilities to reconfigure a firm's resources and routines in the manner envisioned and deemed appropriate by its principal decision maker(s)' (p. 918).
Helfat, Finkelstein, Mitchell, Peteraf, Singh, Teece and Winter, 2007	'The capacity of an organisation to purposefully create, extend or modify its resource base' (p. 4).
Barreto, 2010	'A dynamic capability is the firm's potential to systematically solve problems, formed by its propensity to sense opportunities and threats, to make timely and market-oriented decisions, and to change its resource base' (p. 271).

Table 2-5: Definitions of Dynamic Capabilities

From the multiplicity of definitions listed in Table 2-5, it is apparent that there is little agreement on the nature and characteristics of dynamic capabilities. From the current literature review, there was evidence of considerable discussion on these distinct aspects of dynamic capabilities.

Role

There has been a proliferation of studies delineating the role of dynamic capabilities in changing the critical components of the organisation system. However, these components which are the locus of change have been interpreted rather differently

among the authors. For example, some authors refer to the locus of change as 'organisational routines' (Nelson and Winter, 2002, p. 31; Zahra et al., 2006, p. 922), 'strategic routines' and 'operating routines' (Zollo and Winter, 2002, p. 339; Eisenhardt and Martin, 2000, p. 1107), while others refer to them as 'resources' (Teece et al., 1997, p. 510), capacity (Helfat et al., 2007) and 'capability' (Winter, 2003, p. 991). To develop their arguments, some authors justified the need for a hierarchy to organise multiple levels of capabilities ranging from the lower level (e.g., 'substantive capabilities' coined by Zahra et al., 2006, p. 917) to the higher level (e.g., 'third-order' dynamic capabilities used by Wang and Ahmed, 2007, p. 36).

Antecedents

There has been interest among the scholars of management, strategy and entrepreneurship on the antecedents of dynamic capabilities (Karim, 2006; Rothaermel and Hess, 2007; Teece, 2007; Danneels, 2008). In particular, Danneels' (2008) study of 77 manufacturing enterprises in 2000 and 2004 investigated the antecedents for dynamic capabilities for marketing R&D functions. He found that an organisational culture that was open to new ideas and experimentation, tolerant of mistakes, willing to give up short-term revenue for longer-term growth were significant conditions for the existence of dynamic capability. Rothaermel and Hess (2007), on the other hand, conducted empirical research on 81 firms from the global pharmaceutical industry during the 1980-2001 period, reporting that the antecedents of dynamic capabilities could exist at multiple levels: individual employee, organisation and cluster network.

Market dynamism

Regarding the external context for which the concept of dynamic capabilities is applicable, various lines of arguments have emerged. Some researchers (Teece et al., 1997; Teece, 2007) advocated the significance of the concept for a firm operating in a highly volatile environment, such as in markets where the technological, regulatory and economic factors are highly uncertain. Other scholars (Eisenhardt and Martin, 2000) contended that the perspective of dynamic capabilities should not be limited to highly volatile environment, but should also be relevant to moderately volatile environment. Meanwhile Zollo and Winter (2002) and Zahra et al. (2006)

argued that market dynamism was not a necessary condition for the development of dynamic capabilities.

Outcomes –Dynamic Capabilities and Organisational Performance

There are opposing views on the possible effect of dynamic capabilities on a firm's performance. Some researchers asserted that dynamic capabilities would necessarily improve a firm's performance by enhancing its responsiveness and agility (Helfat, 1997; Teece et al., 1997; Zollo and Winter, 2002, Teece, 2007). Other authors were sceptical of assuming a direct relationship between dynamic capabilities and organisation performance. As Eisenhardt and Martin (2000) put it, dynamic capabilities may have potential to positively influence organisational outcome, but it may not necessarily lead to superior organisational outcome. Zahra et al. (2006) attributed the disagreement in part to the tautological definition of dynamic capabilities, which are described in terms of their outcome, such that dynamic capabilities are not so if they do not produce good performance. Zahra et al. (2006. p. 943) contended that the effect of dynamic capabilities on a firm's performance should be indirect, as it would be contingent upon other factors such as the firm's 'substantive capabilities' and the 'quality of the organisation's knowledge base'. Danneels (2012, p. 42) studied the effect of second-order competences on a firm's profitability performance, and observed that 'marketing competence on ROA was positive under stable and moderate competitive conditions, whereas the effect of R&D competence on ROA was positive under volatile competitive conditions'.

Learning processes

Different processes based on various theoretical models have been proposed for the nurturing of dynamic capabilities. Eisenhardt and Martin (2000) built on the theory of economic evolution to describe the processes as recursive learning from experience and past mistakes, focusing on selection for markets of high volatility and on variation for markets of medium volatility. Zahra et al. (2006), on the other hand, built on the absorptive capacity theory (Cohen and Levinthal, 1990) and the behavioural theories of the firm (March and Simon, 1993) to advocate that the development of dynamic capabilities would require learning by 'trial and error',

'improvisation' and 'experimentation' (Zahra et al., 2006, p. 932). Zollo and Winter's (2002, pp. 341-342) proposition was similar, with the additional elements of 'knowledge accumulation', 'knowledge articulation' and 'knowledge codification' in reference to organisation learning (Argyris and Schon, 1978; Levinthal and March, 1993). Table 2-6 provides a summary of the significant contributions to the literature on dynamic capabilities.

Authors	**Significant Contributions to Dynamic Capabilities**
Teece, Pisano and Shuen, 1997	Built on the perspectives of RBT, Schumpeter's endogenous growth theory (Schumpeter, 1934), TCE theory (Williamson, 1985), strategic factors market (Barney, 1986) and evolutionary theory (Nelson and Winter, 1988) to develop the concept of dynamic capabilities. Articulated the concept of dynamic capabilities as spin-off of the RBT and argued that a firm's competitive advantage is the result of combining resources (also known as specific assets), organisational routines, as well as market and technological opportunities.
Eisenhardt and Martin, 2000	Built on organisational theory and RBT and drew on previous empirical studies to provide a more theoretical perspective to dynamic capabilities. Articulated that while dynamic capabilities were firm-specific, there were common underlying learning processes across firms. Asserted that markets of different volatility would require dynamic capabilities of different kinds, although dynamic capabilities alone were not sufficient for sustaining a firm's competitive advantage.
Galunic and Eisenhardt, 2001	Conducted an empirical study on a Fortune 100 company to investigate the characteristics of dynamic capabilities. Adopted the view of organisation as a 'dynamic community' and studied how its dynamic capabilities could 'reconfigure resources' to develop 'architectural innovation at the corporate level' (p. 1229).
Zollo and Winter, 2002	Postulated the relationships among dynamic capabilities, organisational routines and learning processes: 'knowledge accumulation', 'knowledge articulation', and 'knowledge codification' (p. 340).
Helfat and Peteraf, 2003	Asserted that the fundamental concept of dynamic capabilities was concerned with the change from one competency to another.
Winter, 2003	Defined the basic capabilities that allow a firm to survive for a short time horizon as 'zero-order', enhanced capabilities as dynamic capabilities, and strategic capabilities with costly investment as higher-order capabilities (e.g., in NPD activity).

Authors	Significant Contributions to Dynamic Capabilities
Karim, 2006	Built on the research of organisational system, structure and dynamic capabilities to compare the modes and outcomes of reconfiguration between internally developed business units and acquired business units. Found that reconfiguration was regarded as beneficial by the organisations.
Zahra, Sapienza and Davidsson, 2006	Integrated the learning theory through absorptive capacity (Cohen and Levinthal, 1990; Zahra and George, 2002) and behavioural theories of the firm (March and Simon, 1993) with the perspective of dynamic capabilities to develop a model that distinguishes dynamic capabilities from substantive capabilities, clarifies their antecedents and outcomes, and contrasts their development between new and established firms.
Helfat, Finkelstein, Mitchell, Peteraf, Singh, Teece, and Winter, 2007	Expanded the original definition of dynamic capabilities by Teece et al. (1997) to emphasise not only 'the ability to perform a task in at least a minimally acceptable manner' but also its recurring characteristic (p. 4).
Rothaermel and Hess, 2007	Studied 81 firms from the global pharmaceutical industry in the 1980-2001 period and found that the antecedents of dynamic capabilities could exist at multiple levels: individual employee, organisation and cluster network.
Teece, 2007	Provided the micro-foundations for dynamic capabilities characterised by the capacity (e.g., entrepreneurial judgement of management) that the firm must possess to sense and seize opportunities before transforming to sustain its competitive advantage and improve its performance in an open economy.
Wang and Ahmed, 2007	Advocated a hierarchy of resources and capabilities forming the zero- and first-order level, core capabilities as the second-order and dynamic capabilities as the third-order. Articulated the role of dynamic capabilities in the 'adaptation, renewal, reconfiguration and re-creation of resources, capabilities and core capabilities responding to external changes' (p. 43). Proposed three component factors for dynamic capabilities: 'adaptive capability', 'absorptive capability' and 'innovative capability' (p. 43).
Danneels, 2008	Studied 77 manufacturing enterprises in 2000 and 2004 to investigate the antecedents for dynamic capabilities for marketing R&D functions. Found that an organisational culture that was open to new ideas and experimentation, tolerant of mistakes, willing to give up short-term revenue for longer-term growth comprised significant conditions for the existence of dynamic capability.

Authors	Significant Contributions to Dynamic Capabilities
O'Connor, 2008	Applied systems theory, Dynamic Capabilities Theory and the innovation literature to propose a framework for developing Major Innovation dynamic capability. The framework comprised seven elements of the management system.
Barreto, 2010	Reviewed the literature on dynamic capabilities and proposed a 'composite' construct with four dimensions: 'propensity to change the resource base', 'propensity to sense opportunities and threats' 'propensity to make timely decisions', and 'propensity to make market-oriented decisions' for future research (p. 272).
Allred, Fawcett, Wallin and Magnan, 2011	Used a mix of quantitative and qualitative methods to demonstrate that 'collaboration, as a dynamic capability, mediates the conflict resulting from functional orientations, and improves performance' (p. 129).
Danneels, 2012	Studied the effect of second-order competences on a firm's profitability performance. Observed that 'marketing competence on ROA was positive under stable and moderate competitive conditions, whereas the effect of R&D competence on ROA was positive under volatile competitive conditions' (p. 42).
Priem, Li and Carr, 2012	Highlighted the limitation of RBT and dynamic capabilities in determining the value of a firm's resources as the factors exogenous to the firm. Proposed the application of demand-side research on consumer heterogeneity to address the issue and to complement RBT's focus on resource heterogeneity and dynamic capabilities.
Wang, Jaw and Tsai, 2012	Integrated the perspectives of strategic human resource management, organisational change and RBT with dynamic capabilities to study 154 firms. Results revealed that nurturing dynamic strategic capabilities requires firms to optimise human resources for productivity and development of core competence as part of the renewal and evolution process.

Table 2-6: Summary of significant contributions to Dynamic Capabilities

More recent studies show attempts to introduce multiple dimensions to define the construct of dynamic capabilities (Barreto, 2010) and adopt a systems approach based on the systems theory (von Bertalanffy, 1960, pp. 11–12; Capra, 1996) to propose a framework for developing a dynamic capability for major innovations (O'Connor, 2008).

From the review of the literature, there are certain limitations that have been highlighted as possible directions for future research. Zahra et al. (2006) observed that extant studies tend to focus on the relationship between organisational learning and dynamic capabilities, as well as their moderating effect on the business performance of international established companies in high-technologies industries rather than on young ventures or SMEs. These studies were mostly cross-sectional research that concentrated on new product and market development in established organisations. Little attention has been paid to the start-ups and SMEs, which are likely to be different from the established firms in their ability to afford the time and resources needed for learning and nurturing dynamic capabilities. This research addresses the above gaps by focusing on what dynamic capabilities are significant for spin-offs, SMEs and MNCs in their innovation process and how dynamic capabilities interact with the firms' internal and external resources in affecting the innovation outcome and commercial adoption performance.

Having reviewed the recent development of the RBT, KBT, CBT and Dynamic Capabilities Theory in Sections 2.3.3 to 2.3.6 respectively, the next section examines the application of these theories in the literature on university-industry collaboration. In particular, the significant contributions to the four strands of this literature are reviewed, each focusing on a distinct group of factors affecting university-industry technology collaboration: (a) university and PRI-related organisation factors, (b) TTO organisation-related factors, (c) entrepreneur and new venture-related factors, and (d) environmental factors.

2.3.7 Factors Affecting University-Industry Collaboration

2.3.7.1 University and PRI-related Organisation Factors

The first strand of literature reviews the university policies, practices and procedures and their impact on university commercial adoption in terms of patenting, licensing and spin-offs.

Financial Resource - R&D Expenditure

Lockett and Wright's (2005) study on 98 UK universities showed that the number of spin-offs is positively associated with R&D expenditures of the university. Similarly, O'Shea et al. (2005) highlighted the significance of science and engineering research funding on the spin-off formation. Earlier research by Bania, Eberts and Fogarty (1993) also found the positive influence of university R&D on the number of spin-offs generated. Based on the data set of 120 universities during the period from 1991 to 2000, Powers and McDougall (2005) showed that, in addition to the university financial resources, the availability of venture capital funding was a predictor of spin-off being formed and going public. They further established that a greater number of spin-offs and those going for initial public offering were found among universities situated in the US Census Bureau's Metropolitan Statistical Area (MSA), where venture capital abounded for investment. Apart from providing research grants to public universities and PRIs to perform basic and mission-oriented research respectively, the governments also set aside grants for firms to adopt technologies from universities and public research laboratories (Lockett, Siegel, Wright and Ensley, 2005). For example, the US has the Small Business Innovation Research Programme to encourage technology-based entrepreneurship, while the UK has Higher Education Innovation Fund, University Challenge, Science Enterprise Challenge and the Higher Education Innovation Fund to promote university research and university spin-offs (Lockett et al., 2005). Similarly, Singapore has a considerable number of funding programmes such as the Technology Innovation Programmes to stimulate R&D in SMEs to help raise their market competitiveness. These programmes are important initiatives by the governments as part of their NIS (Martin and Scott, 2000).

Commercial Resource - IP Protection Policies and Incentives

With the enactment of the Bayh-Dole Act in 1980 and other science and technology policy changes, patenting and licensing activities by US universities have been increasing (Shane, 2004). Lockett and Wright's (2005) study of the UK universities revealed that the number of spin-offs correlated positively with IP protection expenditure. Although the Bayh-Dole Act requires the US research scientists to disclose their inventions to their institutions while working on government-funded

projects, Siegel, Waldman, Atwater and Link (2003b, 2004) found that many chose not to do so, citing as reasons their lack of awareness of the commercial relevance of their research, concern with organisational bureaucracy, and publication delay from patenting lead time (Thursby, Jensen and Thursby, 2001).

The enforcement of full disclosure requirements has presented challenges: more than half of the faculty inventions of commercial relevance went undisclosed (Thursby and Kemp, 2002). As most of the Bayh-Dole studies have been conducted on universities, Link et al. (2011) chose instead to focus on the government research institutes: Sandia National Laboratories and the National Institute of Standards and Technology. While the Bayh-Dole Act did not seem to have a significant impact on these organisations' patenting activities, the researchers made the following observation:

> …the establishment of financial incentive systems, embodied in passage of the Federal Technology Transfer Act, as well as the allocation of internal resources to support technology transfer, stimulated an increase in such activity. (Link et al., 2011, p. 1094)

Previous studies indicated that appropriate incentives must be in place for the researchers, such as royalty sharing (Link and Siegel, 2005) and new venture equity ownership (Di Gregario and Shane, 2003) that significantly impact technology transfer activities (Friedman and Silberman, 2003).

In the context of Singapore, Wong et al. (2007) applied the Triple Helix framework (Leydesdorff and Etzkowitz, 1998) to analyse the role of the National University of Singapore (NUS) as an entrepreneurial university in support of the development of a knowledge-based economy in Singapore. Their findings supported the Triple Helix perspective of advocating universities to espouse the principles of the entrepreneurial university to contribute more effectively to national economic development.

Human Capital Resource - Researchers' Competencies

The faculty and researchers are important human capital resources for the university and research institutes. These are the knowledge experts whom the organisations hire and motivate to explore the technology frontiers and discover new materials or

innovative applications. Faculty and researchers of high quality, as evidenced by strong publication records and patent filings, are highly sought after for the value that they bring to the institutions. Prior studies have shown their significance on national innovation (Bozeman, 2000; Filippetti and Archibugi, 2011) due to their competencies in conducting basic research of cutting-edge technologies (Rosenberg and Nelson, 1994). While Zucker, Darby and Armstrong (1998) found positive association between researchers' reputations and product innovation, Deeds, DeCarolis and Coombs (1998) observed that the performance of biotechnology firms was influenced by the researchers' talents. Jensen, Thursby and Thursby (2003) found that there is a significant positive relationship between quality of the faculty and technology disclosure rate. Powers and McDougall (2005) concluded that the faculty quality positively influenced spin-off formation rate by providing greater innovation value.

Technological Resources

Although basic research has been the primary area of focus for publicly-funded universities and research institutes, their increasingly significant role in contributing to national economic development would require them to shift from the traditional investigator-led research in Mode-1 to context-driven research Mode-2 production of knowledge (Gibbons et al., 1994). With mounting pressure to propose fundamental research projects with commercial relevance even in their bids for public research grants, there is growing expectations for the universities and public research institutes to demonstrate industry interest in their projects before proposals are accepted for grant awards (van Den Kroonenberg, 1989; Hauber, 1996). With research funding becoming more competitive, public research institutes are looking at technologies which are more likely to find private sector buyers (such as MNC or SME) which are willing to develop and commercialise them. Similarly, buyers would be interested to find some ways to evaluate the commercial potential of these technologies as part of their due diligence efforts (Heslop, McGregor and Griffith, 2001). However, the process of matching technologies between the public sector technology producers and the private sector buyers has presented challenges due to the difference in success criteria that each uses (Robertson and Weijo, 1988).

Although the rate of failures in technology commercialisation is high, there has been limited analysis and lack of predictive models for successful technology matching and commercialisation (Heslop et al., 2001). The US Department of Defense stipulated their process and methodology for Technology Readiness Level (TRL) assessment (DoD, 2005). Heslop et al. (2001) proposed the cloverleaf model for evaluating TRL based on four criteria pertaining to readiness of (a) market (e.g., benefits and competitive advantage of the technology), (b) technology (e.g., patent strength), (c) commercialisation (e.g., licensing interest) and (d) management support (e.g., inventors' capabilities and status). Roberts and Hauptman (1986) identified success factors for technology commercialisation from university and hospital research centres to biomedical firms, including strategic fit between the external technology and the firm's internal R&D.

2.3.7.2 Technology Transfer Organisation Factors

With the growing emphasis on commercial adoption of R&D by universities and PRIs in recent decades, many academic and national research laboratories have set up TTOs to manage the transfer of technology from the laboratories to the industry. The TTOs have been instrumental in contributing to the phenomenal growth in patenting and licensing activities in the US, Europe and other parts of the world, which emphasise the importance of public research commercial adoption. According to AUTM (2010), the patents granted to the US universities shot from less than 300 in 1980 by more than tenfold to 4,400 in 2010. Even more dramatically, licensing fees swelled from $160m in 1991 to $2.3 billion in 2010. Given the significant 'intermediary' role that TTOs play in facilitating the transfer between the technology producer (PRI scientists) and the technology adopters (new ventures or existing enterprises), there has been a high level of interest among the scholars and practitioners to review the TTO factors and their impact on commercial adoption in terms of patenting, licensing and spin-offs. Among the factors, those that generate much discussion are the efficiency of the TTO process in converting knowledge to economic returns, the roles and competencies of the TTO staff. The second strand of literature therefore delves into these TTO-related factors.

TTO process efficiency

For successful university-industry technology transfer (UITT), some studies suggested the need for university policy and TTOs to improve the efficiency of technology transfer process (Siegel et al., 2003b; Siegel et al., 2007; Lockett and Wright, 2005). Most of these studies adopt the production function to analyse TTO efficiency, using inputs such as R&D expenditures, patents filed and granted, TTO staff strength and patenting expenditures (Chapple, Lockett, Siegel and Wright, 2005). On the other hand, the production function outputs for TTO are typically defined by the number of licenses signed, the number of intellectual properties licensed, the license income and the number of spin-offs (Siegel, Waldman and Link, 2003a). In particular, the empirical study by Chapple, Lockett, Siegel and Wright (2005) of 98 top UK university TTOs revealed differences in TTO efficiency between the UK and US universities and attributed these to the differences in the tenure of university research programmes. Given that many universities in the UK have ramped up R&D effort only in recent years, it will take some time for the technology to be developed and commercial adoption effort to bear fruits. To improve TTO efficiency, Chapple et al. (2005) recommended TTO to upgrade business skills and capabilities of their managers and licensing staff, while Zahra et al. (2007, p. 569) suggested developing 'knowledge conversion capability' based on KBT (Grant, 1996) that advocates firms to possess the ability to combine different forms of knowledge for a stronger competitive edge.

TTO staff capabilities

From the analysis of TTO efficiency studies and suggestion for improving the capabilities of the TTO staff, the skills and knowledge of TTO staff have taken centre stage among the scholars and the TTO community. O'Shea et al. (2005) highlighted the significance of the magnitude of TTO resources on the spin-off formation. Powers and McDougall (2005) found that the experience of TTO were predictors of spin-off being formed and going public. Eisenhardt and Martin (2000, p. 1105) asserted that the competitive advantage of a firm was determined by a firm's dynamic capabilities which they defined as a 'set of specific and identifiable processes such as product development, strategic decision making, and alliancing'. Building on the much-cited works of Eisenhardt and Martin (2000), Lockett and

Wright (2005, p. 1047) postulated that these dynamic capabilities are the set of skills that should be 'embodied' in the TTO staff. Lockett and Wright (2005, p. 1047) referred to these skills as 'business development capabilities' that the TTO staff must develop and hone in order to be effective in performing due diligence to manage their IP portfolio, gathering intelligence on technology applications and market, identifying and working with the potential technology adopters and collaborators. These capabilities are essential for TTO staff to facilitate technology commercialisation and adoption by the industry. Lockett and Wright's (2005) study of UK universities shows that the number of spin-offs correlates positively with the number of technology transfer staff and business development capability of university TTO.

In Switzerland, the quantitative research by Arvanitis, Kubli and Woerter (2008) of 241 research institutes highlighted UITT challenges such as TTO's inclination to play the role of contract negotiators rather than intermediaries and researchers' fear of losing scientific independence or under-publishing. Siegel et al. (2007, p. 499) called for the need for TTO staff to become 'boundary spanners' who can 'speak' the languages of both the researchers and the industry, playing the role of intermediaries between them so as to develop a deep relationship between the research and business communities.

2.3.7.3 Entrepreneur and New Venture-related Factors

While the first two strands of university-industry collaboration literature focus on the knowledge producers (university, PRIs) and their intermediaries (TTOs), there are also studies on the characteristics of knowledge recipients, which comprise the new ventures that are spin offs from the universities. The third strand of literature focuses on the individual attributes of academic entrepreneurs using human and social capital theories (Coleman, 1988, 1990), and their influence on resource acquisition for their new ventures within the RBT framework.

Roberts, who published their *Entrepreneurs in High Technology: Lessons from MIT and Beyond* in 1991, is among the pioneers of this literature strand. His work illuminated the personality traits and characteristics of high-technology

entrepreneurs in the US and has been much cited by other scholars in their subsequent works using theoretical models from other fields, such as the personality traits theory from psychology, social capital theory and social network theory from sociology, and the RBT (Wernerfelt, 1984) from the field of strategic management. Other pioneers of entrepreneurial literature are Amar Bhide and Scott Shane. Bhide's (2000) publication of *The Origin and Evolution of New Business,* is perhaps the most comprehensive study on how new ventures were initiated, although these are not limited to high-technology ventures. Bhide (2000) discussed the initial endowments in new ventures, including human capital. Shane's (2005, p. xx) *Finding Fertile Ground,* on the other hand, focused on high-technology ventures and elaborated on how to harness critical success factors such as 'intellectual property, increasing returns, dominant designs, diffusion, and S-curves' to improve the business performance of the new high-technology ventures.

Human Capital and Social Capital

In the social capital literature, social capital is postulated as a significant mechanism (Bozeman and Mangematin, 2004) to 'underpin the production of knowledge and critical for its subsequent distribution and use' (Mosey and Wright, 2007, p. 909). Drawing upon the social capital theory, Mosey and Wright's (2007) qualitative study of 24 academic entrepreneurs from six UK universities found that those subjects with prior industry experience (human capital) were more effective in building effective relationships (social capital) with other stakeholders (e.g., industry partners and investors). The novice academic entrepreneurs from material sciences and engineering disciplines faced less difficulty in establishing ties than did their counterparts from biological sciences. Based on Normann's business idea model from the business model literature (Normann, 1977, 2001), Grandi and Grimaldi (2005) reported similar findings based on their quantitative research of 42 academics in Italy, whose human capital influenced business idea articulation positively. They found that academics' 'prior joint experience' (which refers to prior experience of working together and hence indicates familiarity) allowed them to reach consensus among themselves fairly quickly in the definition of their business idea, particularly in the early phase of the venture when the business idea was in the process of being formulated (Grandi and Grimaldi, 2005, p. 821). Nevertheless, this 'prior joint experience' may become a liability arising from

groupthink (Grandi and Grimaldi, 2005, p. 840), leading to a compromise in the quality of the business idea, in the later phase of the new venture (Katz and Allen, 1982).

In addition to the human and social capital aspects of academic entrepreneurs, scholars have examined their competencies in resource acquisition for the new firm creation, based on RBT (Wernerfelt, 1984; Barney, 1991; Connor, 1991). Examples of studies using the RBT are O'Shea et al.'s (2005) study of 141 US universities, as well as Powers and McDougall's (2005) research of 120 US universities, which highlight the importance of faculty quality (human capital) on university spin-off activity and technology transfer performance respectively. Zhang, Souitaris, Soh and Wong (2008) conducted a recent study on 226 new high-tech ventures in Singapore and Beijing. Drawing on RBT, Zhang et al. (2008, p. 608) found that the 'social competence' of the entrepreneurs in terms of their 'social perception, impression management, persuasiveness and adaptability' could influence their propensity to use their existing network to access prospective investors for the financial resources they needed for their new ventures. Building on the works of Zhang et al. (2008) and the perspective of social networks, Kwanghui Lim and Brian Cu (2010, p. 2) studied 70 venture-backed start-ups in the US and 15 in Singapore and established that venture capitalists are more likely to give advice to entrepreneurs when they have direct ties, while disagreement is more likely to arise between them when they have indirect ties. Heirman and Clarysse's (2007) study of 99 research-based spin-offs founded in Belgium during the period from 1991 to 1997 corroborated the importance of social and human capital, as their results reveal that founders' prior experience and management team tenure significantly correlated with shorter product time-to-market.

In Zahra et al.'s (2007) comparison between university spin-offs and corporate spin-offs, the researchers integrated the social capital, RBT and knowledge-based literature to distinguish between the concepts of capabilities (Barney, 1991) and competences (Hamel and Prahalad, 1994), arguing that the former deserve focus as it represents a competitive advantage (Dutta, Narasimhan and Rajiv, 2005). Their study revealed that the university spin-offs enjoyed higher productivity and revenue growth rate than the corporate spin-offs possibly due to their laser focus on a

particular technology arising from autonomy in academic settings, and stronger capability to integrate different forms of knowledge. However, their findings contrasted with those of Lindholm's (2001) study, which observed that the corporate spin-offs overtook the university spin-offs in the revenue growth possibly due to differences in the sectors and samples being studied. Nevertheless, these apparent contradictions provide areas for further research and exploration of other factors at play contributing to the differences (Zahra et al., 2007).

Citing the importance of social networks (Nicolaou and Birley, 2003) and entrepreneurial behaviours (Roberts, 1991), Walter et al. (2006) built on these concepts in their empirical study of 149 German university spin-offs. Their results show that network capability could positively influence a spin-off's performance, while entrepreneurial orientation could positively influence its competitive advantage.

The existing literature shows the majority of studies focus on the entrepreneurs and their new ventures in the US and Western Europe, which have placed their emphasis on entrepreneurial universities and technology-based spin-offs earlier than the rest of the world, such as in Asia. As the various aspects of the entrepreneurs and their entrepreneurial activity in the spin-off may be influenced by the national science and technology policies, more in-depth studies of this strand are required beyond US and Western Europe to enrich the current literature with the perspectives from other countries such as Singapore, which has her distinct national science and technology policies, as well as regulatory structures for managing public research institutes and spin-offs (Clarysse, Wright, Lockett, Mustar and Knocka, 2007). Other emerging areas of research interest are the analysis of other new venture-related factors such as the new ventures' existing technological capabilities and their impact on firm performance.

2.3.7.4 Environmental Factors

The fourth strand of literature revolves around environmental factors that could influence academic entrepreneurship. The traditional macro-environmental factors include the market conditions, the regulatory structures for managing IP, policies

for invention disclosures, publicly-funded financial assistance for spin-offs, government grants for TTOs for patenting and gap-funding activities (Clarysse et al., 2007). In the last decade, there has been growing interest in the micro-environment comprising intermediaries and networks that work directly with the university and PRIs, such as science parks, incubators/accelerators and innovation networks (Rothaermel et al., 2007). This section provides an overview of the literature centring on the macro- and micro-environmental factors and their impact on academic entrepreneurship and commercialisation activities.

Macro-environmental factors

The market conditions could directly impact the commercialisation success of the new ventures or existing firms embodying the new technologies developed by universities and PRIs (Cassiman and Veugelers, 2006). What the favourable market conditions are for high-technology firms has been an area of interest among scholars. Among these studies, a notable study was conducted by Katila and Shane (2005) to track 1,397 inventions that were patented by MIT between 1980 and 1996. They tested the innovative responses of new firms to four market conditions (competitive, munificent financial resources, manufacturing-intensive and small markets) and found that firm innovation was greater in competitive and small markets.

The implementation of invention disclosure and patenting policies to encourage research commercial adoption by universities and PRIs, such as the Bayh-Dole Act enactment in the US in 1980, has been a topic of much research (Shane, 2004; Mowery and Sampat, 2005b), not only in the US but also in other countries where the Bayh-Dole Act equivalent was introduced in Germany, Belgium and Italy in 1999 (Clarysse et al., 2007). Shane's (2004) study of the university's contribution to patents and its licensing effectiveness from 1969 to 1996 shows a significant relationship with the Bayh-Dole Act enactment in the US. However, Mowery and Sampat (2005b) argue that prior to the enactment of Bayh-Dole Act in 1980s, there had been extensive effort to promote university-industry collaboration and technology commercialisation, and thus there was emphasis on higher education in the US throughout the 20th century. It is therefore unlikely that the Bayh-Dole Act singularly contributes to the rise in patenting and licensing activities of universities

and PRIs. Implementation of the Bayh-Dole Act equivalent in other countries may not lead to the same outcome of technology commercialisation. Fabrizio's (2007) longitudinal analysis of US patenting data from 1975 to 2000 shows that the rise in university patenting with the introduction of the Bayh-Dole Act has actually decreased the rate of diffusion of technology from the university to the industry (Sampat, 2006; Siegel et al., 2007).

To encourage spin-off formation, many countries have publicly-funded assistance programmes in place. In a similar vein, there are public funds set aside for TTOs for patenting and gap-funding activities. Clarysse et al. (2007) observe that while Germany introduced the EXIST programme to support spin-offs through pre-seed funding in 2000 and the EEF-Fund for research to spin off in 2002, the UK implemented the University challenge funds in 1998 to support spin-offs. Other European countries, such as Belgium, France and Italy, have similar support programmes for both spin-offs and TTOs. In Singapore, there are also support schemes such as the Technology Enterprise Commercialisation Scheme (TECS, 2012) to encourage innovation and spin-offs. Given the high level of uncertainty associated with spin-offs, it is understandable that the venture capital investors be highly selective in their evaluation and investment decisions. Therefore, the effectiveness of the role of venture capital investors in generating university spin-outs has generated much interest in this literature (Defazio, Lockett and Wright, 2009). Wright, Lockett, Clarysse and Binks (2006) adapted the finance pecking order theory to examine the problems faced by university spin-offs in seeking internal financing before complementing internal financing with debt financing and final access to venture capital. While the publicly-funded support programmes may be available to spin-offs to address their pre-seed capital needs, Clarysse et al. (2007) are sceptical about their effectiveness based on their study of 135 spin-offs from universities and public research organisations across five European countries (Belgium, France, Germany, Italy and UK). Their results show that the spin-offs that had started with pre-seed capital funding from the government agencies in the early stage of their venture seemed to have difficulty raising funds from the venture capitalists in the later stage. This could be due to valuation issues of the IP at the seed stage which may not be able to meet the expectations of the discerning venture capitalists during the subsequent rounds of financing at the later stage (Clarysse et

al., 2007). These results have important policy implications for the implementation of publicly-funded pre-seeds capital as sources of funding for spin-offs from universities and public research organisations to alleviate inefficiency in the capital market for spin-offs and its side effects of inadvertently introducing other forms of inefficiency in raising capital at later stages (Wolf, 1988; Clarysse et al., 2007).

Similarly, publicly-funded support for the patenting and gap-funding activities of TTOs is likely to be justified by the phenomenon of market inefficiency due to the lack of interest by the private equity or venture capital investors in funding such activities (Wolf, 1988). However, the availability of such public funds to the TTOs will come with some form of pressure to file patents and sponsor gap-funded commercialisation to utilise the allocated funds and meet certain key performance indicators in terms of patents filed and gap-funded projects awarded. There is, however, no easy solution to this challenge, which is certainly an area for further research that will be of great interest to the policy makers who are eager to improve the effectiveness of their policies and programmes.

Micro-environmental factors

In the last decade, there has been growing interest in the micro-environment comprising intermediaries and networks that work directly with the university and PRIs, such as science parks, incubators/accelerators and innovation networks (Rothaermel et al., 2007). Studies around the innovation networks and their impact on the performance of the new venture have drawn upon social network theory to argue that importance of human and social capital on competitive advantage (Lockett, Wright and Franklin, 2003; Murray, 2004) and the firm performance measured by R&D outcome and productivity (Lofsten and Lindelof, 2005; Medda, Piga and Siegel, 2005). The results have shown that a positive relationship exists between the firm's performance and the innovation network in which it operates. Science parks and incubators as well as their impact on entrepreneurial activity form a key topic of discussion in the fourth strand. Link and Scott's (2003) study of 88 US universities found that their relationship with the science park could positively influence their patenting, publishing and scientific talent recruitment and development. Mian's research on six incubators in the US demonstrated that the

incubators had provided a 'conducive' (Mian, 1994, p. 515) and 'nurturing' environment' (Mian, 1996, p. 325) for the growth of the university spin-offs.

Phan, Siegel and Wright's (2005) comprehensive review of the literature on both science parks and incubators showed that the then current literature lacked robust theoretical frameworks for analysis given the complexity of the innovation ecosystems in which universities and spin-offs operate. For future research, they suggested several theories, such as the institutional theory (Langlois, 1989; North, 1990) for analysing how incubators establish new firms, resource dependence theory (Pfeffer and Salancik, 1978) for studying the mitigation of the risks inherent in the new ventures, and the agency theory (Alchian and Demsetz, 1972; Eisenhardt, 1985, 1989) for understanding the effectiveness of incubation process. Figure 2-1 provides an overview of the relevant studies contributing to the university-industry collaboration literature in the past two decades.

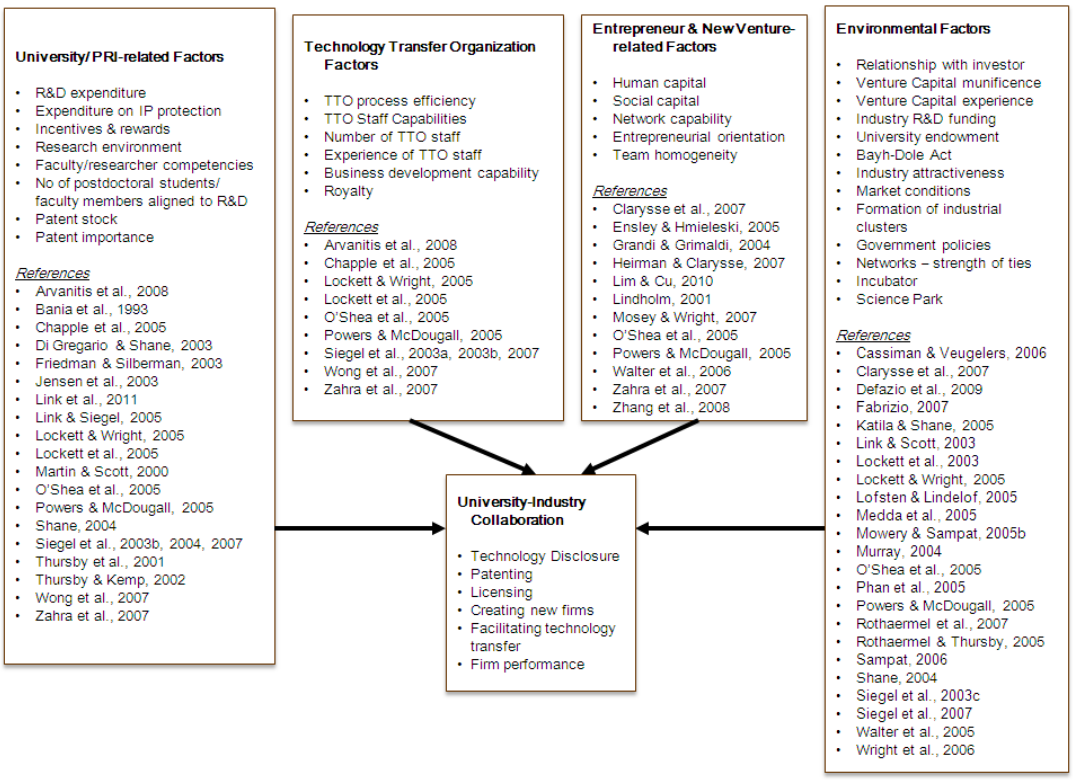

Figure 2-1: An overview of factors affecting university-industry collaboration (adapted from Rothaermel et al., 2007)

Although considerable research has been done pertaining to universities, TTOs, new ventures and the external environment, including incubators, science parks and venture capitalists, there has been a dearth of studies on existing firms that license

technologies from PRIs. This stark contrast may be due to the relative ease of obtaining spin-off data from universities compared to collecting existing firm data from PRIs, as the former have the mission to promote education and learning, while the latter do not. Nevertheless, given the hefty R&D investment in PRIs to perform mission-oriented research (Feng, 2011) and that the existing firms make up a significant proportion of the knowledge recipients, it is important that similar rigour be accorded to the study and analysis of PRIs and existing firms as well. While there could be similarities in certain aspects between universities and PRIs that suggest applicability of the university-centred study results from university-industry collaboration literature for the case of PRIs, there could also be other aspects where the unique characteristics of PRIs make them distinct from universities. An example of such aspects would be the difference in their organisational missions as highlighted earlier: while PRIs have the primary mission for research, universities have the mission for education and learning, in addition to research. The difference in the missions and foci between universities and PRIs would have implications for the relative importance of their organisational factors (e.g., resource allocation for financial investment, human capital development, technology commercialisation priorities and TTO activities) in affecting their collaboration performance with the industry. This research contributes to the body of knowledge by examining how PRI-related and TTO-related organisational factors impact the innovation outcome and performance of firms (both existing and new ventures) that commercialise the technologies developed by PRIs.

In the next section, this research scans the literature on external technology acquisition for relevant studies of firms that acquire external technologies. In particular, the development of the TCE theory focusing on complementary assets and IP appropriation, as well as the absorptive capacity theory are reviewed in order to examine their applicability in explaining the propensity of firms to license external technologies from PRIs. These theoretical lenses help us understand the factors that contribute to variation in performance across the firms that acquire external technological innovation.

2.4 External Technology Acquisition

2.4.1 Transaction Cost Economics Theory

The concept of transaction costs was first introduced by Coase (1937), which asserted that market transactions were not costless and that firms exist because of market failures. The current review of the literature on Transaction Cost Economics (TCE) found that the discussion could be categorised into three areas: (a) types of transaction costs, (b) the factors leading to transaction costs and effect of transaction costs, and (c) measurement of transaction costs.

Types of Transaction Costs

Numerous types of transaction costs were posited by a multiplicity of studies: costs of coordinating investments (Chandler, 1977) and diverse resources (Teece, 1986; Chesbrough and Teece, 1996), specificity of assets (Klein, Crawford and Alchian, 1978), threat of lock-in (Williamson, 1979), and appropriability, which refers to the risk of expropriation of IP (Teece, 1986; Oxley, 1997). Drawing upon Coase's (1937) concepts, Williamson (1985, p. 172) developed TCE to address the various types of contractual hazards associated with a transaction exchange, such as the hazard of 'hold up' arising from asset specificity. Other hazards include the difficulty of measuring the quality of the transaction outcome, also referred to as 'observability' (Holmstrom, 1979, p. 74). In situations where it is challenging to observe and compensate for the outcome quality, the suppliers may have the incentives to maximise profits by cutting costs and underperforming. In these circumstances, a firm has greater incentives to internalise the transaction than to incur costs of monitoring the supplier's outcome (Holmstrom, 1979; Mayer and Nickerson, 2005). This section shall focus on two types of transaction costs: asset specificity (or complementary assets) and IP appropriability, as they are relevant for the research questions of commercialising publicly-funded research in this thesis.

Factors Leading to Transaction Costs and Effect of Transaction Costs

Appropriability describes the risk of disclosing IP to expropriation (Oxley, 1997). When a firm intends to engage another firm in some form of transaction, it is common practice for firms to share information about their IP to ascertain

technology complementarity and develop understanding and consensus on the allocation of ownership and rights of the background and foreground IP. However, there is a possibility that valuable proprietary information gets exposed and expropriated, resulting in revenue loss from the intellectual asset. Despite the presence of contracts such as non-disclosure agreements to govern the transactions and protect the contracting parties of such occurrences of expropriation, their usefulness may be restrictive and their costs prohibitive (Shapiro and Varian, 1999). Therefore, in situations where the risks of expropriation are high, firms would prefer internal development to engaging external suppliers (Mayer and Salomon, 2006).

Asset specificity refers to the degree to which the assets can be transferred to other purposes. Assets that are specific to a particular transaction hold little utility value in other transactions. According to Klein et al. (1978, p. 302), if a firm requires very specialised assets for its operation, the firm is vulnerable to the risk of 'hold up' by suppliers which may seize the opportunity to maximise profits at the expense of the firm. The authors introduced the concept of 'appropriable quasi rents of specialised assets' to explain the opportunistic behaviour of the suppliers (Klein et al., 1978, p. 298). Although the firm may engage in contracting mechanisms to protect its interests against the opportunistic behaviour of the suppliers, these mechanisms may incur more costs than internal development of the same assets by the firm. In essence, firms would prefer internal development to engaging external suppliers when the required assets are transaction-specific, so as to mitigate the threat of 'hold-up' (Klein et al., 1978, p. 302; Williamson 1985; Mayer and Salomon, 2006). In summary, the TCE model (Williamson, 1985) explains that the more specific the nature of the co-specialised complementary assets, the greater is the corresponding increase in the risks of hold-up and opportunitism, thereby increasing contractual hazards and reducing the PAET.

Building on the works of the TCE model, Mayer and Salomon (2006) examined 405 service contracts from a single information technology company and found that strong technological capabilities would enable firms to govern their contracts despite the hazards. These results are important to explain why differences exist among firms in the ways they organise and manage their transactions even though

they are subject to similar contractual hazards highlighted in the TCE model. Although the transaction cost model advocates that in-house R&D may be substituted by externally acquired knowledge, there is empirical support that external technological knowledge and internal R&D could complement each other (Rigby and Zook, 2002; Cassiman and Veugelers, 2006).

Rigby and Zook (2002) demonstrated that the capability of complementing internal and external knowledge could form the basis for competitive advantage in some industries. Cassiman and Veugelers' (2006) study of Belgian manufacturing firms highlighted that complementarity between internal and external R&D could significantly influence the firms' decision to acquire external technology from both public and private sectors.

Measurement of Transaction Costs

The measurement of transaction costs has been challenging due to the difficulty of distinguishing between operation costs and transaction costs (Benham and Benham 2001; Peng and Shen, 2008). Some authors use the 'objectivist' approach (Klaes, 2000) to refer to market prices for determining the quantitative value of transaction costs, typically in the finance industry (Collins and Fabozzi, 1991; Polski, 2001). Other researchers are sceptical of the validity of the quantitative valuation of transaction costs. They prefer to employ the 'subjectivist' approach to make a qualitative assessment by comparing with alternatives (Knack and Keefer, 1995; Ghertman, 1998). Most subjective theorists use proxies for transaction costs such as asset specificity and uncertainty to determine 'the relative efficiency of alternative institutional/ property rights arrangements or contractual choices' (Musole, 2009, p. 51). Time and energy have also been used to measure transaction costs (Buitelaar, 2002, 2003).

Beyond the three strands, the TCE literature produced spin-offs such as the Profit from Innovation (PFI) framework by Teece (1986, 2006). Building on TCE, Teece integrated the perspective of industrial organisation and research from strategic management to develop the PFI framework comprising three key elements: 'appropriability regime, complementary assets, and the dominant design paradigm' (Teece, 1986, p. 286). The PFI model enables firms to examine the distribution of

innovation profits among the innovators and owners of complementary assets in the value chain. Zi-Lin He, Kwanghui Lim and Poh-Kam Wong (2006) enriched the PFI model by postulating that having complementary assets and IP appropriability is necessary but insufficient, particularly for new entrants in the telecommunications industry. Citing 'Ericsson, Nokia and Samsung' as examples, the authors emphasised the imperative for 'knowledge spillovers from the leader and other external sources' to enhance their IP portfolio in order to challenge incumbents with strong patent stock like Motorola (He et al, 2006, p. 1148). Concurring with the findings of He et al. (2006), Clayton Christensen, Chang-Chieh Hang, Kah-Hin Chai and Annapoornima Subramanian (2010, p. 5) cautioned that even incumbents with strong IP could still run the risk of losing their competitive advantage and thus recommended an alternative strategy to 'rely on open innovation and partner with firms and universities in emerging economies'. We shall review the literature on open innovation in Section 2.5.1.

More recent contributions include the application of TCE in the research area of land policy to examine the transaction costs of property rights (Musole, 2009), the integration of the theory with the field of entrepreneurship to understand the appropriate organisation (in the form of 'spin-off' or 'technology licensing agreement') for successful technology commercialisation as a transaction from the university (Wood, 2009, p. 929) and the extension of TCE to international marketing (Seggie, 2012). In particular, Wood (2009, pp. 937-941) postulated four elements of innovation as critical success factors for university technology transfer transactions: 'codifiability' – degree to which knowledge can be articulated and transferred; 'teachability' – degree to which to the knowledge worker can be taught; 'complexity'- the diversity of requisite competencies for knowledge; and 'system dependence' – the degree to which innovation depends on human factors, equipment or technologies. Wood (2009) suggested investigating the effect of these four elements on university commercialisation performance as directions for future research. Gibbons (2010, p. 15) suggested four different areas for further investigation: '(1) costs of integration, (2) identification, (3) internal organisation, and (4) formal models'.

Table 2-7 summarises the significant contributions to TCE theory.

Author	Significant contributions to TCE theory
Coase, 1937	First introduced the concept of transaction costs to optimise organisational boundaries. Defined transaction costs as the cost of using the mechanism of pricing (Coase, 1988).
Chandler, 1977	Found that the modern large enterprises were successful as a result of higher profits from decreased costs and increased productivity. Observed the costs of coordinating interdependent and complex investments and systems and explained the need for the US enterprises to develop the 'managerial class' to manage these coordination costs.
Klein, Crawford and Alchian, 1978	Introduced the concept of 'appropriable quasi rents of specialised assets' to explain the opportunistic behaviour of the suppliers (p. 298). Building on Coase's framework, they recommended either internal development or contracting to mitigate the threat of 'hold up' (p. 302).
Holmstrom, 1979	Examined principal-agent contracts and observed that 'additional information [about actions or states of nature] is of value because it allows a more accurate judgment of the performance of the agent' to address the issue of 'moral hazard' (p. 89).
Williamson, 1985	Discussed the costs and benefits of vertical integration. Identified various integration costs: 'accounting contrivances' (p. 138), 'unilaterally' set transfer pricing (p.139), 'costs of bureaucracy' (p. 148) and 'the strategic propensity to use the resources of the organisation to pursue subgoals' (p. 149).
Teece, 1986	Built on TCE theory to integrate the perspective of industrial organisation and research from strategic management to develop a framework of Profit from Innovation (PFI) comprising three key elements: 'appropriability regime, complementary assets and the dominant design paradigm' (p. 286). The PFI model enables firms to examine the distribution of innovation profits among innovators and owners of complementary assets in the value chain.
Chesbrough and Teece, 1996	Cautioned that there would be a trade-off between incentives and control as organisations move from vertical integration to contracting external parties for developing innovation. Emphasised the need to nurture core competencies if the innovations are critical to the organisations. Introduced factors to consider in make-versus-buy decisions: 'systemic' versus 'autonomous' types of innovation and existence of industry standards (p. 6).

Author	Significant contributions to TCE theory
Oxley, 1997	Applied the transaction cost theory to examine the impact of appropriability hazards on the governance structure for inter-firm alliances. Results support that the severe appropriability regimes arising from complexity of scope or technologies would require a hierarchical form of alliance governance.
Shapiro and Varian, 1999	Advocated the cost of information and its use in product differentiation as part of organisational strategy in competitive environments. Cautions costs of 'lock-in' and 'switching costs' incurred by customers and new service providers (pp. 103-172).
Zhao, Luo and Su, 2004	Reviewed 30 studies and found that their findings supported TCE and highlighted the influence of location, nation and type of market as moderating variables on the firms' selection of business entry mechanisms.
Mayer and Nickerson, 2005	Analysed 190 projects of a large information technology service provider using TCE theory to examine how the factors and effects of engaging independent contractors differ from those of hiring employees. Results show that 'Projects that use independent contractors despite the presence of contracting difficulties arising from expropriation concerns and measurement costs experience lower performance than projects that use employees. Conversely, using independent contractors leads to higher profitability than using employees when projects are not subject to these contracting difficulties' (p. 2).
Cassiman and Veugelers, 2006	Studied Belgian manufacturing firms to illuminate that the complementarity between internal and external R&D influence their decision to acquire external technology from both the public and private sectors.
He, Lim and Wong, 2006	Enriched the PFI model by postulating that having complementary assets and IP appropriability is necessary but insufficient, particularly for new entrants in the telecommunications industry. Exhorted the need for spillovers and external knowledge for competitive advantage.
Mayer and Salomon, 2006	Examined 405 service contracts from a single information technology company and found that strong technological capabilities would enable firms to govern their contracts despite the hazards. These results are important to explain why differences exist among firms in the ways they organise and manage their transactions although they are subject to similar contractual hazards highlighted in the TCE model.
Teece, 2006	Reviewed the Profiting From Innovation framework built upon the TCE theory two decades ago and subsequent studies. Proposed a framework based on the Schumpeterian theory to

Author	Significant contributions to TCE theory
	develop strategies for taking technologies from concept to commercialisation.
Peng and Shen, 2008	Discussed the challenges of measuring transaction costs directly. Proposed that measurement could be adjusted as transactions became more complex.
Musole, 2009	Reviewed the definition, factors and performance of the TCE theory. Applied the theory to examine the transaction costs of property rights.
Wood, 2009	Extended the TCE theory to entrepreneurship to examine the appropriate organisation in the form of either 'spin-off' versus 'technology licensing agreement' for 'innovation transfer as a transaction' from the university (p. 929). Proposed four elements of innovation as key factors affecting transactions in university technology transfer transactions: 'codifiability', 'teachability', 'complexity' and 'system dependence' as directions for future research (pp. 937-941).
Christensen, Hang, Chai and Subramanian,2010	Supported He et al.'s (2006) findings and recommended open innovation response strategy in the form of collaboration with other firms and universities to sustain competitive advantage.
Gibbons, 2010	Provided a detailed discussion of Williamson's contributions to the TCE theory. Suggested directions for future research: '(1) costs of integration, (2) identification, (3) internal organisation and (4) formal models' (p. 15).
Seggie, 2012	Reviewed the development of TCE in the field of international marketing. Highlighted potential areas for future research.

Table 2-7: Summary of significant contributions to the TCE theory

From the literature review of transaction cost theory, it is evident that little attention has been paid to the transaction of transferring technology from national R&D laboratories to firms by technology licensing (Wood, 2009). This research helps to address this limitation by focusing on the licensing transaction outcome between national R&D laboratories and firms. The next section traces the development of the absorptive capacity theory to discuss its relevance in sharpening the focus of this research.

2.4.2 Absorptive Capacity Theory

The term absorptive capacity was first introduced in macroeconomics to refer to the ability of an economy to assimilate foreign resources and knowledge (Adler, 1965; Tu, Vonderembse, Ragu-Nathan and Sharkey, 2006). Cohen and Levinthal (1990) subsequently adapted the term to describe a firm's ability to innovate by identifying, assimilating and applying new knowledge for commercialisation. The authors argued that external knowledge sources could be critical to the firms' NPD process. Given the rapid changes in both technological and market landscapes, the ability of the firm to identify, assimilate and exploit the outside sources of knowledge is essential for its innovation activities. These innovation activities could include basic research, the dissemination of innovation or inter-firm R&D collaboration. The authors highlighted the importance of internal R&D to enable firms to benefit from external technologies.

Prior to Cohen and Levinthal, some studies argued that absorptive capacity was generated as a by-product of the R&D process, while others contended that a firm's manufacturing operations are the origin of absorptive capacity (Abernathy and Utterback, 1978; Rosenberg, 1982). Cohen and Levinthal, on the other hand, emphasised the dimensions of cognitive structures based on the learning-set theory and the organisational aspects in their concept of absorptive capacity. They postulated that engaging in basic research would enlarge the breadth and depth of the firm's existing knowledge base to move into the frontier of the new technology and equip the firm with know-how and prior experience to exploit the new development work. Since the ground-breaking research of Cohen and Levinthal, more than 900 academic papers have been published using the construct. Notwithstanding this, Lane, Koka and Pathak's (2006) review of 289 papers from 14 journals on the topic raised some concern over its reification. Further analysis shows that 80% of the publications merely mentioned the construct of absorptive capacity without further elaboration. Similarly, Lane et al. (2006) observed that, despite the proliferation of publications on this topic, there were only six publications that utilised the construct of absorptive capacity as a central dimension of their research, of which four made substantive contributions to the refinement and extension of its meaning (Mowery, Oxley and Silverman, 1996; Szulanski,

1996; Lane and Lubatkin, 1998; Dyer and Singh, 1998; Koza and Lewin, 1998; Zahra and George, 2002).

Based on 271 observations of 122 transfers in eight firms, Szulanski (1996) examined the concept of internal stickiness in firms with multiple units. In addition to the construct of absorptive capacity as defined by Cohen and Levinthal (1990), the author introduced another construct, 'retentive capacity' as the 'ability of a recipient to institutionalise the utilisation of new knowledge' (1996, p. 31). Szulanski (1996) found that the key motivation-related obstacles to internal knowledge transfer are the lack of absorptive capacity before the transfer and tension in knowledge recipient-source relationship. His study has broadened the definition of absorptive capacity beyond the original R&D centrality to include a more comprehensive dynamic capability dimension.

Dyer and Singh (1998) built on Szulanski's research on internal stickiness to argue that the difficulty of knowledge transfer would mean that firms that are able to out-perform their competitors in this innovation activity of knowledge transfer are more likely to sustain competitive advantages. They further extended the definition of absorptive capacity by bringing in the concept of the relational view and RBT (Wernerfelt, 1984) to argue that alliance partners in the form of a dyad or network could co-develop relational capability through the practice of 'sociological interaction' and the 'iterative process of exchange' (1998, p. 666). Through sharing of relation-specific knowledge, resources and assets, collaborating firms could co-generate supernormal relational rents and sustain inter-firm competitive advantage. By integrating the notion of absorptive capacity with the literature on networks and alliances, Dyer and Singh (1998) made significant theoretical contributions.

Lane and Lubatkin's (1998) research builds along the same theme of alliance partners as does the work of Dyer and Singh (1998). Concerned that the firm-level construct of absorptive capacity by Cohen and Levinthal (1990) was too restrictive in its application and that a recipient may have an equal learning capacity from different organisational sources, Lane and Lubatkin reconceptualised it as a 'dyad construct, relative absorptive capacity' (Lane and Lubatkin, 1998, p. 473). The dyad construct is characterised by the relation between the 'student firm' and 'teacher firm', and the value of construct will vary across different teacher firms (Lane and

Lubatkin, 1998, p. 462). Based on data from student pharmaceutical firms and teacher biotechnology firms, Lane and Lubatkin (1998) found the student firm's ability to identify, assimilate and apply the new knowledge from the teacher firm was influenced by (a) the relevance of the knowledge to the student firm, (b) congruence of reward and incentive practices between student and teacher firms, and (c) the number of joint research communities.

Zahra and George (2002, p. 186) defined absorptive capacity as a dynamic capability: 'a set of organisational routines and processes by which firms acquire, assimilate, transform, and exploit knowledge'. They also introduced two possible states of absorptive capacity: (a) realized absorptive capacity, which refers to the external knowledge that the recipient organisation has actually transformed and exploited, and (b) potential absorptive capacity, which depicts the external knowledge that the recipient organisation could acquire for exploitation. They suggested the notion of absorptive capacity 'efficiency' which refers to 'the ratio of RACAP (realized absorptive capacity) to PACAP (potential absorptive capacity)' (Zahra and George, 2002 p. 191). Although Zahra and George's (2002, p. 191) suggestion of 'profits are created primarily through RACAP' may be valid, they have raised concern among critics about being over-focused on short-term exploitation of knowledge 'pipeline' at the expense of long-term exploratory learning (Lane et al., 2006, p. 855). Zahra and George's (2002) short-term perspective is therefore in sharp contrast with Lane and Lubatkin's (1998) focus on the funnel of exploratory learning.

More recent studies have attempted to review and reconceptualise the construct of absorptive capacity (Todorova and Durisin, 2007; Leahy and Neary, 2007; Fabrizio, 2009). Building on Zahra and George's (2002) work, Todorova and Durisin (2007, p. 774) recommended re-conceptualisation of 'recognising the value', and 'transformation', and an elaboration of 'potential absorptive capacity', with further examination of the influence of 'socialization', 'power relationships', and 'feedback loops' in the framework of absorptive capacity.

Based on data from biotechnology and pharmaceutical firms that collaborate with university scientists in basic research, Fabrizio (2009) found that the firms' search for new inventions and knowledge at universities tend to yield better quality of

outcomes for firms with higher level of absorptive capacity-building routines. Leahy and Neary's (2007, p. 1089) study provided strong empirical support that R&D enhances the recipient organisation's absorptive capacity, that is, 'its ability to absorb spillovers from other firms) as well as contributing directly to profitability'. However, the authors caution that 'costly absorption both raises the effectiveness of own R&D and lowers the effective spillover coefficient' (Leahy and Neary, 2007, p. 1089). This means that, even in the event of full information sharing between the firms, it may reduce the firm's incentives to engage in collaborative R&D with other firms. Nevertheless, this could also turn out to be an additional strategic benefit for firms that encourage general industry research.

Kwanghui Lim (2009, p. 1252) also made significant contribution with his conceptualisation of absorptive capacity having three distinct aspects and mapping them to different phases of technology life cycle: (a) initial phase focusing on the 'disciplinary' aspect that involves exploratory R&D with potential commercial relevance, (b) growth phase concentrating on the 'domain specific' aspect that emphasises commercialisation of technological innovation into useful products or services, and (c) established phase revolving around the 'encoded' aspect that relates to the conversion of knowledge from tacit to explicit states in the form of 'tools and processes'. Lim's (2009) work has been much cited as it continues to inspire the works of subsequent authors in examining the dynamics of collaborative effort among different actors through the various stages of technology life cycle (e.g., Kapoor and McGrath, 2012).

A summary of the key definitions of absorptive capacity and key research contributions is provided in Table 2-8.

Author	Definitions of Absorptive Capacity	Significant contributions
Cohen and Levinthal, 1990	'The ability of a firm to recognise the value of new, external information, assimilate it, and apply it to commercial ends' (p. 128).	Represented the notion of absorptive capacity as a single-loop learning (Argyris and Schon, 1978), and by-product of innovation. Absorptive capacity is influenced by the organisational routines of internal knowledge sharing, communication and transfer.

Author	Definitions of Absorptive Capacity	Significant contributions
Szulanski, 1996	Used the construct of 'lack of absorptive capacity' (p. 28) Introduced new construct of 'retentive capacity' as the 'ability of a recipient to institutionalise the utilisation of new knowledge' (p. 31).	Broadened the definition of absorptive capacity beyond the original R&D centrality to include a more comprehensive dynamic capability dimension.
Dyer and Singh, 1998	'Partner-specific absorptive capacity refers to the idea that a firm has developed the ability to recognise and assimilate valuable knowledge from a particular alliance partner' (p. 665).	Integrated the notion of absorptive capacity with the literature on networks and alliances.
Lane and Lubatkin, 1998	'Relative absorptive capacity' refers to 'the student's ability to value, assimilate and commercialise its teacher's knowledge' (p. 473).	Found that relative absorptive capacity is influenced by (a) the relevance of the knowledge to the student firm, (b) congruence of reward and incentive practices between student and teacher firms, and (c) the number of joint research communities.
Zahra and George, 2002	Absorptive capacity, as a dynamic capability, is 'a set of organisational routines and processes by which firms acquire, assimilate, transform, and exploit knowledge' (p. 186).	Redefined absorptive capacity as a dynamic capability and postulated two possible states: (a) realized absorptive capacity, which refers to the external knowledge that the recipient organisation has actually transformed and exploited, and (b) potential absorptive capacity, which depicts the external knowledge that the recipient organisation could acquire for exploitation. Suggested the notion of absorptive capacity 'efficiency' which refers to 'the ratio of RACAP (realized absorptive capacity) to PACAP (potential absorptive capacity)' (Zahra and George, p. 191).
Todorova and Durisin, 2007	Absorptive capacity is the firm's ability to 'recognise the value, acquire, transtorm or assimilate, exploit new knowledge' (p.776-	Asserted that knowledge may oscillate between assimilation and transformation processes before successful exploitation.

Author	Definitions of Absorptive Capacity	Significant contributions
	777).	Introduced the concept of power relationships as a factor that can influence resource-allocation process for exploitation.
Leahy and Neary, 2007	Absorptive capacity is the firm's 'ability to absorb spillovers from other firms' (p. 1089).	Introduced the construct of spillover and postulated that 'costly absorption both raise the effectiveness of own R&D and lowers the effective spillover coefficient' (p. 1089).
Lim, 2009	Absorptive capacity has three distinct elements: 'disciplinary, domain specific and encoded' (p. 1252).	Postulated three aspects of absorptive capacity and mapped them to the various stages of technology life cycle. Inspired subsequent research on dynamics of interaction among different actors of the technology life cycle (e.g., Kapoor and McGrath, 2012).

Table 2-8: Definitions of Absorptive Capacity and significant contributions

From the above review, it is evident that the absorptive capacity theory has been gaining popularity in the literatures on external technology acquisition (Jones, Lanctot Jr and Teegen, 2001; Vanhaverbeke, Beerkens and Duysters, 2004; Tsai and Wang, 2008; Rothaermel and Alexandre, 2009) and NPD (Ettlie and Pavlou, 2006). The application of absorptive capacity in the research on external technology acquisition and NPD is discussed in detail in Section 2.4.3 and Section 2.5.2, respectively.

2.4.3 Factors affecting External Technology Acquisition

Since the 1990s, there has been an increasing awareness that technological innovation may not be confined within the boundaries of an organisation (von Hippel, 1988; Corey, 1997). In particular, incumbent firms in the high-technology sectors must be responsive to the fast pace of technology changes facilitated by diffusion of knowledge through de-regulation and technological breakthroughs in the info-communication sector. With paradigmatic shifts in market conditions fuelled by the uncertainty that the waves of international financial crises in the past two decades, the firms must be well-positioned for both the opportunities of new

products and services and the threat of competition and substitution (Andrews, 1971). It has been widely acknowledged that technology is an essential resource that can be converted into a capability and competitive advantage for a nation, particularly for developing economies where industrialisation-driven growth is critical (Haque, 1995).

There has been growing concern among both developed and developing nations to put in place the appropriate science, technology and education policies to promote research in both the public and private sectors and encourage stronger linkages between PRIs and the industry to facilitate the transfer of technology and spillover of knowledge. Correspondingly, the management of the firms have been giving more attention to the sourcing of external knowledge to complement and enhance their existing R&D stock (Hagedoorn, 2002; Clarysse et al., 2007), and the acquisition of external technology as part of their R&D process. The acquisition of suitable technology and the knowledge transfer that follows play a critical role in sustaining a firm's competitive advantage and its market share (Wagner and Yezril, 1999). According to Hemmert (2004), external technology acquisition takes place by (a) licensing technology, (b) research collaboration with other organisations and (c) purchasing technology from other organisations. A recent literature review on external technology acquisition by Tsai and Wang (2008) revealed that the current research could be grouped into three categories: (a) significance of the institutional factors on a firm's technology acquisition performance, (b) factors affecting a firm's decision to acquire external technology and (c) relationship between external technology and a firm's performance. This section reviews the three strands of literature with a focus on the theoretical frameworks used, contributions, limitations and suggestions for future research.

2.4.3.1 Institutional Factors

The first stream of literature attempts to examine the institutional factors that correlate with technology acquisition performance, with some studies referring to NIS and R&D management literature, and others drawing upon the concept of absorptive capacity. In 1999, OECD published a report on *Managing National Innovations Systems* to analyse the transformations taking place in the interaction

between the industry and science; more specifically, the changes required of the new and existing firms in capability development and innovation. The report made reference to the NIS and demonstrated how different institutions of innovation systems engaged with one another to influence the innovation performance at various levels from the firm through the nation to the region. To facilitate a comprehensive coverage of the study, a wide range of factors was defined for business institutions, educational institutions, research institutions, etc, for comparison and analysis. These institutional factors included the factor and product markets, the knowledge production and distribution infrastructure, as well as the political and regulatory systems. Furman et al. (2002, p. 899) supported the use of these indicators to examine the 'national innovative capacity' of 17 OECD economies. Building on the NIS framework (reviewed in Section 2.2.1) and the empirical work of Furman et al. (2002) (highlighted in Section 2.2.2), Hemmert classified the comprehensive range of institutional factors into four categories:

1) External resource factors (technological resource and human capital from the external technology provider),
2) Internal resource factors (human capital and financial resource owned by the receiving firm),
3) Knowledge and technology transfer system from the external technology provider to the receiving firm, and
4) Environmental factors (science and technology policy).

Despite the proliferation of empirical studies on the influence of these factors on the firms' performance of technology acquisition using the NIS framework (Lundvall, 1992; Nelson, 1993; Saxenian, 1994; Breschi and Malerba, 1997), some scholars found that the NIS was very useful as a general framework but required to be extended with the literature on R&D management for a detailed analysis of how each of these factors interacted to impact the technology acquisition performance. However, the studies in the R&D management literature focused on the firms' productivity performance from technology acquisition from other firms, rather than from PRIs. The remaining part of this section builds on Hemmert's (2004) suggestion to integrate the literature on NIS and R&D management. It provides an overview of how the latter has contributed to the development of four types of

institutional factors to explain the variation in firms' performance from external technology acquisition.

External Resource Factors

The first category of external resource factors was refined to denote the relevance and complementarity of the external technological resources from PRIs to the receiving firms (Cockburn and Henderson, 1998). McMillan, Narin and Deeds' (2000) study of 119 US biotechnology firms revealed the significance of the firms' reliance on basic science from public research, and supported the results of Patel and Pavitt (1991) pertaining to the significance of firm's ability to customise external technology for internal production and use. Kumar's (2001) research on the factors affecting the decision of international R&D sites among the US and Japanese multi-national companies observed that the relative cost of staffing and the availability of the external technological knowledge were the most critical factors.

Internal Resource Factors

Authors contributing to this area include Lokshin, Belderbos and Carree (2008), whose study of 372 Dutch firms over six years emphasised the importance of strong internal R&D to benefit from the complementarity between internal and external R&D. The findings reinforce the results of an earlier study by Griffith, Redding and van Reenen (2004), who traced the R&D productivity trajectory among the OECD industries.

Knowledge and Technology Transfer System Factors

Empirical research on the knowledge and technology transfer system from the external technology provider to the receiving firm has received much attention. Among these contributions are Mowery et al. (1996), who found that equity joint ventures seem to be more effective vehicles than licensing arrangements to transfer knowledge, particularly in the area of basic research, where knowledge is in tacit form residing in the minds of the scientists of PRIs (Kogut, 1998). They also found that knowledge transfer appeared to be more effective in bilateral than unilateral agreements, since the former arrangement implies a higher level of interdependence

than does the latter. Other studies on the topic included the importance of knowledge transfer as part of the R&D function (Clark and Fujimoto, 1991; Nonaka and Takeuchi, 1995)

Environmental Factors

Environmental factors, such as the country and industry variables, are also of interest to scholars such as Hemmert (2004). Based on a survey of 16 business units in Japan and Germany, Hemmert found that the important factors for technology acquisition performance are: firms' education and training, competency level of their R&D staff, technological readiness level, linkages with PRIs and publicly-funded assistance programmes for the firms' R&D activities. These findings are consistent with the results of Caluori and Schips' (1991) study on Swiss firms, and von Boehmer's (1995) research on American, British and German firms, for the factors affecting the choice of suitable locations for internationalisation of R&D. In both studies, the availability and quality of R&D staff, as well as that of the external technological resource, are rated to be of paramount importance. However, von Boehmer (1995) observed that the government assistance programmes and regulations were not regarded as significant by the firms surveyed. A similar study by Guan et al. (2006) of 2,334 China industrial firms highlighted the need for better coordination among universities, research institutes and industrial organisations to ensure timely and effective application of external technological knowledge in their R&D process.

Implications of First Literature Strand

As mentioned previously, the first literature strand has attempted to examine the influence of the institutional factors on the firms' performance of technology acquisition using the NIS framework (Lundvall, 1992; Nelson, 1993; Saxenian, 1994; Breschi and Malerba, 1997) and R&D management concepts. These studies, however, focused on very specific aspects of certain institutional factors affecting the firms' productivity performance from technology acquisition. There is no distinction in the sources of the external knowledge between public and private sector organisations. Although the authors applied the framework for studying R&D function to external technology acquisition, they acknowledged that the R&D function is not an exact equivalent of external technology acquisition (Hemmert,

2004). In the same vein, the considerations for choosing international sites for R&D activities may not be the same as those for selecting the appropriate public-sector research organisation to work with in the home country for technology licensing. This study addresses the limitations of the first literature strand by considering how the internal and external resource factors interact to impact firms' commercial adoption performance from technology acquisition with public-sector rather than private-sector research organisations.

Another area of future research was highlighted by Tsai and Wang (2008) to investigate the influence of complementarity between internal and external R&D on a firm's performance. Recent studies have shown that a growing number of industries rely on basic scientific research from universities and PRIs to develop internal innovation (Narin, Hamilton and Olivastro, 1997). Drawing upon absorptive capacity theory, McMillan, Narin and Deeds (2000) found that firms in the biotechnology industry have a greater reliance on basic R&D from universities and PRIs than do the large pharmaceutical firms. Apart from emphasising the significant role of public science in enhancing an organisation's innovation effort, the authors' findings also highlight the importance of strong internal R&D to benefit from complementarity between internal and external R&D (Lokshin et al., 2008). The results corroborate the observations of earlier studies on the criticality of knowledge transfer for the firm performance (Clark and Fujimoto, 1991; Nonaka and Takeuchi, 1995). However, despite the significance of this research topic, empirical studies are lacking. It is therefore imperative for future research to analyse external acquisition from the perspective of complementarity of assets and organisational learning (Fosfuri, 2006; Tsai and Wang, 2008). This research contributes to this literature strand by examining the perspectives of asset complementarity and organisational learning through the theoretical lenses of TCE, KBT and absorptive capacity theory.

2.4.3.2 Factors Affecting Firms' Decision

The second stream analyses the factors that affect a firm's decision to acquire external technology. Some authors examine the determinants from the perspectives of the licensor (Fosfuri, 2006; Lichtenthaler and Ernst, 2008; Motohashi, 2005; Arora and Ceccagnoli, 2006). The other contributors study the variables from the

viewpoints of the licensees (Jones et al., 2001; Zahra, Keil and Maula, 2005; Yoshikawa, 2003; Ziedonis, 2004; Atuahene-Gima, 1993). Most of these studies draw upon the TCE theory (Williamson, 1985) and the RBT (Wernerfelt, 1984; Barney, 1991) in their analysis of the factors, their interactions and impact on the firm's propensity for licensing.

From licensor's perspective

Since the 1990s, there has been a phenomenal increase in technology licensing in the US, accounting for US$45 billion of the worldwide technology licensing volume of about US$100 billion annually (*The Economist*, 2005; Fosfuri, 2006). The chemicals, biotechnology, semiconductor, computer and telecommunications sectors have been active participants in the technology licensing markets. Since the start of the 20th century, the practice of cross-licensing contracts among firms in the chemical and manufacturing industries has become a way of life. In Japan, Nagaoka and Kwon's (2006) study of more than 1,100 licensing agreements of the manufacturing firms shows that cross-licensing is more commonly found than unilateral licensing, particularly between large firms of comparable size. Cross-licensing arrangements are also adopted by the firms in pursuit of protecting market share and erecting entry barriers to the market (Grindley and Teece, 1997; Arora, 1997; Hall and Ziedonis, 2001). After World War II, chemical industries began to use technology out-licensing as a source of revenue. Fosfuri (2006) examined the technology out-licensing for 107 chemical products by large chemical firms from the developed nations (Canada, Japan, Western Europe and the US) in 1986-1996. The author's results show that the 'licensor's market share' and 'degree of technology-specific product differentiation' negatively affected their technology licensing rate (Fosfuri, 2006, p. 1141). The author attributed this to the trade-off between 'licensing payments net of transaction costs (revenue effect)' received by the licensor and the 'lower price–cost margin and/or reduced market share implied by increased competition (profit dissipation effect) from the licensee' (Fosfuri, 2006, p. 1141). This implies that licensors need to be aware of the value created from the sale of their own products embodying their technology less the cost of production, against the value derived from the sale of out-licensing the technology less the loss incurred from the licensees' competitive products.

With reference to the transaction cost model, Motohashi (2005), when analysing the out-licensing activities of Japanese firms, found that the size of the firms could impact their propensity to out-license. There seems to be an inverse relationship between the size of the licensor organisation and its propensity to license, where the very small organisations tend to have relatively high licensing propensity possibly due to their lack of internal resources to exploit their technologies internally, which is consistent with the study of Arora and Fosfuri (2003). However, Motohashi found that the very large organisations seemed to display a relatively high propensity as well, and suggested comparison of his results with the empirical research findings in the US and Europe.

Based on the responses of 757 industrial R&D laboratories in the US manufacturing industries during the 1991-1993 period, Arora and Ceccagnoli (2006) found that the ownership of specialised complementary assets and strong patent protection would raise the propensity to patent, while the lack of complementary assets and strong patent protection would positively affect the propensity to license external technology. These findings are consistent with Teece's (1986, 2006) argument that innovators that lack complementary assets but enjoy strong patent protection or tight appropriability regime should consider licensing external technology.

With reference to the RBT (Wernerfelt, 1984), Lichtenthaler and Ernst (2008) tested the relevance of innovation intermediaries in addressing inefficiency in the technology licensing market due to the firms' lack of resources to perform out-licensing exploitations. Based on the data of 152 firms across various industries, they observed that, although intermediaries positively influenced the licensing revenues, their revenue performance was not significantly better than that of their competitors. Considering that intermediaries come at a cost and may also be engaged by the competitors in technology exploitation, Lichtenthaler and Ernst (2008) recommended that, while the innovation intermediaries may play a complementary role in providing the technological and commercial expertise in commercialising technology externally, it is still of paramount importance that the licensors develop their own expertise.

From licensees' perspectives

There is much interest among scholars in examining the dimensions affecting the potential licensees in their decision or propensity to in-license technology. One of the earlier empirical studies was conducted by Atuahene-Gima (1993), who examined 183 engineering and 46 pharmaceutical and chemical firms in Australia to understand the factors determining the propensity for inward technology licensing. Atuahene-Gima found that the firm's size, R&D and NPD capability tend to negatively influence its decision to in-license technology. In other words, firms that have strength in staff and internal R&D are less inclined to in-license external technology, as they are more likely to perform their own NPD (Link, Tassey and Zmud, 1983). On the other hand, Atuahene-Gima (1993, p. 235) observed that 'satisfactory ITL [inward technology licensing] experience' could positively influence the firm's propensity for inward technology licensing.

Using the data of 188 US firms with domestic and foreign parent companies, Jones et al. (2001) studied how a firm's propensity to in-license external technology and performance were affected by IP protection regime, the stage of its technology change life cycle, and the availability of internal resources. While the first two variables were not found to have significant influence on the firm's propensity for external inward licensing, the last variable was observed to negatively impact its inclination to license. This corroborates prior studies (Atuahene-Gima, 1993) that firms with a higher level of internal resources have a lower propensity to license external technology.

New ventures are characterised by limited experience and resource constraints in the face of uncertain technological and market conditions. To gain market share, they compete by developing new innovative products and services based on external technologies. Drawing upon KBT, Zahra, Keil and Maula (2005) studied 361 US new ventures to examine how their propensity for inward technology licensing was affected by their industry characteristics and business strategies. Their results revealed that in industries characterised by a high degree of technological change, new ventures tend to look at inward technology licensing as a strategic option to mitigate the risk of technological obsolescence while building up their internal knowledge and resources.

Yoshikawa (2003) studied how time pressure and the strategic value of the technology could influence a firm's propensity for inward technology acquisition. In another study of 67 US semiconductors between 1980 and 1994, Ziedonis (2004) combined TCE with IP exchange studies to argue that these firms patented aggressively in highly fragmented markets for technology, under a strong legal appropriability regime.

Implications of Second Literature Strand

From the above review of the literature on the key factors determining a firm's technology acquisition propensity, it is apparent that most studies are on firms that in-license to or out-license technologies from other firms, rather than public-sector R&D institutions. Unlike the firms in the industry which are likely to be driven by profit for the firms, public-sector R&D institutions are established as part of the NIS to commercialise publicly-funded research to promote research and knowledge diffusion and spillovers into the industry. While the factors affecting the profit-driven firms in licensing out their technologies may be illuminating, they cannot be generalised to public-sector R&D institutions, which have the social and economic objectives that are not found in the traditional profit-maximising licensors from the industry. The propensity of public-sector R&D institutions to commercialise technology will understandably be relatively much higher while their expected rate of return in the form of upfront payment and royalty stream is likely to be relatively lower, compared to the industry licensors.

In addition, unlike the industry firms, public-sector R&D institutions are neither product designers nor product developers. This means that the technologies that they offer for out-licensing are likely to have a relatively lower readiness level. This may be an additional factor influencing a firm's propensity to license from public-sector R&D institutions. Hence, there is a gap in the current licensing literature to examine the licensing dynamics between public-sector R&D institutions and firms. In addition, Jones et al. (2001) highlighted the need for future research efforts to consider the organisational learning (Hamel, 1991) and absorptive capacity (Lane and Lubatkin, 1998) dimensions in the research design. This research addresses the literature gap by studying public-sector R&D institution-firm licensing

transaction through the perspectives of organisational learning and absorptive capacity.

2.4.3.3 Relationship between External Technology and Firm Performance

In addition to looking at the relative importance of the institutional factors on technology acquisition performance and the determinants of technology acquisition, there are studies focusing on firm performance from acquisition of external technology. The third stream investigates the relationship between external technology and firm performance, including market and financial performance, with extensive reference to the absorptive capacity theory. Examples of studies include Zahra, (1996), Ahuja and Katila (2001), Jones et al. (2001), Vanhaverbeke et al. (2004), Yasar and Morrison Paul (2007), Tsai and Wang (2008), and Rothaermel and Alexandre (2009).

Zahra (1996) studied 112 US new ventures from both independent entrepreneurs and existing corporations to investigate how technology strategy (including external technology acquisition) would impact the firm's performance. Their results reveal that there is a positive relationship between acquisition of external technology and the venture's performance measured by its revenue growth and profitability (Tsai, MacMillan and Low, 1991; Yasar and Morrison Paul, 2008). These findings are supported by the empirical research of Kiyota and Okazaki (2005), who investigated the relationship between external technology acquisition and performance of the public-listed firms in Japan during the 1957-1970 period. They observed that the licensing of external technology is positively associated with higher rate of productivity growth.

This body of literature is informed by theories of organisational learning (Cohen and Levinthal, 1989), innovation and the RBT (Wernerfelt, 1984; Barney, 1991) For example, Ahuja and Katila (2001) applied these theories in the situation of mergers and acquisitions of 72 large firms in the worldwide chemicals industry involving technology acquisition to investigate and predict how the characteristics of the acquisition target could affect the performance of the acquiring companies. In their study, the authors observed that the absolute size of the acquired technology knowledge base could positively influence the innovation output (measured by

patenting output volume) of the acquiring firms. However, when the acquired technology knowledge base became either too closely related or hardly or unrelated to that of the acquiring firm, there was actually a negative effect on the innovation output. Following the process of external technology acquisition, much effort has to be spent on integrating the acquired technology and knowledge into the acquiring firm's technology to be embodied in its products. While the complexity of this effort and the risk of failure are often underestimated (Singh and Montgomery, 1987), the issues of excessive exploration or over-exploitation are possible pitfalls of the acquiring firms (Levinthal and March, 1993). The findings of Ahuja and Katila (2001) have important implications for the managers in their external technology evaluation and assimilation process.

Drawing upon the theory of absorptive capacity (Cohen and Levinthal, 1990), Jones et al.'s (2001) study of US firms found that external technology acquisition has a negative effect on the firm's performance. While the availability of internal resources has a positive relationship with the firm's performance, it is not conclusive that the internal resource availability moderates the relationship between external technology acquisition and the firm's performance. Although inconsistent with the results of Zahra et al. (1996), these findings have significant managerial implications: while external technology acquisition is becoming increasingly prevalent, technology managers must exercise caution in their technology strategy, as it is 'not necessarily a panacea' (Jones et al., 2001, p. 278).

Vanhaverbeke et al. (2004) contributed to the literature with their empirical research on 116 companies from the automotive, pharmaceutical and chemicals industries. Integrating the theoretical concepts of absorptive capacity (Cohen and Levinthal, 1990), technology alliances with complementary assets (Teece, 1986) and social capital theory (Coleman, 1988, 1990), Vanhaverbeke et al. (2004) investigated how the direct ties and indirect ties of a firm affect its success in exploratory and exploitative learning. The direct ties in the social capital notion refer to the other firms with which the focal firm is in primary or direct contact. On the other hand, indirect ties denote the other firms that the focal firm is in secondary or indirect contact with. Both direct and indirect ties represent the quality of the social capital that a firm possesses. Exploitative learning takes place when a firm is

planning to deepen its existing capabilities in the technological areas that it is familiar with, while exploratory learning occurs when the firm does not have the technological capabilities but is experimenting with the new technology to gain some degree of knowledge and familiarity. Vanhaverbeke et al. (2004) found that the acquisition of external know-how is particularly important when firms are exploring with new technologies compared to when they are exploiting existing technologies. Drawing on the concept of social capital, they observe that having indirect ties yields a positive effect on both exploratory and exploitative forms of learning.

More recent studies include those of Tsai and Wang (2008) as well as Rothaermel and Alexandre (2009). Tsai and Wang (2008) showed that firms acquired external technologies to improve their business performance. They conducted a longitudinal study of 341 manufacturing firms in Taiwan's electronics industry from 1998 to 2002 to examine the importance of internal R&D on enhancing their absorptive capacity (Cohen and Levinthal, 1990) for effective use of external technology to improve firm performance. Their results suggest that the acquisition of external technology does not have a significant positive relationship with the firm performance that is measured by value added, computed as sales volume less the material cost. Nevertheless, the availability of internal resources measured in the form of internal R&D has 'positive moderating effect on the relationship between external technology acquisition and firm performance' (Tsai and Wang, 2008, p. 92). This implies the significance of the role of absorptive capacity in enhancing this relationship. These results are corroborated by the findings of Rothaermel and Alexandre (2009), whose study of 141 US manufacturing firms indicated that absorptive capacity enabled firms to balance the tension between internal and external acquisition of new technologies, so as to optimise the benefits arising from the simultaneous pursuit of internal and external technology sourcing.

Implications of Third Literature Strand

Studies in the third strand of literature have enriched our understanding of the effect of external technology acquisition on firm performance in terms of productivity, revenue growth, and innovative output such as patenting frequency. These studies have also connected with the research streams of organisational learning (Cohen

and Levinthal, 1989), innovation and the RBT (Wernerfelt, 1984). However, the reviewed studies have the following issues.

First, the contributions tend to investigate external technology acquisition to be a broad construct encompassing research collaboration agreements, joint-ventures and licensing rather than focusing on particular contract types such as licensing agreements (Stuart, 2000; Vanhaverbeke et al., 2002). As different forms of alliance relationships have distinct characteristics contributing to variation in the dynamics of interaction between the contracting parties (Teece, 1986), it is likely that the agreement type could have a bearing on the technology acquisition propensity and performance of the acquiring firm (Mowery et al., 1996). This research addresses this issue by focusing on a particular type of alliance contract: licensing agreements with PRIs governed by the same umbrella agency, so as to control for variation within the contract types that may affect a firm's technology licensing propensity and performance. According to Tsai and Wang (2008), accounting for variation within the contract types will allow the study to derive more conclusive results on their antecedents, determinants and effects (Tsai and Wang, 2008).

Second, prior research employs the construct of human capital as a proxy to measure absorptive capacity to investigate its effect on the firm performance (Glass and Saggi, 1998; Keller, 1996; Liu and White, 1997). However, given that some studies have established that there is a positive relationship between absorptive capacity and the acquisition of external technology (Kim, 1999; Zahra and George, 2002), there is a need for future research to investigate the 'interaction effects between human capital measures and external technology acquisition effects' on the performance of the acquiring companies (Tsai and Wang, 2008, p. 106). This research addresses this need by examining the interaction effects between firms' human capital and their external technology commercial adoption performance.

Third, most studies have focused on particular geographical regions to study the effects of external technology acquisition, but acknowledge the lack of generalisability of their findings due to the different regional conditions that could introduce unknown and unintended variation to the results (Jones et al., 2001). Given the scarcity of such studies in Southeast Asian countries with their distinct institutional factors (Lundvall, 1992; Nelson, 1993; Saxenian, 1994; Breschi and

Malerba, 1997), this research therefore expands existing studies to Singapore, a country in the Southeast Asian region that is leading in innovation. A summary of the three literature strands of the external technology acquisition literature may be found in Figure 2-2.

From the above review, it is apparent that much literature may be found pertaining to acquisition of external foreign technology in both developing countries such as China and developed economies such as Japan. However, there has been little research done on the firms that acquire indigenous technologies from publicly-funded R&D centres.

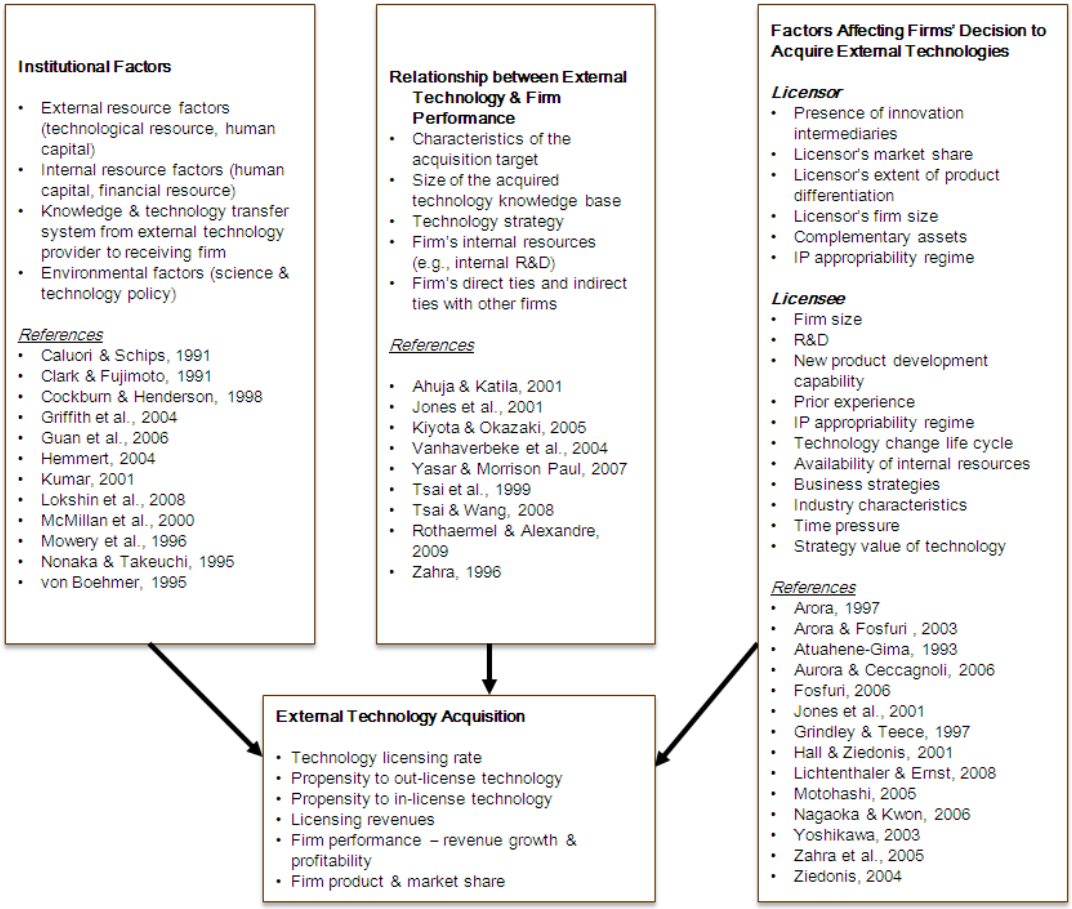

Figure 2-2: An overview of external technology acquisition literature

This may be due to the nascent nature of publicly-funded R&D as both industrialised and industrialising economies strive to increase public R&D investment as part of their NIS (Carlsson, 2006). This research thus contributes to the current literature by investigating the interaction effects between 'human

capital' (in the form of internal and external resources) and 'external technology acquisition' (in terms of propensity) on the commercial adoption 'performance' (sales revenue) of the acquiring companies, which has been highlighted as an important area for further studies in the literature (Tsai and Wang, 2008, p. 106). Further, this research captures the organisational learning (Hamel, 1991) and absorptive capacity (Lane and Lubatkin, 1998) dimensions in the research design. To enrich the contribution of this research to the current body of knowledge, this study also reviews in the next section the other literature areas on open innovation and NPD performance to examine the extant studies on firms acquiring technological innovation from publicly-funded R&D centres.

2.5 Innovation and Performance at Firm Level

The concept of innovation being more transnational and sharpening distinction between innovation ownership and inventorship is gaining importance in the literature on innovation. The increase in transfer of patents and technologies across organisational and national boundaries has managerial implications on the willingness of firms to open up channels to acquire and absorb external knowledge. The *Innovation Union Competitiveness Report* (European Commission, 2011, p. 303) shows that the trend of foreign ownership of domestic inventions for a range of countries as highlighted in Figure B-9 of Appendix B. It is apparent that, with the growing distribution of knowledge across the globe, most countries except the European Union, Japan, China and the Russian Federation, see the outbound transfer of the technologies that are invented locally to another country. The average proportion of foreign ownership of domestic inventions filed at European Patent Office (EPO) increased from 16.3% in 2000 to 17.6% in 2007. According to the Report (European Commission, 2011), most of technology transfers were the activities of multi-national enterprises which have R&D activities beyond their home countries.

In Figure B-10 of Appendix B, it is noteworthy that countries such as Japan and South Korea have a relatively low level of domestic ownership of foreign inventions. China has shifted from acquisition of foreign inventions to absorption of her indigenous inventions (European Commission, 2011, p. 304). It is apparent

from the above charts that the system of knowledge production has become more distributed as firms begin to pursue alternative channels of innovation to enhance their competitive advantage (van de Vrande, Lemmens and Vanhaverbeke, 2006). This process of innovation that firms engage in to generate knowledge and capture its value from its interactions with the external environment has been conceptualised as open innovation by Chesbrough (2003).

This section reviews the literature on open innovation. It examines how the academic community has assessed the role of technology flow across organisational boundaries and contribution of ideas from users on open innovation. The significance of a firm's business models and IP appropriability that has been highlighted in the extant literature with reference to the theoretical framework of TCE (Williamson, 1975) and complementary assets (Teece, 1986) is also discussed. In addition, the growing role of intermediaries has gained attention and started a separate stream in the literature on open innovation. Accordingly, the existing research on how intermediaries facilitate inter-organisation innovation exchanges and impact organisational performances is reviewed. This section concludes with a review of the literature on NPD to establish the relationship among innovation, NPD and performance.

2.5.1 Open Innovation and Intermediation

The term open innovation was first introduced by Chesbrough (2003) to delineate the processes of innovation that firms engage in to generate knowledge and capture its value from its interactions with the external environment (van de Vrande et al., 2006).

According to Chesbrough, 'Firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology' (2003, p. xxiv). He and his colleagues further defined open innovation as 'the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively' (Chesbrough, 2006b, p. 1). Hence 'openness' refers to acquisition of external knowledge (Lichtenthaler, 2011, p. 76). As openness implies interaction with external parties and traversal across boundaries, some scholars

trace the initial development of the open concept back to prior studies as early as the TCE (Williamson, 1975; Dahlander and Gann, 2010). The TCE concept defined the boundaries of firm and regarded interactions as internal routines, but it assumed transactions as activities with external actors characterised by shallow relationships and the firm's interest safeguarded by legal arrangements.

As different forms of transaction with external parties evolve depicting relationships of varying depths and levels of trust, the hybrid arrangements are discussed in the subsequent studies by Williamson (1985) and the concept of complementary assets developed by Teece (1986). Studies by Powell (1990) emphasised the importance of network for knowledge generation in many disciplines, while Langlois (2003) highlighted that innovation may not necessarily occur within the organisational hierarchy. This implies that the notion of openness refers to the firm's flexibility in choosing between internal or 'closed' innovation in the form of in-house R&D and 'open' innovation in the form of collaboration with external actors who may be individuals or organisations (Dahlander and Gann, 2010, p. 703).

In the last decade, the concept of open innovation gained more prevalent attention. According to Dahlander and Gann's (2010) analysis of the articles published in Thomson's ISI on Web of Knowledge (ISI), the authors found a growing volume of publications for the past decade on the topic of open innovation. The author of the current research performed a similar search on Science Direct database and found a similar trend from 2000 to 2011, as shown in Figure 2-3. The top 10 journals publishing articles on the topic of open innovation may be found in Table 2-9.

In these publications, Chesbrough's book on *Open innovation* (2003) was most frequently cited, followed by other models such as absorptive capacity by Cohen and Levinthal (1990) and the complementary assets by Teece (1986) (Dahlander and Gann, 2010). Based on their review of the 150 papers authored by 244 scholars, Dahlander and Gann (2010) identified research trends and developed an approach that employs two dimensions for defining different types of openness. The first dimension pertains to the direction of the flow of innovation: (a) 'inbound innovation' which refers to innovation from the external actor that could be of benefit to the firm, and (b) 'outbound innovation' denoting innovation that is of

benefit to the external actor to which the firm would like to be exposed (Dahlander and Gann, 2010, p. 704).

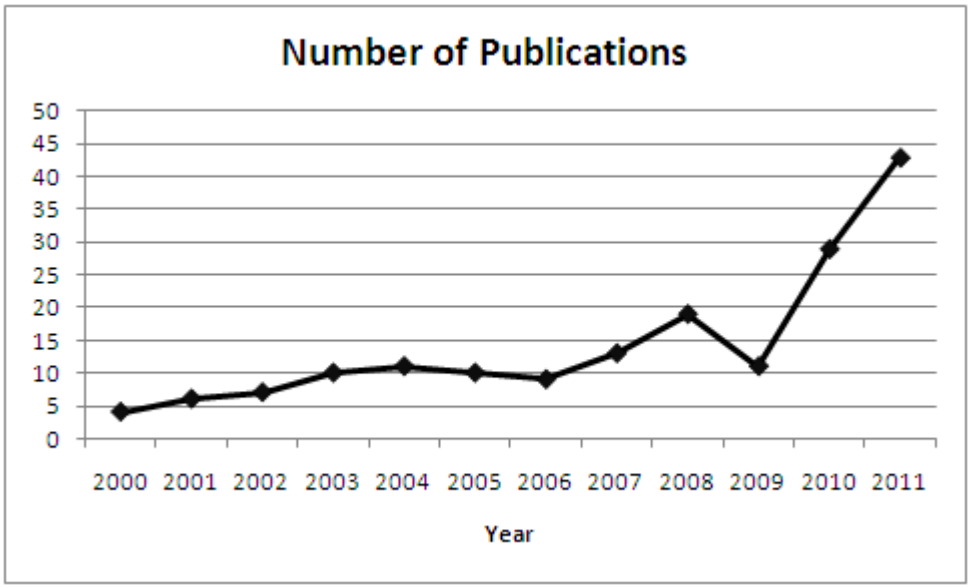

Figure 2-3: Number of publications on open innovation, 2000-2011 (Source: Science Direct database)

Major Journals	Number of publications on open innovation
Research Policy	42
Technovation	36
Technological Forecasting and Social Change	18
Telecommunications Policy	7
European Management Journal	7
Futures	7
Journal of Business Research	7
Long Range Planning	6
Technology in Society	5
Journal of World Business	4

Table 2-9: Major journals with publications on open innovation, 2000-2011 (Source: Science Direct database)

The second dimension accounts for the kind of benefits involved from the flow of innovation: (a) 'pecuniary' which describes monetary benefits arising from the flow such as in-licensing as an example of 'acquiring' inbound innovation and out-licensing as that of 'selling' outbound innovation; (b) 'non-pecuniary' which comprises non-monetary benefits derived from the innovation flow, such as technology intelligence gathering from interaction with the external environment as

a means of 'sourcing' to sharpen the firm's R&D focus as inbound innovation; and the firm's sharing of new technology with the potential buyers as a means of 'revealing' to market the firm's technology (Dahlander and Gann, 2010, pp. 703-705). With this framework to analyse the studies for the past decade, Dahlander and Gann (2010) demonstrated that the practice of open innovation could be costly (Laursen and Salter, 2006), suggesting that future research should look at improving the clarity between open innovation and the firm's strategy and performance (Chesbrough and Appleyard, 2007).

Among the studies on the topic of open innovation reviewed by Dahlander and Gann (2010), Lichtenthaler was found to have made significant contribution. In his recent work (2011), Lichtenthaler noted that research on open innovation tend to focus on integration of various aspects. In addition to looking at the assimilation of external knowledge into the internal knowledge base of the firm drawing upon the concept of absorptive capacity (Chesbrough, 2006a; Cohen and Levinthal, 1990), open innovation also looks at the integration of internal and external processes to manage knowledge from both internal and external sources (Chesbrough, 2003; Cassiman and Veugelers, 2006). Another aspect that open innovation literature scrutinizes is the linkage of the concept of technology management (such as external technology acquisition) with the notion of NPD (Laursen and Salter, 2006; Tsai and Wang, 2008).

The four strands of literature on this topic pertain to the roles of the following in open innovation: (a) flow of technology across organisational boundaries, (b) contribution of ideas from users, (c) business models and IP appropriability, and (d) intermediaries that facilitate inter-organisation innovation exchanges.

Flow of technology across organisational boundaries

The first strand of literature on open innovation revolves around both inward and outward technology transfer, the role of absorptive capacity in assimilation of external knowledge. As this strand relates to external technology acquisition literature, which has been covered extensively in Section 2.4.3, the same concepts will not be repeated here.

Role of users in innovation

The role of users in innovation has gained attention since the significant contribution to the literature strand by von Hippel in the 1970s. His study comprising 111 innovations (1976) found support for the role of scientific instrument users in the process of innovation, who reportedly participated in the idea generation, implementation and pilot testing activities of about 80% of the innovations. Similar results of user-inspired innovations were found in earlier studies in the chemical industry where users contributed to 70% of significant process innovations (Freeman, 1968), in the textile industry where 80% of unit cost savings were improvements made by user organisations (Hollander, 1965). From the literature review, it is apparent that there are two types of user innovators: intermediate user innovators and consumer user innovators (Bogers, Afuah and Bastian, 2010).

Intermediate users typically refer to firms that utilise materials or machinery from the supplier to manufacture goods and services. They may also include professionals such as researchers and clinicians in utilising tools and equipment in performing their tasks. Corroborating evidence of intermediate users as sources of innovation is also found in the computer-aided design application (Urban and von Hippel, 1985), semiconductors (von Hippel, 1988), information systems (Morisson, Roberts and von Hippel, 2000; Franke and von Hippel, 2003) and banking and finance industry (Oliveira and von Hippel, 2009).

Consumer users generally include end users of products and services, who could be well positioned to suggest improvements to the products and services consumed based on their experience of interaction. Evidence of consumer-inspired innovation is documented in the land sports industry (Lüthje, 2004; Franke and Shah, 2003) and sea sports industry (Tietz, Morrison, Lüthje and Herstatt 2005; Baldwin, Hienerth and von Hippel, 2006; Raasch, Herstatt and Lock, 2008).

Some studies attempt to analyse the reasons for user-led innovation. For example, Bogers et al. (2010) postulated that users' propensity to innovate could be influenced by the monitoring costs arising from incompatibility of goals between the users who play the role of principals and the producer of the products/services

who assume the position of agents (von Hippel, 2005). While the users would like the innovation to be as customised to their own needs as possible, the producers would like to minimise the cost of production or maximise profit by making the solution as general as possible for the other potential users. Apart from costs, the benefits that users could expect from innovation constitute another factor that could affect the users' propensity to innovate (von Hippel, 2005; Bogers et al., 2010).

While there is also research on how to harness the power of user innovation as partners, (Prahalad and Ramaswamy, 2003; Buur and Matthews, 2008), there are other contributions to examining the process of co-invention and co-production between the users and the producers and their interaction dynamics (Sawhney, Verona and Prandelli, 2005; Jensen, Johnson, Lorenz and Lundvall, 2007). This research generally focuses on the mechanisms (such as the Internet platform) and their effectiveness of engaging users to provide innovative ideas and feedback at various stages of the NPD process.

Role of business models and IP appropriability

The third strand of literature on open innovation pertains to business models that can capture the value of open innovation. As Chesbrough (2007b, p. 22) put it, 'Using outside technologies to develop products and licensing internal IP to external parties will carry a company only so far'. He went to advocate that '[t]he next frontier in innovation is to open the business model itself' (Chesbrough, 2007b, p. 22). With the growing competition in the market that is becoming boundary-less with de-regulation and increasing connectivity, firms face the threat of reduced revenue streams from shorter product life cycles and challenge of rising innovation costs driven by rapid technological changes (Chesbrough, 2006b, 2007b). Chesbrough (2007b) advocated that the firms should respond by transforming their business model from the traditional closed form to the new open form. In the new open business model, firms could use inbound innovation (such as inward technology licensing or joint research alliance) to manage the growing R&D costs and exploit outbound innovation (such as outward technology licensing or spinning off new ventures) as new sources of revenue (Zahra et al., 2005; Fosfuri, 2006). Other authors continue to build on the works of open business model to examine

the issue of IP appropriability as firms expose their technological knowledge for inter-firm transfer (van der Meer, 2007; Alexy, Criscuolo and Salter, 2009).

In particular, Kwanghui Lim, Henry Chesbrough and Yi Ruan (2010) analysed how a large incumbent (IBM) attempted to respond to the challenges of two new market entrants (Intel and AMD) from the late 1970s till 2004 to gain insight in how firms could adopt 'co-opetition' strategy to manage their IP appropriability issues while pursuing an open innovation business model (Chesbrough, 2007b). They suggested that one of the more sustainable R&D management strategies for incumbents in the semiconductor industry is to turn to 'universities, research consortia, research institutes, suppliers and others' to provide the basic research services as these services require very hefty investment that are hard to recover by a single firm (Lim et al., 2010, p. 24).

Frans Carpay, Hang Chang-Chieh and Dan Yu (2007) developed the literature strand of open innovation business models further by examining a specific form of open innovation – R&D outsourcing – and its associated issues. Based on their study of two firms in Consumer Electronics business, the authors extended Prahalad and Hamel's (1990) argument by confirming a firm's core competence remains a significant source of competitive advantage, and adding that 'there is no conflict between open innovation and core competence in outsourcing R&D' (Carpay et al., 2007, p. 256).

Other authors such as van de Vrande, de Jong, Vanhaverbeke and de Rochement (2009), Lee, Park, Yoon and Park (2010), as well as Vanhaverbeke (2012) argued that the motives and management challenges faced by SMEs in open innovation are distinct from those of large MNCs, particularly in the areas of business models and IP management. As Chesbrough (2006b, 2007b)'s model is confined to large companies which are well-resourced, the works of these authors on SMEs are therefore a significant contribution to the literature on open innovation. From a dataset of 605 Dutch SMEs, van de Vrande et al. (2009) found that the SMEs were primarily motivated by pressures from customers and competitors. The SMEs also faced organisation cultural challenges such as communication problems with external partners. Lee et al. (2010) found empirical support for the effectiveness of

an intermediated network among Korean SMEs. They compared barriers to innovation between SMEs and large firms, and found SMEs' preference for technology purchase from university research centres, as shown in Figure B-11 of Appendix B. These results imply the critical role of universities and PRIs in the innovation market of SMEs. Vanhaverbeke's (2012) in-depth case study of ten European innovative SMEs revealed that conceiving and experimenting with innovative business model that creates value for target customers was critical for superior business performance. One of the key drivers for business model change would be new technologies that might not necessarily be developed in-house (Vanhaverbeke, 2012, p. 34). SMEs pursuing open innovation practices are particularly vulnerable to IP management issues given the high costs of patenting (Vanhaverbeke, 2012, p. 76) and partner commitment risks due to limited financial and bargaining power of the SMEs (Vanhaverbeke, 2012, p. 90).

There are other scholars who enriched the literature on open innovation business models further by integrating it with the perspective of disruptive innovations[25] (Christensen, 1997, 2006; Govindarajan and Kopalle, 2006). Especially noteworthy is the review by Dan Yu and Chang-Chieh Hang (2010, p. 447), who suggested the application of open innovation model to develop a response strategy for firms to manage disruptive innovations in the form of 'collaboration between incumbents and start-up firms'.

Role of Intermediaries

Chesbrough (2006a) argued that firms must be open to innovation beyond the organisational boundaries, including those that are not in the high-tech industries. More recent studies on open innovation focus on the role of innovation intermediaries and their intermediation process in facilitating inter-organisation technology and innovation transfer to improve the innovation market efficiency by matching the buyers and sellers of innovative technologies. These studies form the

[25] The concept of disruptive innovation was first heralded by Christensen (1997) in his publication of *The Innovator's Dilemma.* The concept has been refined subsequently by many scholars, including Govindarajan and Kopalle (2006). These authors defined disruptive innovations as having the following characteristics: (a) attributes that are inferior to those valued by the mainstream market, (b) attributes that are valued by new emerging market, (c) lower prices, and (d) growth rate of performance trajectory exceeds that demanded by mainstream market (Yu and Hang, 2010, p.439).

fourth strand of literature on open innovation (Howells, 2006; Lichtenthaler and Ernst, 2008; Nambisan and Sawhney, 2007).

Howells (2006) argued that the concept of intermediaries in innovation is not new. He traced the history of intermediaries in the development of technological knowledge to the history of 'middlemen' between the 16th and 18th centuries in the UK (Howells, 2006, p. 715-716), where they were instrumental in diffusing innovation as part of their trade in the textile and agricultural industries (Farnie, 1979; Smith, 2002). Based on case studies of 22 innovation intermediaries in the UK, Howells (2006) provided a framework for the different roles of intermediaries in the intermediation process, ranging from technology brokers to bricoleurs.

While Watkins and Horley (1986) explored the role of intermediary agencies in facilitating the innovation transfer from large to small enterprises, Braun (1993) discussed the role of intermediary agencies that formulate policies for R&D with the principal-agent theoretical framework. Turpin, Garrett-Jones and Rankin (1996, p. 267) investigated the role of 'bricoleurs' and 'boundary riders' in seeking opportunities for new technology applications within the research network. Similarly, Provan and Human (1999, p. 185) studied the role of 'network broker' in knowledge dissemination within the small business network.

Millar and Choi (2003) built on earlier studies to examine the intermediaries and ethical challenges involved in supporting the knowledge recipient's assessment of the non-pecuniary benefits of the inbound innovation. Lichtenthaler and Ernst (2008) tested the relevance of innovation intermediaries in addressing inefficiency in the technology licensing market due to the firms' lack of resources to perform out-licensing technology exploitation. From their study of 152 firms across various industries, they observed that, although the intermediaries positively influence the licensing revenues, their revenue performance was not significantly better than that of their competitors. As intermediaries come at a cost and may also be engaged by the competitors in technology exploitation, Lichtenthaler and Ernst (2008) recommended that, while the innovation intermediaries may play a complementary rather than a substitution role in introducing external innovation, it is still of paramount importance that the recipient organisations continue to develop their own expertise.

Nambisan and Sawhney (2007, p. 110) likened the innovation market to that of an 'innovation bazaar' that can be 'chaotic and bewildering'. In response, they developed an approach for external sourcing of innovation from a range of innovation intermediaries based on their development stage, company factors as well as industry and market factors. A summary of the four literature strands of the innovation literature may be found in Figure 2-4.

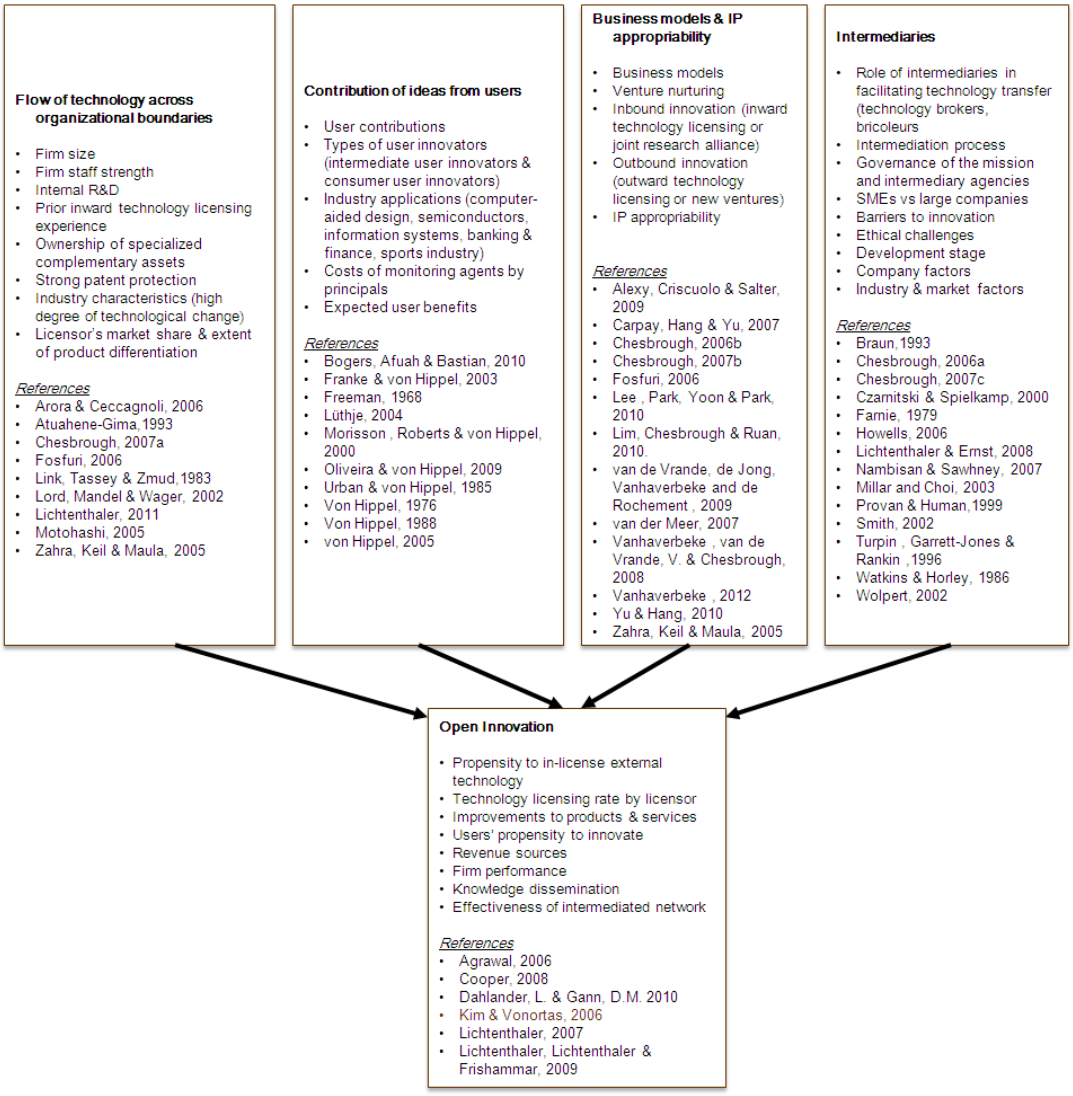

Figure 2-4: An overview of open innovation literature

Implications of Open Innovation Literature

We have seen that the first strand of open innovation literature revolves around the inward technology transfer and the role of absorptive capacity in assimilation of external knowledge. Most of the studies in this strand have looked at the inbound

and outbound open innovation activities between firms across industries and geographical areas (Atuahene-Gima, 1993; Jones et al., 2001; Lord et al., 2002; Fosfuri, 2006; Motohashi, 2005). However, given the growing importance of the university and PRIs as one of the triple helices in the NIS, there is a lack of studies in this strand on how the characteristics of these new innovation sources from the public sector are similar to, or different from, the traditional innovation sources of the private sector enterprises in influencing the propensity and performance of the technology acquisition recipients (Lichtenthaler, 2011).

In the second strand of open innovation literature that pertains to user-led innovation, critics have found a lack of theoretical frameworks for the study of user-led innovation (Bogers et al., 2010; Lichtenthaler, 2011). It appears that some authors are sceptical about the effectiveness of users' roles as innovators as the users possess tacit or sticky knowledge and the producers may have limited absorptive capacity (Polanyi, 1966; Cohen and Levinthal, 1990). Moreover, the definitions of users and the relative effectiveness of their roles in the various types of innovation from incremental to radical innovations (Henderson and Clark, 1990; Bogers et al., 2010), and during different stages of the technology life cycle (Utterback, 1994) have yet to addressed by existing studies.

The third strand of open innovation literature that focuses on business models and the roles of IP appropriability as a catalyst or inhibitor is beginning to gain attention. There is a need to develop rigorous theoretical frameworks to identify the typologies of various profitable open innovation business models for analysing the relationships between the models and the different new product types that maximise the capture of value derived from the opening of innovation under different types of IP appropriability regimes (O'Connor, 2006). In addition, more attention is warranted on the effective ways to manage the process of open innovation from initial stage of idea conceptualisation through transfer and assimilation of external knowledge for product or process innovation to the final stage of commercial adoption from the theoretical lenses of NPD and technology life cycle (Dahlander and Gann, 2010).

The innovation intermediaries that form the fourth strand of open innovation literature is a relatively new stream of discussion on how they facilitate inter-

organisation innovation exchanges and impact organisational performances (Howells, 2006; Lichtenthaler and Ernst, 2008; Nambisan and Sawhney, 2007). With the increasing significance of innovation markets, there is also growing interest in the dynamics of the markets and the role of IP (Bessen and Meurer, 2008; Ziedonis, 2008; Lichtenthaler, 2011). As indigenous research organisations gain importance as centres of technological innovation, the role of TTOs as intermediaries in facilitating IP licensing and transferring technological knowledge to the recipient firms, as well as the impact on the firms' performance are also areas that deserve more focus. This research studies the innovation outcome of knowledge transfer from indigenous research organisations to firms through TTOs as intermediaries, and examines how the TTO staff availability and quality affect the relationship between firms' NPD and their commercial adoption performance. The next section examines the extant literature on NPD and business performance.

2.5.2 NPD and Business Performance

In high-technology businesses, NPD has long been an important process for bringing innovation from the research laboratory to the market for revenue growth. Its theoretical underpinnings could be traced back to the innovation diffusion model (Rogers, 1983), illustrating the rate of adoption in the form of an S-curve. The diffusion model is based on communication theory and the diffusion process refers to the dissemination of innovation to members of the society across certain media for a period of time (Rogers, 1983; Martinez, Polo and Flavian, 1998). The notion of diffusion first started in the 1960s in the literature on consumer behaviour (Arndt, 1967; Frank, Massy and Morison, 1964) and was developed further in the 1980s by authors such as Gatignon and Robertson (1985) and Rogers (1983) in the paradigm of consumer marketing. Rogers grouped the consumers into five categories according to their willingness to adopt new products: (a) 'innovators', (b) 'early adopters', (c) 'early majority', (d) 'late majority' and (e) 'laggards' (Rogers, 2002, p. 990). The first two categories, innovators and early adopters, were recommended by Moore (1998) to be the target customer for high-tech market in the early NPD stage. He postulated that their response to the initial product could spell success or failure for the product. Von Hippel's (1986) study also emphasised the importance of close communication with lead users to improve the chances of new product success.

According to Ernst (2002), the literature on NPD, existing since the 1970s, have continued to gain attention among scholars and practitioners for the past decades. A review of his grouping of the NPD success determinants suggests that there are three strands during the period from 1970s to 1990s. In the recent decade, two new strands have emerged in the NPD literature. The fourth strand examines the innovation-performance link using the CDM model based on the Cobb-Douglas production function. The fifth strand focuses on inter-firm NPD in the face of rising costs and technology complexity as well as new models of NPD collaboration by integrating the literatures of organisation learning, dynamic capabilities and trust (Bhaskaran and Krishnan, 2009; Ettlie and Pavlou, 2006; Bstieler, 2006; Li, Bingham and Umphress, 2007).

This section reviews the five strands of NPD literature that have emerged: (a) NPD process, (b) organisational dimension, (c) new product and technology strategy, (d) innovation-performance link and the CDM model, and (e) new models of inter-firm NPD collaboration. The current limitations and future research directions are also highlighted.

2.5.2.1 NPD Process

The first strand pertains to the critical success factors on the NPD process. Based on a study of 104 companies hosting 195 projects in Canada, Cooper (1979a, 1979b, 1980a, 1980b) identified that NPD activities such as prototyping, market testing and information gathering about consumer needs and buying behaviour are positively associated with NPD project success. In subsequent studies of 122 companies in Canada by Cooper and Kleinschmidt (1986, 1987a, 1987b, 1987c), the results revealed a positive influence of rigorous market due diligence and technology evaluation activities, as well as clarity of target market definition and product conceptualisation on NPD profitability. Similar findings were obtained by the same authors from their studies of the chemical industry in the UK and the US (Cooper and Kleinschmidt, 1993, 1994, 1995b). These results were corroborated by the studies of other authors (Utterback, Allen, Hollomon and Sirbu, 1976; Souder and Chakrabarti, 1978; Calantone and di Benedetto, 1988; Dwyer and Mellor, 1991a, 1991b; Parry and Song, 1994; Atuahene-Gima, 1995; Mishra, Kim and Lee, 1996; Balbontin, Yazdani, Cooper and Souder, 1999).

2.5.2.2 Organisational Dimension of NPD

The second strand of NPD literature examines the organisation dimension. The studies contributing to this strand consistently highlight the significance of project team leadership, diversity of disciplines and dedication of project team members on NPD success (Pinto and Pinto, 1990; Cooper and Kleinschmidt, 1993, 1994, 1995a, 1995b, 1996; Song, Montoya-Weiss and Schmidt, 1997; Song and Parry, 1997). In addition, Balbontin et al. (1999) highlighted the relevance of organisational communication and project management skills (Ebadi and Utterback, 1984; Yap and Souder, 1994), while Gerwin and Moffat (1997) emphasised the importance of autonomy for high-performance team (Thamhain, 1990). In addition to the project team structure and dynamics, other authors have examined the role of organisational culture on NPD performance.

In the area of organisation culture and NPD, there were studies that examined the constituents of a culture that encourages innovation, comprising entrepreneurial climate (Cooper and Kleinschmidt, 1995a) and risk-taking behaviour (Voss, 1985), the presence of strong executive supporter or champion (Chakrabarti, 1974; Maidique and Zirger, 1984; Cooper and Kleinschmidt, 1993; Yap and Souder, 1994; Barczak, 1995; Song and Parry, 1997). In particular, Cooper and Kleinschmidt (1995a) defined entrepreneurial climate along various dimensions involving support for bootstrapping and availability of resources for unsanctioned projects. The 3M culture has been frequently cited as an example of a climate that encourages new ideas to be conceptualised and developed into new products with a high level failure tolerance, work autonomy and employee empowerment (Ernst 2002). The role of available resources such as ‘internal venture capital’ or ‘seed capital’ for bootstrapping of skunk projects have also been investigated to be of relevance to encouraging NPD (Siegel, Siegel and MacMillan, 1998; Sykes, 1990; Chesbrough, 2000).

Another aspect of the organisational dimension strand in the NPD literature revolves around the influence of senior management on NPD performance. There was general consensus on the role of senior management commitment and involvement in prioritisation of NPD projects and allocation of financial, technological, marketing and sales resources (Thamhain, 1990; Voss 1985; Yap and

Souder, 1994). Cooper and Kleinschmidt (1995b) also highlighted that the incentives for senior management in championing NPD projects as being critical in ensuring their success. March (1991) also cautioned that organisational emphasis on short-term financial goals may drive managerial behaviour to prefer exploitative or incremental innovation at the expense of exploratory or radical innovation that would be crucial for the future of the firm.

2.5.2.3 New Product and Technology Strategy

The third strand of NPD literature dwells on the role of new product road mapping strategy on the NPD performance. Based on a study of 122 Canadian firms, Cooper (1983, 1984a) found that a coherent strategy of related new products that complement existing product family has a positive relationship with the overall NPD performance and impact. These findings are supported by similar results obtained by Perillieux (1987). There is also consensus for the significance of a NPD programme with sharp strategic focus and well-defined objectives among Maidique and Zirger (1984), Meyer and Roberts (1986), Thamhain (1990), Cooper and Kleinschmidt (1995a, 1996) and Griffin (1997).

Despite the proliferation of works on the role of process, organisation and strategy on NPD performance from 1970s to 1990s, Ernst (2002) argued that the studies lack theoretical underpinnings. For example, the concept of culture and its typologies were not defined clearly in this strand of literature, resulting in a spate of disparate studies of different aspects of what the authors perceived as culture based on individual variables not firmly grounded in rigorous organisational theory. As for the methodology of empirical research, Ernst (2002) observed that more rigour would be required of most of the research works. As a case in point, the methodology employed by Cooper and Kleinschmidt seemed relatively stable for the thirty decades from 1970s to 1990s. Furthermore, bivariate analysis was performed rather than multivariate validation when there were multiple variables involved and the interaction among the variables and multi-collinearity issues were not adequately investigated (Ernst, 2002).

2.5.2.4 Innovation-Performance Link and CDM

The fourth strand discusses the innovation-performance link and CDM. For several decades, there have been many firm-level studies in Europe and the US examining the link between innovation and performance, such as firm productivity using the CDM. The earlier studies were carried out in the US (Lichtenberg and Siegel, 1991), Norway (Klette and Johansen, 1996), Sweden (Lööf and Heshmati, 2002), Germany (Bönte, 2003), France (Mairesse and Mohnen, 2005), the Netherlands (van Leeuwen and Klomp, 2006), and Italy (Parisi et al., 2006). These studies found support for the positive effect of R&D on firm productivity. However, some researchers argued that while R&D is a significant factor, it is just an innovation input that should not directly affect a firm's performance. Rather, the latter is influenced by innovation output, such as process innovation, product innovation or both. To address this concern, Crépon et al. (1998) developed the CDM approach that depicts two key relationships pursuant to a firm's decision to invest in innovation. The first relationship describes the link between innovation input (comprising primarily R&D) and innovation output (in the form of product or process innovation) as accepted in the knowledge production function (Pakes and Griliches 1984). The second relationship established the connection between the innovation output and productivity based on Cobb-Douglas production function.

More recent studies on innovation and productivity have adopted the CDM with some modification depending on the nature of the data (Parisi et al., 2006; Hall et al., 2009). However, there is currently a dearth of studies in linking the relationships among propensity to license external technology, innovation outcome and public research commercialisation performance other than productivity.

2.5.2.5 Inter-Firm NPD Collaboration

In the last decade, more recent literature tends to have improved on theoretical frameworks and empirical research methodologies. The NPD body of research tends on focus on the need for inter-firm NPD in the face of rising costs and technology complexity. Greater uncertainty of product adoption due to shorter product life cycles and increasing competition has led to more interest among scholars and practitioners to look at new models of NPD collaboration by

integrating the literatures of organisational learning, dynamic capabilities and trust (Bhaskaran and Krishnan, 2009; Ettlie and Pavlou, 2006; Bstieler, 2006; Li et al., 2007), giving rise to the fifth strand of the NPD literature.

Drawing upon the theoretical framework of absorptive capacity (Cohen and Levinthal, 1990; Zahra and George, 2002), Ettlie and Pavlou (2006) studied 72 automotive company managers and their suppliers. The authors used absorptive capacity as a first-order construct along with coordinating capability and collective mind, to develop the second-order construct NPD partnership capabilities. The second first-order construct, coordinating capability, refers to the inter-firm NPD alliance capability to coordinate activities and resources to enhance the process of NPD. This coordinating capability construct is similar to those used in the literature on project team behaviour such as coordination (Argote, 1982), cooperation (Pinto, Pinto and Prescott, 1993), integration (Kahn, 1996), and collaboration (Liedtka, 1996). As for the third first-order construct, collective mind describes the inter-firm NPD alliance capability to 'integrate disparate resources with heedful contribution, representation, and subordination into a collective system' (Ettlie and Pavlou, 2006, p. 122; Weick and Roberts, 1993). Their results show that 'absorptive capacity, coordination capability and collective mind' have a significant impact on inter-firm NPD dynamic capabilities (Ettlie and Pavlou, 2006, p. 122). These findings are supported by the prior studies of Zahra and George (2002), Crowston (1997), and Helfat and Peteraf (2003).

According to the definition by Teece et al., NPD dynamic capabilities denote 'the ability to integrate, build, and reconfigure internal and external competencies to address rapidly-changing environments' (Teece et al., 1997, p. 517). The inter-firm NPD dynamic capabilities in turn positively influence the NPD partnership success, defined as the rate of new product success and superior product commercialisation.

Other studies on inter-firm NPD examine the notion of collaborative problem-sharing (Li et al., 2007) and communication capability (Bstieler, 2006) that influence NPD performance. Based on the study of 44 NPD alliances in the manufacturing industry in Austria, Bstieler (2006) made a significant contribution to the NPD literature by introducing the mediating role of trust between a set of factors and the NPD project performance. Trust is defined as the 'willingness to

accept vulnerability based upon positive expectations of the intentions or behaviour of another within a particular context' (Bstieler, 2006, p. 57; Rousseau, Sitkin, Burt and Camerer, 1998). The set of factors that are found to positively affect trust formation as an intermediate outcome comprised willingness to share information, collaborative problem-solving and perceived procedural justice. On the other hand, trust formation could be negatively affected by the existence of dispute between the partners, and partners seeking their own gain at the expense of the partnership. Bstieler's study (2006) concluded that a positive relationship exists between trust formation and NPD performance.

In the same vein, Li et al. (2007) conducted a study of 109 technology enterprises and 91 project groups from the manufacturing industries to examine the critical factors for successful partnership among project team members by drawing upon the literature on procedural justice. Procedural justice may be defined as the fairness of organisational procedures or routines as perceived by the employees. The perception of fairness by the staff would in turn drive their behaviours and responses to certain events. Their results indicate the mediating role of 'collaborative problem solving' between 'perceived procedural justice' and 'new product development performance' (Li et al., 2007, p. 200). A summary of the key strands of the NPD literature may be found in Figure 2-5.

From the above literature, it is apparent that the theoretical frameworks and research methodologies have become relatively more developed in the last decade. However, the current NPD literature tends to focus on the new models of NPD collaboration between firms within a single industry (Bstieler, 2996; Ettlie and Pavlou, 2006). There are therefore limited studies on how firms respond to universities and public research laboratories as partners for NPD collaboration. The critics have also highlighted that the present studies deliberate on 'what NPD professionals learn from NPD' and 'how NPD professionals learn still needs much investigation' (Goffin and Koners, 2011, p. 315).

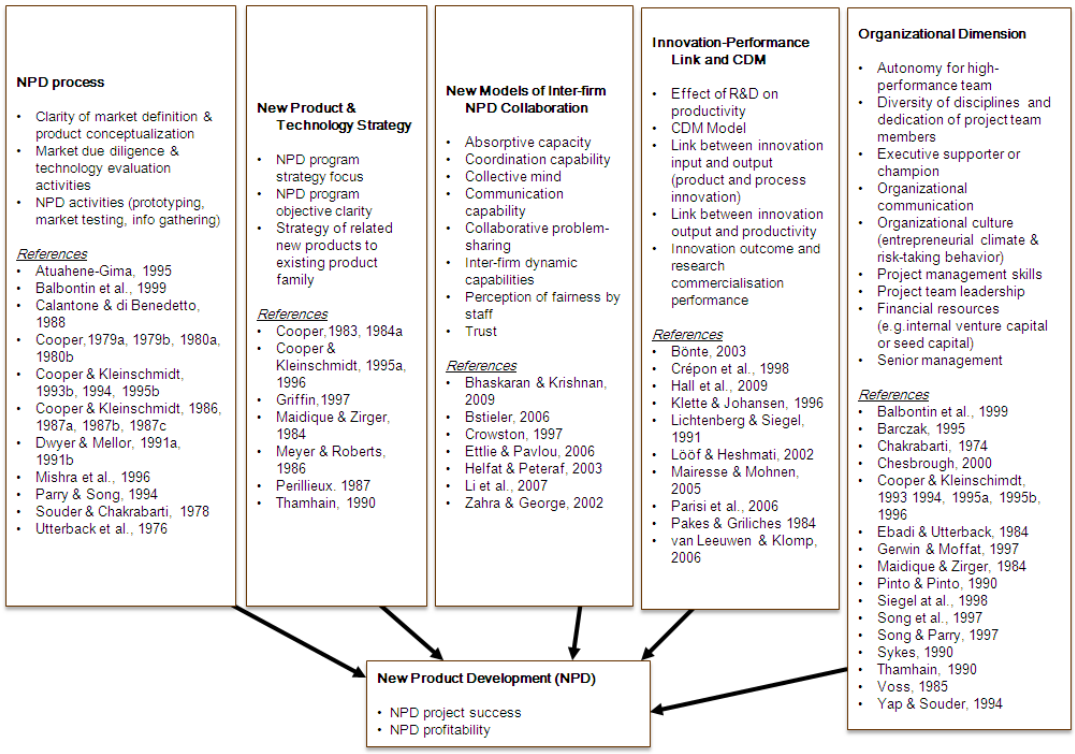

Figure 2-5: An overview of NPD literature

Given the increasingly significant role of public research laboratories in the technology strategy of the firms, it is imperative for both scholars and practitioners in future research to examine the characteristics of this group of technology providers which have a mission to promote research and innovation to the industry rather than a pure profit orientation that is found in a typical private sector technology provider. Similarly, the focus of public research laboratories with relatively greater autonomy in conducting basic and mission-oriented research than the industrial research laboratories would also spell differences in the commercial readiness level of their technologies and the participation level of their researchers in the NPD process of the firm acquiring the technologies from public research laboratories. It is also unclear how the appropriability of the underlying IP could influence the inter-organisation NPD process and impact the performance of the firm. This research makes a significant contribution to the literature through its examination of the areas that are highlighted above for future research.

2.6 Conclusion

The concepts of ***endogenous growth theories, cluster theory, NIS and national innovative capacity*** have spawned research in diverse fields including economics, management, strategy and innovation. From the review in Section 2.2, it is apparent that empirical studies have shown that R&D plays a pivotal role in economic and productivity growth, in support of the endogenous growth theories. Discussion of the cluster theory shows that more research is required to examine the moderating effect of factors related to collaboration, institutions and entrepreneurship on the linkages among clustering, innovation and economic growth (de Groot et al., 2008; pp. 20-21). The review of the current NIS and national innovative capacity studies reveals a paucity of research on how firms as important actors in the systems were impacted by the other actors and related components of the innovation systems and the innovation process (Yam et al., 2011; Herrmann and Peine, 2011). This research examines these areas of interaction between the firms and the other actors such as PRIs and their related components of TTOs within the context of Singapore NIS.

In general, the perspectives of endogenous growth theories, cluster theory, NIS and national innovative capacity have been criticised for assuming the centrality of the firm's role in innovation (Etzkowitz and Leydesdorff, 1996). To address this concern, Etzkowitz and Leydesdorff heralded the concept of the ***Triple Helix*** to advocate the significance of the three institutional spheres and their relationships on the development of innovation systems in the increasingly knowledge-based societies: the government, the industry and the university (Etzkowitz and Leydesdorff, 1996; Leydesdorff and Etzkowitz, 1998). Section 2.3 reviewed the relevance of the Triple Helix model in the literature on ***university-industry collaboration***, highlighting the prevalent theories used: RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996), CBT (Prahalad and Hamel, 1990) and Dynamic Capabilities Theory (Teece et al., 1997). The section also discussed the four groups of factors affecting university-industry technology collaboration: (a) university and PRI-related organisation factors, (b) TTO organisation-related factors, (c) entrepreneur and new venture-related factors, and (d) environmental factors. Although much literature may be found pertaining to these factors, they tend to

focus on universities as technology providers rather than PRIs, possibly due to the relative ease of obtaining empirical data from the former compared to the latter.

Given the above gap in the current literature on commercial adoption of publicly-funded technological innovation, Section 2.4 scanned the related research area, external technology acquisition and its impact on firm innovation and performance. In this section, three literature strands based on TCE and absorptive capacity theories were identified and critically reviewed from the scan of ***external technology acquisition*** literature: (a) reviewing the significance of the institutional factors on a firm's technology acquisition performance, (b) understanding the factors affecting a firms' decision to acquire external technology and (c) analysing the relationship between external technology and a firm's performance (Tsai and Wang, 2008). It is evident that most studies of these strands tend to focus on firms that in-license to or out-license technologies from other firms, rather than PRIs. This section has argued that, unlike the firms in the industry which are likely to be profit-oriented, PRIs pursue different goals as they have been established as part of the NIS to promote knowledge diffusion and industry spillovers for economic growth or societal benefits. While the study of the factors affecting the profit-driven firms in out-licensing technologies may be illuminating for learning, they cannot be generalised to PRIs which have the social and economic objectives that are not found in the typical profit-oriented licensors in the industry. The propensity of PRIs to commercialise technology will understandably be relatively much higher while their expected rate of royalty is likely to be relatively lower compared to the industry licensors. This section further posited that, unlike the industry firms, PRIs are neither product designers nor product developers. This means that the technology that they offer for out-licensing may have a relatively lower readiness level. This may be an additional factor influencing a firm's propensity to license from PRIs. Hence, there is a gap in the current licensing literature to examine the licensing dynamics between PRIs and the firms (both new and existing), and the need for future research efforts to consider the organisational learning (Hamel, 1991) and absorptive capacity (Lane and Lubatkin, 1998) dimensions in the research design (Jones et al., 2001). To contribute to this current literature gap, this research focuses on the particular type of alliance contracts, that is, technology licensing, to control for variation within the contract types to derive more conclusive results on

the antecedents, determinants and effects (Tsai and Wang, 2008) of firms that license technologies from PRIs.

To further delineate the contribution of this research to the current body of knowledge, the other research streams of ***knowledge, innovation and performance*** have been reviewed in Section 2.5. In particular, the scan examined the research conducted on open innovation and CDM model, as well as the firms acquiring publicly-funded technological innovation from PRIs. In this section, two literature streams were identified and discussed: (a) open innovation and intermediation, and (b) firm innovation and its relationship with NPD performance. The review of the first stream shows as future research avenues: the public-private innovation source comparison (Fosfuri, 2006; Motohashi, 2005), the effectiveness of user-led innovation in innovation types and life cycle (Bogers et al., 2010; Lichtenthaler, 2011), effective mechanisms of managing open innovation from concept to commercialisation (Dahlander and Gann, 2010), and the role of intermediaries as TTOs and the dynamics of market mechanisms (Lichtenthaler, 2011). The second stream of literature on firm innovation-NPD performance discussed about the NPD process, organisation dimension, NPD strategy, innovation-performance link and how firms respond to NPD collaboration with such IP owners whose technologies are less ready for productisation and hence may require distinct dynamic NPD collaboration capabilities for successful commercial adoption.

This research contributes to these under-developed areas by focusing on how external knowledge source (in the form of R&D from PRIs) and in-house R&D could moderate the relationship between a firm's PAET and its innovative outcome in the form of product or process innovation. Further, this research examines how internal R&D could moderate the relationship between innovative outcome and firm performance, drawing upon the perspectives of RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996), Dynamic Capabilities Theory (Teece et al., 1997), TCE Theory (Williamson, 1985), absorptive capacity theory (Cohen and Levinthal, 1990), PFI theory (Teece, 1986) and the CDM model (Crépon et al., 1998).

Based on the review of the relevant literature streams in this Chapter, the research questions, the conceptual framework and hypotheses will be dealt with in the next Chapter.

3 Research Questions, Conceptual Framework and Hypotheses

The previous chapter has presented extensive reviews of a range of relevant literature areas: (a) National Innovation System (NIS), national innovative capacity and economic growth with highlights of the endogenous growth theories, cluster theory and evolutionary theory; (b) university-industry collaboration with reference to Triple Helix and Mode-2 knowledge production models, and drawing upon Resource-based Theory (RBT), Knowledge-based Theory (KBT), Competence-based Theory (CBT) and Dynamics Capabilities Theory; (c) external technology acquisition based on Transaction Cost Economics (TCE), PFI and absorptive capacity theories; and (d) open innovation and New Product Development (NPD) performance at firm level building on the CDM model. This chapter introduces the main research questions, the underlying theories, the conceptual model and the hypotheses.

3.1 Research Questions

To address the literature gaps highlighted in the previous chapter, this research aims to investigate the determinants affecting firms' propensity to license technologies developed by PRIs, and the factors influencing their innovative outcomes and firm performance.

- The first research question is: *What are the determinants of a firm's Propensity to acquire External Technology (PAET)*? Prior studies have focused on a firm's propensity to out-license technologies (Fosfuri, 2006), or to in-license from multi-national organisations (Lopez, 2008). This research question examines a firm's propensity to in-license from PRIs. In their study on in-licensing, Ceccagnoli et al. (2010) found that firms in the pharmaceutical industry with strong R&D productivity or co-specialised complementary assets (such as resources to manufacture, market, sell and distribute) have a lower PAET. Transaction Cost Economics (TCE) (Williamson, 1985) explained that the more specific the nature of these assets, the greater is the corresponding increase in the risks of hold-up and opportunitism, thereby increasing contractual hazards and reducing the

PAET. Cassiman and Veugelers' (2006) study of Belgian manufacturing firms pointed to the significance of complementarity between internal R&D and external knowledge in their decision to acquire external technology from both the public and private sectors. This research question will build on these earlier studies to explain the variation in propensity among firms to in-license from PRIs.

- The second research question is: *For firms that acquire external technologies from PRIs, what factors influence their innovation outcome?* In this study, a firm's Innovation Outcome measures whether the firm has embodied externally licensed technology from PRIs into any of its product or processes, using five-point Likert scale. Previous studies have analysed the impact of licensing foreign, rather than indigenous, technology on the innovation outcome of the firms in Chile (Lopez, 2008) and Japan (Kiyota and Okazaki, 2005). Other studies have analysed both firms and research institutes as external sources of technologies, whose availability and quality are pivotal for the innovation outcome of the importing firms (Hemmert, 2004). This research question draws attention to PRIs as sources of external knowledge. It further investigates why some importing firms are more successful than are others in applying this external knowledge to develop product or process innovation.
- The third research question is: *For firms that acquire external technologies, what factors influence their commercial adoption performance?* In this study, commercial adoption performance relates to (a) the percentage of total actual sales that consist of new or improved products embodying the licensed technology in latest fiscal year (categorised into ordinal values), (b) the percentage of total actual production volume that consist of new or improved processes from the licensed technology in the latest fiscal year (categorised into ordinal values), and (c) the projected annual growth rate in percentage of sales revenue of the product(s) embodying the licensed technology in the next three years. These three dimensions are captured in the survey questionnaire from the licensees. Earlier studies have focused on the role of absorptive capacity in enhancing a firm's ability to benefit from technology licensing (Tsai and Wang, 2008). Apart from absorptive

capacity, the significance of other capabilities, such as NPD collaboration capabilities (Ettlie and Pavlou, 2006), have not been carefully examined in the commercial adoption process of publicly-funded research. This research question explores these capabilities to explain why some firms that introduce product and/or process innovation are more successful than are others in commercial adoption performance.

To answer the above research questions, this research applies the RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996), TCE (Williamson, 1985), PFI (Teece, 1986), as well as the perspectives of absorptive capacity theory (Cohen and Levinthal, 1990) and Dynamic Capabilities Theory (Teece et al., 1997) in the inter-firm NPD partnership model. The next section presents the conceptual model used to address the research questions of what factors affect a firm's PAET, its innovation outcome and commercial adoption performance. It also provides an overview of the relevant constructs and hypotheses that develop the conceptual model.

3.2 Conceptual Development

3.2.1 Conceptual model and Hypotheses

Based on the review of the various literature streams in Chapter 2, the conceptual model of this study was developed to show the key variables and their relationships with one another, as hypothesised in H1- H7. The conceptual model is depicted in Figure 3-1.

In this model, the *Internal Resources* variables comprise *Technological Resources*, *Commercial CA Resources*, *Commercial IP Resources* and *Human Capital*. The *Internal Resources* as an independent variable are expected to have a negative impact on the firm's *PAET* as a dependent variable (Hypothesis 1 or H1). The higher the level of *Internal Resources* a firm has, the lower its *PAET* is likely to be. Section 3.2.3 will elaborate on the variables and their relationships hypothesised in H1, with reference to the underpinning theories and prior studies (Atuahene-Gima, 1993; Ceccagnoli et al., 2010).

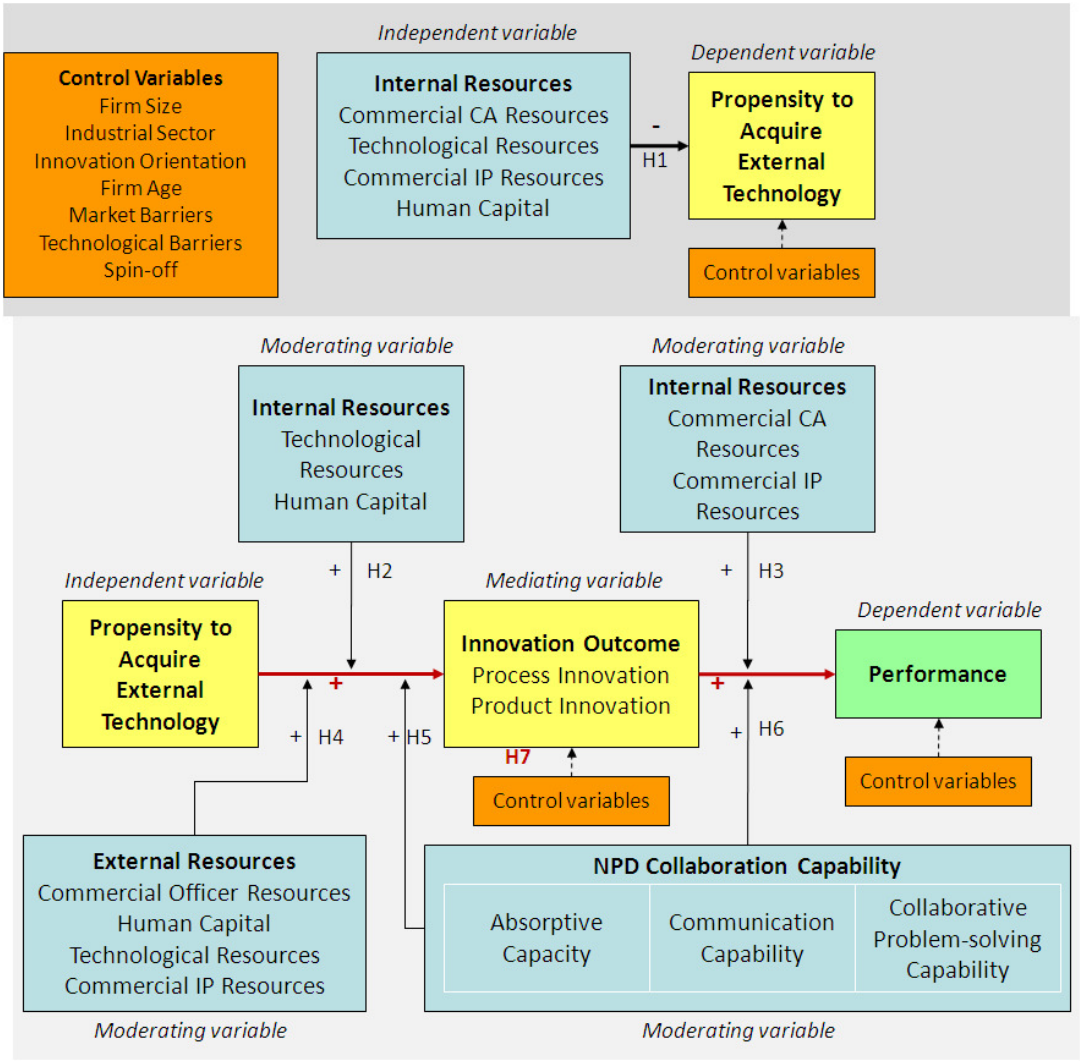

Figure 3-1: Conceptual Model – Hypotheses and Key Variables

For firms that have high levels of *PAET*, their *Internal Resources (Internal Technological Resources* and *Internal Human Capital)* are predicted to have a positive moderating effect on the relationship between their *PAET* and their *Innovative Outcome*, which comprises *Process and Product Innovation* (Hypothesis 2 or H2). This means that among firms that have high levels of *PAET*, the firms that have higher levels of *Internal Resources* are more likely to report higher levels of *Innovative Outcome*. Similarly, among firms that have high levels of *Innovation Outcome* with external technologies, the firms that report better commercial adoption *Performance* have higher levels of *Internal Resources (Internal Commercial CA Resources* and *Internal Commercial IP Resources)* (Hypothesis 3 or H3). In other words, *Internal Resources* are hypothesised to have a positive moderating effect on the relationship between the firm's *Innovation Outcome* and its commercial adoption *Performance*. The firm's *Performance* could be measured

by the actual or projected sales of the newly launched products or services in the sales phase. Section 3.2.4 will discuss how H2 and H3 draw on the general principle of NPD process, whereby the development phase of new products or process precede the sales phase of these new products or services, as illustrated in the CDM model (Crépon et al., 1998) and corroborated by Michael Porter's value chain (Porter, 1985). The distinction between the product development phase and sales phase is illustrated with H2 capturing the *Innovation Outcome* in the form of *Product* or *Process Innovation* during the product development phase, and H3 focusing on the resulting commercial adoption *Performance* in terms of actual or projected sales generated during the sales phase.

The *External Resources* variables are *Human Capital, Technological Resources, Commercial CA Resources* and *Commercial IP Resources*, using similar categories as the *Internal Resources* variables (O'Shea et al., 2005). The *External Resources* could make up for the lack of *Internal Resources* that a firm faces, as part of its open innovation strategy (Chesbrough, 2007b; Vanhaverbeke, 2012). As such, a firm's *External Resources* could play a positive moderating role on the relationship between its *PAET* and its *Innovation Outcome*. This means that among firms that have high levels of *PAET*, the firms that report higher levels of *Innovation Outcome* have greater access to *External Resources* (Hypothesis 4 or H4).Section 3.2.5 will provide details on the association among the variables of H4.

As highlighted in Section 3.2.6, the inter-organisation *NPD Collaboration Capability* is essential for successful *Innovation Outcome* and commercial adoption *Performance*, and comprise three dynamic capability variables: *Absorptive Capacity* (Ettlie and Pavlou, 2006), *Communication Capability* (Bstieler, 2006) and *Collaborative Problem-solving Capability* (Li et al., 2007). We hypothesise that among firms that have high levels of *PAET,* the firms that report higher levels of *Innovation Outcome* have superior *NPD Collaboration Capability* (Hypothesis 5 or H5). In line with H2 and H3, we expect that among firms that have high levels of *Innovation Outcome* with external technologies, the firms that report better commercial adoption *Performance* have superior *NPD Collaboration Capability* (Hypothesis 6 or H6). This means that a firm's *NPD Collaboration Capability* variables have positive moderating effect on the relationship between its *PAET* and

its *Innovation Outcome*, as well as that between its *Innovation Outcome* and its commercial adoption *Performance*. Finally, we expect the firm's *Innovation Outcome* to positively mediate the relationship between its *PAET* and its commercial adoption *Performance* (Hypothesis 7 or H7) (Crépon et al., 1998).

In the conceptual model, we have also included control variables to control for alternative explanations for the firms' *PAET*, *Innovation Outcome* and *Performance*. These control variables are *Firm Size*, *Firm Age*, *Spin-off* (whether the firm was a spin-off from PRI), *Innovation Orientation* of the firm, the *Industrial Sector* that it operates in, the *Market Barriers* and *Technological Barriers* that it faces. The control variables are discussed in more detail in Section 4.2.1.5.

The next section discusses the theoretical framework underpinning the conceptual model.

3.2.2 Theoretical framework

As discussed in the earlier literature review of the university-industry collaboration in Section 2.3.3, the RBT (Wernerfelt, 1984; Barney, 1991) has been predominantly used in most studies that investigate the individual attributes of academic entrepreneurs using human and social capital theories (Coleman, 1988, 1990), and their influence on resource acquisition for their new ventures based on public research (O'Shea et al., 2005; Powers and McDougall, 2005; Mustar, Renault, Colombo, Piva, Fontes, Lockett, Wright, Clarysse and Moray, 2006; Zahra et al., 2007). These studies have used the RBT of the firm to examine the resource configuration of research-based spin-offs. Acknowledging the need for more suitable typology for the relevant resources found in the research-based new ventures, scholars identified resources that are critical for both new and small businesses' performance (Lichtenstein and Brush, 2001): financial capital, organisational structure, culture, processes, the expertise and leadership of the founding management and technological know-how. These resources have been further classified by scholars into four key categories that new ventures and existing small businesses would require: technological resources, human capital, commercial resources (complementary assets and IP appropriability) (Brush et al., 1997, 2001; O'Shea et al., 2005; Mustar et al., 2006).

In particular, O'Shea et al. (2005) include technological resources as part of institutional resources. These technological resources comprise IP such as patents and technological know-how generated by PRIs. Human capital could be provided by research scientists and engineers of PRIs. Human capital comprises their scientific talent and expertise, contributing to the development of intellectual capital such as publications, technology disclosures and patents. To perform research, PRIs rely on financial resources in the form of research grants endowed by the public funds, which may comprise both non-competitive and competitive grants. As highlighted in the review of university-industry collaboration literature in Section 2.3.2, as the mode of knowledge production shifts from Mode-1 to Mode-2, we also witness the transition to more context-driven research that is more industry-aligned, socially accountable and reflexive (Gibbons et al., 1994). This means that PRIs have greater focus on context-driven research, demonstrating that their public research of greater impact on socio-economic development is accorded either higher priority or greater amount of financial resources.

O'Shea et al. (2005) emphasise the significance of technology transfer office (TTO), which is responsible for managing the patenting of inventions and technology disclosures generated by PRIs, commercial adoption and transfer of these technologies from PRIs to the new or existing ventures. The strengths of the patent portfolios developed by the TTO staff and their relative success in out-licensing their patent stock depend largely on their abilities in performing technology market intelligence. Drawing upon the framework of dynamic capabilities, Lichtenthaler, Lichtenthaler and Frishammar (2009) found strong empirical support in their study of 125 firms that the proficiency level of their technology market intelligence could affect their ability to profit from their technology portfolio. Although Lichtenthaler's research was conducted on private firms aiming to optimise their patent pool to capture returns from outward technology licensing, their results of the criticality of technology market intelligence should be applicable to TTOs which also have the similar objective of exploiting their IP portfolio. Along the same line of argument, O'Shea et al. (2005, p. 998) include the market technology intelligence capabilities as part of the commercial resources owned by TTOs, which have been regarded 'in the innovation management literature as complementary resources for the appropriation of research results (Teece, 1986)'. These

commercial resources possessed by TTOs could also provide the social capital that academic entrepreneurs need in forging the networks with their suppliers, potential customers, angel and institutional investors that are absolutely essential in the start-up phases of the new ventures. These synergistic networks will enable the new ventures to gain access to complementary assets and knowledge sources that can create value (Adler and Kwon, 2002; Zahra et al., 2007, p. 575).

Apart from the new ventures, Chesbrough (2006) and Vanhaverbeke (2012) argue that as existing firms are unlikely to possess all the knowledge required for sustainable growth. There is therefore a need for both large enterprises and SMEs to source for open innovation beyond organisational boundaries, as highlighted in the literature review of Open Innovation in Section 2.5.1. Consistent with the resource-based perspective of the firm, knowledge is a valuable resource, among other resources such as human and financial capital. According to KBT (Grant, 1996), firms that are able to integrate diverse areas of knowledge are well-positioned to exploit their competitive advantage. To remain economically competitive, the firms may source for knowledge and valuable resources possessed by other organisations, including universities and PRIs (O'Shea et al., 2005).

Many researchers have examined the effect of the social, human, technological, financial, organisational, commercial and physical resources on the commercialisation performance variables, such as licensing revenues and number of spin-offs generated by universities. However, most acknowledge that there is a lack of studies on these factors on the performance of firms that acquire and receive technologies developed by PRIs (Link et al., 2011). This research focuses on PRIs, rather than on universities, and how they interact with other institutions and organisations in transferring technology and knowledge.

In this research, Singapore's science and technology policies and plans provide the context of national innovation system comprising institutions and policies to encourage the commercial adoption of publicly-funded R&D by Singapore firms so as to influence the innovation process to spur long-term economic growth (Wong and Singh, 2008). The Singaporean firms under study are those that are considering to license or have licensed technologies from PRIs for access to external human capital, commercial resources and technological resources. These are resources that

are ‘valuable, rare, imperfectly imitable and non-substitutable’ required by the firms for technological innovation (Barney, 1991, p. 117). The human capital could be provided by research scientists, the commercial resources by TTO, and the technological resources by PRIs in the form of patents possessed (Powers and McDougall, 2005). The firms being studied vary in their propensity to license technologies. They also displayed variations in their innovative outcomes from their external technology acquisitions and showed differences in their performance from commercialising their innovative outcomes.

Against this backdrop, the first research question investigates the determinants that affect a firm’s propensity to license technologies from PRIs of Singapore. The second research question examines the factors that explain the firms’ variations in innovative outcomes from their external technology acquisitions. The third research question studies the factors that contribute to the variation in firms' commercial adoption performance. The next section elaborates on the development of constructs and hypothesis to address the first research question.

3.2.3 Internal Resources and External Technology Acquisition

As highlighted in Section 3.2.2, a firm’s resources have generally been classified by previous studies into four key categories that new ventures and existing small businesses would require: technological resources, human capital, commercial complementary asset resources, commercial IP resources (Brush et al., 1997, 2001; O’Shea et al., 2005; Mustar et al., 2006). This research builds on their earlier works based on the perspectives of RBT, KBT, TCE (complementary assets and IP appropriability) and PFI to define *Internal Resources* as *Human Capital, Technological Resources, Commercial CA Resources* and *Commercial IP Resources*.

Internal Resources

The internal *Human Capital* refers to the talent and expertise of the research scientists and engineers of the firms that are interested in external technology acquisition from PRIs (Deeds et al., 1998; Hemmert, 2004).

The internal *Technological Resources* are defined by a firm's technological know-how that contributes to the development of intellectual capital such as technology disclosures and patents. They include its reliance on basic R&D, as a measure of complementarity between its internal R&D and external technology (Roberts and Hauptman, 1986; Rothwell, 1992; Cassiman and Veugelers, 2006).

The firm's internal *Commercial Resources* have two dimensions. The first dimension refers to the firm's *Complementary Assets* for the exploitation of its R&D works (Teece, 1986, 2006; O'Shea et al., 2005). The *Commercial Complementary Asset (CA) Resources* include the firm's resources for production, marketing and sales, as well as distribution of goods and services. The possession and utilisation of these complementary resources are critical for the commercial adoption of industrial research and launch of new products or services, as postulated by Teece's theory of PFI (Teece, 1986, 2006) (discussed in Section 2.4.1). The second dimension of a firm's internal *Commercial Resources, Commercial IP Resources,* describes the effectiveness of strategic protection, that is, the effectiveness of the firm in protecting its competitive advantage using such mechanisms as secrecy and economies of scale (Cassiman and Veugelers, 2006). A summary of a firm's *Internal Resources* of *Human Capital*, *Technological Resources*, *Commercial CA Resources* and *Commercial IP Resources* built on the concepts of RBT, KBT and PFI is found in Table 3-1.

Internal Resources	**Descriptions**	**References**
Human capital	Qualified R&D staff	Deeds et al., 1998 Hemmert, 2004
Technological Resources	Basic R&D reliance (as a measure of complementary between internal R&D and external technology)	Roberts and Hauptman, 1986 Rothwell, 1992 Cassiman and Veugelers, 2006
Commercial Complementary Asset (CA) Resources	Resources for production, marketing and sales, distribution of goods and services (also known as complementary resources)	Teece, 1986, 2006

Internal Resources	Descriptions	References
Commercial IP Resources	Effectiveness of Strategic Protection	Cassiman and Veugelers, 2006

Table 3-1: Description of *Internal Resources* construct

Propensity to Acquire External Technology (PAET)

In this research, the firms that are studied are those that have demonstrated varying degrees of propensity to acquire external technologies. The *PAET* construct that is used in this research has the same meaning as the terms used by other researchers: 'inward technology licensing' or 'in-licensing of external technology' (Atuahene-Gima, 1993, p. 230; Tsai and Wang, 2008, p. 91; Agrawal, 2006, p. 65). This research adopts Atuahene-Gima's (1993, p. 233) definition of 'propensity to adopt inward technology licensing' to describe *PAET*, which refers to a 'firm's attitudinal orientation or intention toward future use of inward technology licensing as an alternative to internal R&D' as part of its open innovation strategy. According to prior studies, a firm's propensity to in-license external technologies is found to be directly related its inward technology licensing experience (Atuahene-Gima, 1993; Crawford, 1985; Kim, 1988). Hence, this research uses prior licensing experience as a proxy measure of *PAET*.

Based on the TCE perspective (Williamson, 1985), as discussed in Section 2.4.1, Ceccagnoli et al. (2010) found that pharmaceutical firms with strong R&D productivity or co-specialised complementary assets (such as resources to manufacture, market, sell and distribute) have a lower PAET. Atuahene-Gima (1993; p, 236-237), on the other hand, found that firms with strong internal R&D capability, negative prior licensing experience, perception of high licensing costs and low benefits, tend to have a lower propensity to acquire external technologies. These findings were not fully corroborated by earlier research results of direct positive relationship between internal R&D resources (such as human capital and technological resources) and participation in technology licensing (Ford, 1985; Reid and Reid, 1988).

Given the mixed findings in the literature on inward technology licensing from the private sector and the dearth of studies in the other literatures of university-industry collaboration and open innovation, the first research question examines the determinants that influence a firm's propensity to license technologies from PRIs of Singapore. How are these determinants related to the availability of a firm's *Internal Resources*? What is the relative significance of the various types of *Internal Resources* on its *PAET*? The following hypothesis is proposed:

Hypothesis 1: Firms that have higher levels of ***Internal Resources*** *are likely to have a lower* ***PAET****.*

Hypothesis 1 posits that firms that have higher levels of *Internal Resources*, comprising *Human Capital, Technological Resources, Commercial CA Resources*, and *Commercial IP Resources* may be more inclined to perform internal R&D than to acquire external technology, as depicted in Figure 3-2. Conversely, firms that have lower levels of *Internal Resources* may be more inclined to acquire external technology than to perform internal R&D. To test the hypothesis, prior research results on (a) inward technology licensing from private sector, (b) university-industry collaboration and (c) open innovation were integrated, and the underlying theoretical frameworks of RBT, KBT, TCE and PFI were built upon to develop the constructs of *Internal Resources* and *PAET* and hypothesise their relationships.

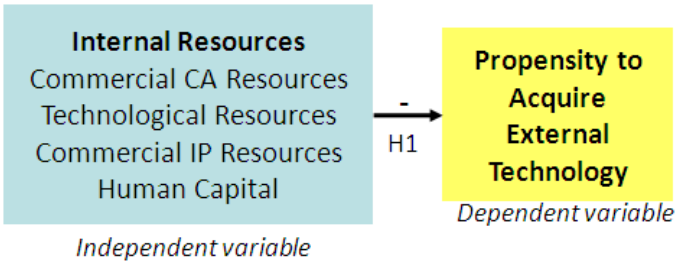

Figure 3-2: Hypothesis 1 describing the relationship between a Firm's *Internal Resources* and its *PAET*

This Section has elaborated on the development of *Internal Resources* and *PAET* constructs and hypothesis of their relationship to address the first research question. The next Section develops the conceptual framework based on prior studies on inward technology licensing, university-industry collaboration, open innovation and

performance built on the theoretical perspectives of RBT, KBT, TCE, PFI, absorptive capacity theory and the CDM model. The conceptual framework underpins the constructs of *Internal Resources*, *PAET*, *Innovation Outcome* and *Performance,* as well as their hypothesised relationship to address one aspect of the second and third research questions.

3.2.4 Innovation Outcome, Performance, Internal Resources and PAET

Innovation Outcome

For the purpose of this research, we refer to the definition of Innovation adapted by Crossan and Apaydin (2010) from the European Commission's Green Paper of Innovation (1995, pp. 1-2), as highlighted in Section 1.5 of this thesis. Based on this definition, *Innovation Outcome* comprises *Product Innovation Outcome* and *Process Innovation Outcome*. The definition of these constructs is consistent with those adopted by the European community in their Community Innovation Survey (Griffith et al., 2006) using the CDM model. The CDM was developed by the integration of knowledge production function and Cobb-Douglas production function to show innovation as a process: (a) starting from an organisation's decision to undertake innovation to, (b) the next phase of providing innovation input before, (c) proceeding to development of innovation output and (d) arriving at the final phase of organisation performance.

As discussed in the literature review of NPD in Section 2.5.2, the CDM model was introduced by Crépon et al. (1998) to address the concern of some critics that, while R&D is a significant factor, it should be regarded as an innovation input that does not directly influence a firm's performance. The critics contended that a firm's innovation input (in the form of its R&D intensity) is influenced by its decision to undertake innovation activity. The firm's input, which could be combined with other external innovation input, leads to the generation of its innovation output (in the form of the firm's product or process innovation). The firm's innovation output, in turn, could lead to its performance (in the form of productivity) (Hall et al., 2009; Chudnovsky et al., 2006).

Performance

In this research, a firm's *Performance* is represented by the percentage of its annual sales of new products embodying the licensed technology to capture *Performance from Product Innovation* in the latest fiscal year. This is consistent with the performance construct adopted by authors such as Cassiman and Veugelers (2006, p. 71), who used 'percentage of sales generated by new or substantially improved products introduced in the past two years' as performance measure. To include a firm's *Performance from Process Innovation*, this research also measures the percentage of its annual production volume using new or improved processes from the licensed technology in the latest fiscal year.

Internal Resources

To develop the conceptual framework of this research, we have applied RBT in the CDM model to propose that a firm's input to its *Innovation Outcome* should involve more than just R&D. According to RBT, the firm's innovation input should include its resources that are 'valuable, rare, imperfectly imitable and non-substitutable' (Barney, 1991, p. 117). These resources are represented by the *Internal Resources* construct that were defined in the previous Section 3.2.3: *Human Capital, Technological Resources, Commercial CA Resources* and *Commercial IP Resources.* Support for the positive relationship between *Internal Resources* (*Internal Technological Resources* and *Internal Human Capital*) and *Innovation Outcome* was found in the literature review (Crook et al., 2008) in Section 2.3.3.

In particular, the literature review of university-industry collaboration in Section 2.3.7 presented positive relationship between *Human Capital* and *Innovation Outcome* explained by the theoretical perspectives of NIS and national innovative capacity as discussed in Sections 2.2.1 and 2.2.2 respectively. Examples of the positive relationship between *Innovation Outcome* and *Internal Human Capital* are linkage between quality of faculty and researchers and national innovation (Bozeman, 2000, Filippetti and Archibugi, 2011), association between researchers' reputation and product innovation (Zucker et al., 1998), as well as relation between university faculty quality and technology disclosure rate (Powers and McDougall, 2005).

As for the association between *Technological Resources* and *Innovation Outcome*, the review of the external technology acquisition literature in Section 2.4.3 showed that a firm's dependence on the basic R&D *(Internal Technological Resources)* performed by universities and public research centres is significantly related to the complementarity between internal and external innovation *(Innovation Outcome)*, as supported by the absorptive capacity theory (Cassiman and Veugelers, 2006; Lokshin et al., 2008).

In selecting the key *Internal Resources* variables that are hypothesised to have significant influence on *Performance*, we consider the profile of the respondents participating in this research. As 41% of the respondents are SMEs with fixed asset investment of less than $1 million (Table 5-4 in Section 5.2), we draw upon the results of prior studies that focus on SMEs that pursue open innovation (van de Vrande et al., 2009; Lee et al., 2010; Vanhaverbeke, 2012). As discussed in the literature review of open innovation in Section 2.5.1, there are distinct differences in the critical success factors for open innovation between SMEs and large enterprises. The high IP management costs (*Internal Commercial IP Resources*) and the lack of complementary asset resources (*Internal Commercial CA Resources*) are key challenges that innovative SMEs encounter in managing the collaborative output (*Performance*) with external partners (Vanhaverbeke, 2012). The above findings highlight the significance of these *Internal Resources* (*Internal Commercial IP Resources* and *Internal Commercial CA Resources*) on the commercial adoption performance of SMEs.

PAET

A firm's *PAET* construct was previously discussed in Section 3.2.3. To develop this conceptual framework further, we have integrated the literature on external technology acquisition and open innovation (Chesbrough, 2003; Vanhaverbeke, 2012) with the RBT (Wernerfelt, 1984; Barney, 1991) and CDM model (Crépon et al., 1998). For firms that pursue open innovation as their competitive strategy, their *PAET* could lead to acquisition of *External Resources* to complement with their *Internal Resources* to develop successful product or process *Innovation Outcome*, which, in turn, could lead to superior *Performance*. However, according the Dynamic Capabilities Theory, while a firm's *Internal Resources* are important, they

are not sufficient to sustain competitive advantage (Teece et al., 1997). The Dynamic Capabilities Theory postulates that the competitive advantage in the form of *Innovative Outcome* or *Performance* is the result of combining *Internal Resources*, *External Resources*, organisational routines, as well as market and technological opportunities. More recent studies have shown a somewhat positive relationship between external technology acquisition and firm performance, explained by the moderating role of absorptive capacity, proxied by its R&D expenditure (Tsai and Wang, 2008; Rothaermel and Alexandre, 2009). With the incorporation of the Dynamic Capabilities Theory and absorptive capacity theory in the conceptual framework of the modified CDM model of this study, the following Hypotheses 2 and 3 are proposed:

Hypothesis 2: Among firms that have high levels of ***PAET****, the firms that report higher levels of* ***Innovation Outcome*** *have higher levels of* ***Internal Resources (Internal Technological Resources*** *and* ***Internal Human Capital).***

Hypothesis 3: Among firms that have high levels of ***Innovation Outcome*** *with external technologies, those that report better commercial adoption* ***Performance*** *have higher levels of* ***Internal Resources (Internal Commercial CA Resources*** *and* ***Internal Commercial IP Resources)****.*

Hypothesis 2 posits that a firm's *Internal Resources* have a positive moderating effect on the direct positive relationship between a firm's *PAET* and its *Innovation Outcome*, as depicted in Figure 3-3. The firm's *Internal Resources* comprise *Internal Technological Resources* and *Internal Human Capital*. The moderating role of *Internal Resources* is consistent with the Dynamic Capabilities Theory that dynamic capabilities are required to organise resources, together with other organisational routines to achieve *Innovation Outcome*.

Building on the development of the PFI theory (Teece, 1986) by authors who found that firms pursuing success in open innovation business model should pay close to IP appropriability issues and complementary assets (Zi et al., 2006; Lim and Wong, 2006; Chesbrough, 2007b; Christensen et al., 2010; Lim et al., 2010; Vanhaverbeke, 2012), Hypothesis 3 was formulated to validate that a firm's *Internal Resources* (*Internal Commercial CA Resources* and *Internal Commercial IP Resources*) have

a positive moderating effect on the direct positive relationship between its *Innovation Outcome* and its commercial adoption *Performance*, as represented in Figure 3-4.

In both Hypotheses 2 and 3, *Innovation Outcome* is made up of *Product Innovation Outcome* and *Process Innovation Outcome*. Support for Hypotheses 2 and 3 may be seen in prior studies in the literature review of external technology acquisition in Section 2.4.3. Although the findings of these prior studies presented direct positive relationship between acquisition of external technology (proxied by costs of licensing external technology) and the venture's performance (measured by its revenue growth and profitability) (Tsai et al., 1991; Yasar and Morrison Paul, 2008), Hypotheses 2 and 3 differ in that they propose an indirect positive relationship between *PAET* (represented by prior licensing experience rather than licensing costs) and *Performance* (measured by percentage of sales embodying licensed technology) that is mediated by *Innovation Outcome*. Such tests on the mediating role of *Innovation Outcome* have not been conducted before and the results of these hypotheses in this research would certainly be of interest and relevance to the body of knowledge.

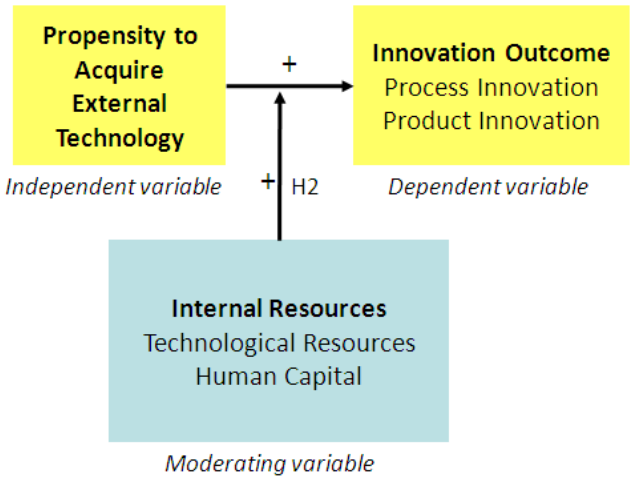

Figure 3-3: Hypothesis 2 describing the Moderating Role of a Firm's *Internal Resources* on the relationship between its *PAET* and its *Innovation Outcome*

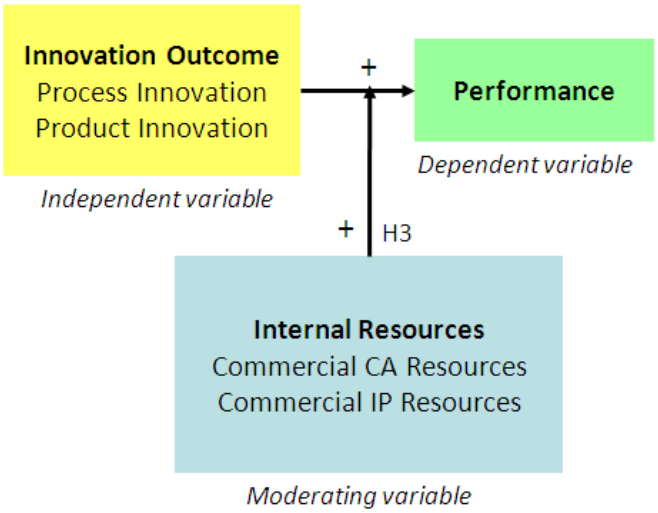

Figure 3-4: Hypothesis 3 describing the Moderating Role of a Firm's *Internal Resources* on the relationship between its *Innovation Outcome* and its *Performance*

Other studies highlight the positive moderating role of internal R&D in the relationship between licensing costs and sales performance of new products embodying the licensed technologies (Tsai and Wang, 2008; Rothaermel and Alexandre, 2009), as well as direct positive relationships between human capital and performance (Hemmert, 2004), technological resource and commercialisation performance (Roberts and Hauptman, 1986), R&D spending and performance (Cooper, 1984a; Cooper and Kleinschmidt, 1995a, 1996).

This Section has discussed the proposed relationships among the *Internal Resources, PAET, Innovation Outcome* and *Performance* constructs to address part of the second and third research questions. The next Section continues to build the conceptual model to develop the construct of *External Resources* and hypothesise its relationship with *Innovation Outcome* to investigate the second research question.

3.2.5 External Resources and Innovation Outcome

External Resources

The *External Resources* introduced in Section 3.2.4 that are of value to a firm should be similar to the *Internal Resources* highlighted in Section 3.2.3 (Brush et al., 1997, 2001; O'Shea et al., 2005; Mustar et al., 2006): *Human Capital, Commercial Resources* and *Technological Resources.*

The *External Human Capital* refers to the talent and expertise of the research scientists and engineers of PRIs. It is measured by the availability and quality of external R&D personnel of the PRIs. Their technological know-how contributes to the development of intellectual capital such as publications, technology disclosures and patents (O'Shea et al., 2005; Hemmert, 2004; Jensen et al., 2003; Powers and McDougall, 2005). O'Shea et al. (2005) found a positive relationship between the quality of science and engineering faculty and the number of university spin-offs generated. While Jensen et al. (2003) found that there is a significant positive relationship between quality of the faculty and technology disclosure rate, Powers and McDougall (2005) concluded that the faculty quality positively influenced spin-off formation rate by providing greater innovation value. As the external knowledge is likely to be basic research that is tacit, Agrawal's (2006) study of 124 license agreements associated with the MIT recommends that the engagement of the inventor, which constitutes external human capital, will positively influence the innovation outcome.

The *External Technological Resources* refer to the IP such as patents and technological know-how that are developed by PRIs. The IP protection regime has been found to be a significant determinant of the prioritisation of innovative activities (Teece, 1986). If appropriability is strong, firms will prefer acquisition of external technology to in-house development. However, when appropriability is weak, firms will prefer internal development to inward technology licensing (Cassiman and Veugelers, 2006). In addition, the innovative outcomes during the product development phase are influenced by the *Technology Readiness Level* of the externally acquired technology from PRIs (Heslop et al., 2001; Markman, Gianiodis and Phan, 2009, p. 630). The lower the technology readiness level of the external technology, the greater will be the amount of development effort required to elevate its readiness to the level that can meet the firm's internal performance specifications prior to embodying the external technology into the firm's new or existing products or processes. Alternatively, the effort to increase the readiness level of the external technology may be undertaken by PRIs if the latter perceive that this may enhance the likelihood of out-licensing to other firms. In this context, the resources available to PRIs could play a significant role in bridging the gap

between the laboratory results and industry specifications, thereby enhancing the probability of successful innovative outcomes by firms.

As highlighted in Section 3.2.2, TTO staff provides *External Commercial Resources* that could be of value to the firms' licensing technologies from PRIs (O'Shea et al., 2005). The availability and capabilities of the TTO staff in performing technology market intelligence as part of intellectual portfolio management could affect the strength of the patents in-licensed by the firm and impact the firm's ability to appropriate the underlying IP (Lichtenthaler et al., 2009). At the same time, TTO staff interacts with many firms that have licensed different, but possibly complementary, clusters of their patent portfolios. TTOs could therefore provide the social capital that academic entrepreneurs and firms need in gaining access to their networks of potential suppliers, customers, distributors, angel and institutional investors. These networks of TTO staff may enable the firms to acquire external commercial resources that are of value in production, marketing, sales, or distribution of goods and services (Adler and Kwon, 2002; Zahra et al., 2007, p. 575).

In this research, the *External Commercial Officer Resource*s measures one of the two aspects of *External Commercial Resources:* the availability and quality of the technology commercialisation personnel from the TTO. Another aspect of *External Commercial Resources* captures the firm's assessment of the effectiveness of IP protection. Although Cassiman and Veugelers (2006) found only marginal significance of this construct on the innovation activities of complementing internal and external technologies, the TCE Theory asserts that appropriability of IP could impact the firm's incentives to engage in transaction of external technology acquisition (Mayer and Salomon, 2006). This research therefore investigates the firm's effectiveness of IP protection using the *External Commercial IP Resources*. Table 3-2 provides a summary of the various types of *External Resources* that are of value of a firm.

External Resources	**Descriptions**	**References**
Human capital	Availability and quality of researchers of PRIs	Hemmert, 2004 Jensen et al., 2003 O'Shea et al., 2005

External Resources	Descriptions	References
		Powers and McDougall, 2005
Technological resources	Technology readiness level	Heslop et al., 2001 Markman et al., 2009
Commercial Officer Resources	Availability and quality of technology transfer/ commercialisation officers	Adler and Kwon, 2002 Lichtenthaler et al., 2009 O'Shea et al., 2005 Zahra et al., 2007
Commercial IP Resources	Effectiveness of IP protection	Cassiman and Veugelers, 2006

Table 3-2: Description of *External Resources* construct

With the growing competition in the market that is becoming boundary-less with de-regulation and increasing connectivity, firms face the threat of reduced revenue streams from shorter product life cycles and challenges of rising innovation costs driven by rapid technological changes (Chesbrough, 2006b and 2007b; Vanhaverbeke, 2012). Chesbrough (2007b) advocates the adoption of open innovation concept by firms through the use of inbound innovation (such as inward technology licensing or joint research alliance) to manage the growing R&D costs or create new sources of revenue (Zahra et al., 2005; Fosfuri, 2006; van de Vrande et al., 2009). Using the perspectives of open innovation and TCE, this research posits the following hypothesis:

*Hypothesis 4: Among firms that have high levels of **PAET**, the firms that report higher levels of **Innovation Outcome** have greater access to **External Resources**.*

Hypothesis 4 builds on the same conceptual framework from 3.2.4 that integrated the literature on external technology acquisition and open innovation (Chesbrough, 2003; Vanhaverbeke, 2012) with the RBT (Wernerfelt, 1984; Barney, 1991) and CDM model (Crépon et al., 1998). For firms that pursue open innovation as their competitive strategy, their *PAET* could lead to product or process *Innovation Outcome* by combining *External Resources* with *Internal Resources*. Applying the Dynamic Capabilities Theory in the same way, we hypothesise that the *External Resources* construct does not have a direct relationship with the *Innovation Outcome*. Rather, a firm's *External Resources* positively moderate the positive

direct relationship between its *PAET* and its *Innovation Outcome*, as expressed in Figure 3-5.

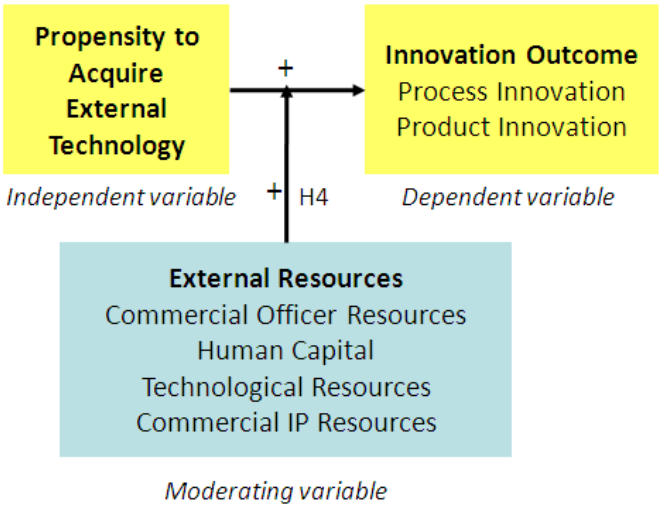

Figure 3-5: Hypothesis 4 describing the Moderating Role of a Firm's *External Resources* on the relationship between its *PAET* and its *Innovation Outcome*

This Section has elaborated the proposed relationships among the *External Resources, PAET* and *Innovation Outcome* constructs to address part of the second research question. The next Section expands the conceptual model based on the theoretical perspectives of collaboration, dynamic capability and absorptive capacity to develop the *NPD Collaboration Capability* construct as a dynamic capability. It also hypothesises its relationship with *PAET*, *Innovation Outcome* and *Performance* to answer the second and third research questions.

3.2.6 NPD Collaboration Capability, External Technology Acquisition, Innovation Outcome and Performance

In the development of new products embodying both internal and external technologies that are yet to be proven for a market that is not yet clearly defined, it is critical for firms to have dynamic NPD capabilities that can bring the external technologies from prototyping to pilot testing before ramping up to production (Burgelman, Christensen and Wheelwright, 2009). From the perspective of dynamic capabilities as discussed in Section 2.3.6, it is important for these firms to have the 'ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments' (Teece et al., 1997, p. 516). What dynamic capabilities should such firms have? The literatures of both NPD

(Section 2.5.2) and external technology acquisition (Section 2.4.2) have both emphasised the significant role of absorptive capacity (Cohen and Levinthal, 1990). Empirical research abounds in presenting evidence of its role in explaining the positive relationship between acquisition of external technology and the performance of the recipient firms (Liu and Buck, 2007; Tsai et al., 1991; Yasar and Morrison Paul, 2007; Kiyota and Okazaki, 2005). Authors such as Zahra and George (2002, p. 186) have even redefined absorptive capacity as a dynamic capability, referring it to 'a set of organisational routines and processes by which firms acquire, assimilate, transform, and exploit knowledge'. However, is absorptive capacity as a dynamic capability sufficient to explain the successful journey from a firm's conceptualisation stage to its final commercial adoption?

The road from concept to commercial adoption is a long and uncertain one for any firm: it has to (a) perform technology and commercial intelligence to identify potential external innovations that are complementary to internal innovations (Lichtenthaler et al., 2009), (b) consider make-versus-buy investment options (Cassiman and Veugelers, 2006), (c) manage the technology licensing contracts to minimise contractual hazards (Mayer and Salomon, 2006), (d) allocate project resources to acquire and assimilate external knowledge (Lichtenthaler, 2009; Newey and Zahra, 2009), (e) transform, exploit and embody external knowledge into new or existing products or processes (Ettlie and Pavlou, 2006), and (f) manufacture, market and sell new/improved products or services (Teece, 2006). It is apparent that the complexity of the tasks, the multi-disciplinarity of the knowledge and skills required, the frequent movement of knowledge workers, the tacit nature of both internal and external knowledge, the uncertainty of production scalability, and the risk of new market entry present many challenges at every stage of the innovation process. A firm certainly requires more than just absorptive capacity dynamic capability to overcome these challenges to achieve superior commercial adoption performance. While this research does not attempt to cover all dynamic capabilities to address the full gamut of challenges to achieve NPD success, we propose looking at two key dynamic capabilities, in addition to *Absorptive Capacity,* that are essential elements of *NPD Collaboration Capability*: *Collaborative Problem-solving Capability* and *Communication Capability*. Based on the literature review in Section 2.5.2, we have identified these three constructs that have been

emerged in recent studies as explanatory variables that should warrant more attention (Bstieler, 2006; Li et al. 2007; Ettlie and Pavlou, 2006).

NPD Communication Capability

The *NPD Communication Capability* refers to the firm's ability to exchange relevant, accurate and sufficient information in a timely fashion with another organisation in collaborative NPD (Bstieler, 2006, p. 99). Prior studies in NPD have observed the significant role of a firm's communication capability on joint-product performance with partner organisations through trust development (Mohr and Spekman, 1994; Littler, Leverick and Bruce, 1995). Such interaction will foster a climate of a high level of trust between the firm and its partner organisations by evoking affective response of care and perception of benevolence (Ring and Van de Ven, 1994). Building on the concepts of trust and communication, Bstieler (2006) defined communication behaviour as information exchange among parties and examined the antecedents of trust formation in inter-firm NPD on 44 product development partnerships in the manufacturing industry. He found strong support that accurate, open and timely information fosters trust and collaboration, thereby positively influencing NPD performance, in the form of 'partnership satisfaction, intentions for partnership continuity, financial performance of the product in the market, and time efficiency' (Bstieler, 2006, p. 67).

NPD Collaborative Problem-solving Capability

The *NPD Collaborative Problem-solving Capability* refers to the firms' ability to seek new ideas, evaluate and choose from alternatives, design and develop a product, implement a plan, and launch a product (Li et al., 2007, p. 202). For NPD to be successful, it is essential for project team members to engage in intensive collaborative behaviour in performing activities such as jointly planning and organising, sharing information, and collectively solving problems relating to the products or processes (Song et al., 1997). Given market uncertainty and the high level of inter-dependence among the project team members, Sutton and Hargadon (1996, p. 703) cautioned that 'no person can consistently design good products alone'. They advanced that 'the process requires knowledge about too many things and making many trade-offs between constraints' (Sutton and Hargadon, 1996, p. 703). According to Li et al. (2007), problem-solving is a process of seeking new

ideas, evaluating and choosing from alternative approaches, designing and developing the product, executing the optimal approach, and releasing the product. As Thomke (1998) observes, firms face external changes that may be driven by customer demands, competition or regulatory requirements, as well as internal changes arising from technological breakthroughs or production challenges. In any event, these changes require dynamic problem-solving capabilities that reside with not one person, but multiple project team members, each with his or her distinct disciplinary expertise and prior experience. For effective problem-solving, it is therefore imperative for every project team member to contribute his or her expertise and tacit knowledge so as to collectively arrive at creative solutions as well as alternatives (Hargadon and Sutton, 1997).

However, mere sharing of information by project members will not be as effective as strong commitment to disclose tacit knowledge and pool resources in a climate of a high level of trust and security with one another (Edmondson, 1999). More recent studies favoured the concept of 'collaboration' as it provides 'a general sense of collective participation, collaboration among project members involves high levels of "at-stakeness," transparency, mindfulness, and synergies' (Li et al., 2007, p. 202; Jassawalla and Sashittal, 1998). Building on the concepts of collaboration and problem-solving in the literature on NPD, Li et al. (2007, p. 202) found positive correlation between 'collaborative problem solving' and 'new product performance' in the form of return on sales and investment, profit margin and market share with respect to the firm's objectives.

NPD Absorptive Capacity

In the literature on NPD, it is noteworthy that Ettlie and Pavlou (2006) used absorptive capacity as a first-order construct along with coordinating capability and collective mind, to develop the second-order construct NPD partnership capabilities. They extended the definition by Cohen and Levinthal (1990) of absorptive capacity as the inter-firm NPD alliance capability 'to learn by identifying, assimilating, transforming, and exploiting knowledge' (Ettlie and Pavlou, 2006, p. 122). This definition of *NPD Absorptive Capacity* is adopted for the purpose of this research as it relates to some collaborative effort on NPD between two organisations even

though this research focuses on firm-PRI rather than the traditional inter-firm collaboration.

NPD Collaboration Capability

In this research, we build on the results of recent studies highlighted above to develop our hypotheses to predict the relationships involving the *NPD Collaboration Capability* constructs: *Collaborative Problem-solving Capability* (Li et al., 2007), *Communication Capability* (Bstieler, 2006), *Absorptive Capacity* (Ettlie and Pavlou, 2006; Tsai and Wang, 2008). This research extends the results of Ettlie and Pavlou to study the *Absorptive Capacity* as well as *Collaborative Problem-solving Capability* and *Communication Capability* as the three constructs for *NPD Collaboration Capability*. The use of *Absorptive Capacity* construct for *NPD Collaboration Capability* is corroborated by the results of Ettlie and Pavlou (2006), who found support for significant and positive impact of their absorptive capacity construct on inter-firm NPD partnership capabilities. They further observe significant relationship between the inter-firm NPD partnership dynamic capability and NPD performance, measured in terms of return on investment and relative internal rate of return (Ettlie and Pavlou, 2006, p. 136). In summary, this research defines *NPD Collaboration Capability* as a variable set that is explained by three dynamic capability variables: *Absorptive Capacity, Communication Capability* and *Collaborative Problem-solving*, as presented in Table 3-3.

NPD Collaboration (Dynamic) Capability	Descriptions	References
Absorptive Capacity	Ability to identify, assimilate, transform and exploit external knowledge	Ettlie and Pavlou, 2006, p. 122
Communication Capability	Ability to perform accurate, open and timely information exchange among parties	Bstieler, 2006, p. 99
Collaborative Problem-solving Capability	Ability to seek new ideas, evaluate and choose from alternatives, design and develop product, implement plan and launch product	Li et al., 2007, p. 202

Table 3-3: Description of *NPD Collaboration Capability* construct

According to Tsai and Wang (2008), absorptive capacity was found to have a moderating role on effective use of external technology to improve firm performance. In our conceptual model, we extend the results of Tsai and Wang (2008) to investigate the role of *NPD Collaboration Capability* in moderating the firm's innovation process from external technology acquisition to *Innovation Outcome* and *Performance*. Applying the *NPD Collaboration Capability* construct in the adapted CDM delineating the innovation process from *PAET* through *Innovation Outcome* to *Performance*, as discussed in Section 3.2.4, the following Hypotheses 5 and 6 are proposed:

Hypothesis 5: Among firms that have high levels of ***PAET****, the firms that report higher levels of* ***Innovation Outcome*** *have superior* ***NPD Collaboration Capability****.*

Hypothesis 6: Among firms that have high levels of ***Innovation Outcome*** *with external technologies, those that report better commercial adoption* ***Performance*** *have superior* ***NPD Collaboration Capability****.*

Hypothesis 5 posits that a firm's *NPD Collaboration Capability* has a positive moderating effect on the direct positive relationship between its *PAET* and its *Innovation Outcome*, as depicted in Figure 3-6.

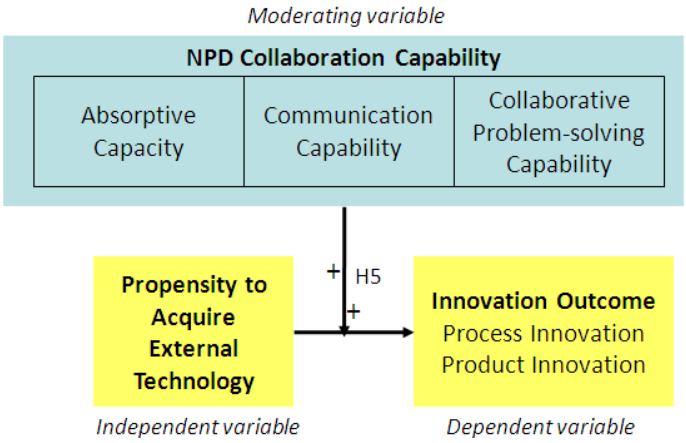

Figure 3-6: Hypothesis 5 describing the Moderating Role of a Firm's *NPD Collaboration Capability* on the relationship between its *PAET* and its *Innovation Outcome*

Hypothesis 6 suggests that a firm's *NPD Collaboration Capability* also has a positive moderating effect on the direct positive relationship between its *Innovation Outcome* and its commercial adoption *Performance*, as represented in Figure 3-7.

As this research adapts the CDM model (Crépon et al., 1998) to hypothesise the mediating role of a firm's *Innovation Outcome* between its *PAET* and its commercial adoption *Performance*, the following Hypothesis 7 is proposed and illustrated in Figure 3-8.

Hypothesis 7: ***Innovation Outcome*** *mediates the relationship between* ***PAET*** *and commercial adoption* ***Performance***.

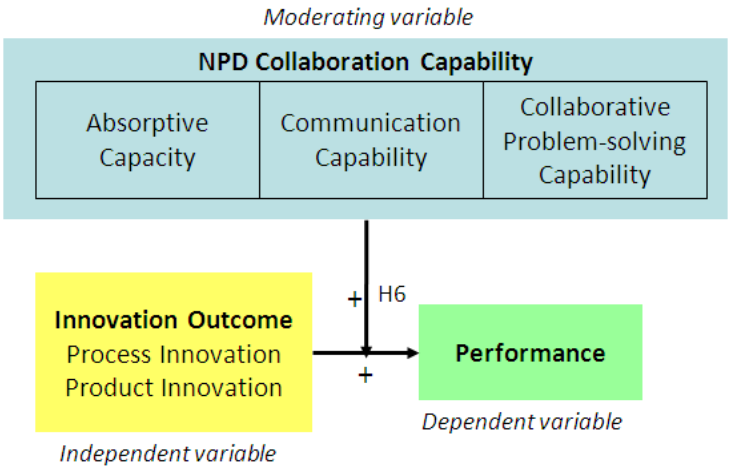

Figure 3-7: Hypothesis 6 describing the Moderating Role of a Firm's N*PD Collaboration Capability* on the relationship between its *Innovation Outcome* and its *Performance*

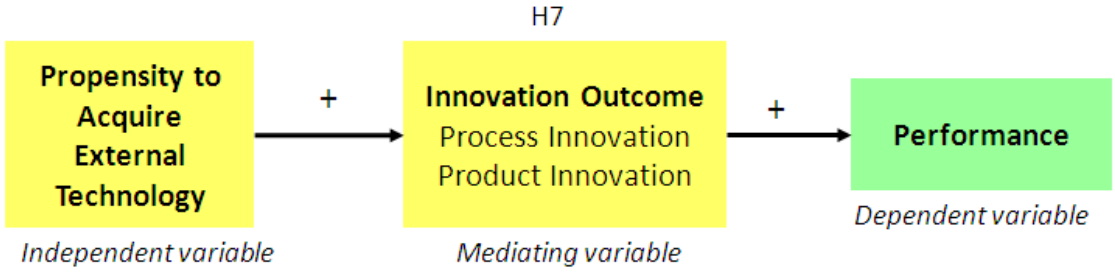

Figure 3-8: Hypothesis 7 describing the Mediating Role of a Firm's *Innovation Outcome* on the relationship between its *PAET* and its *Performance*

Table 3-4 presents a summary of all the hypotheses that were discussed in this Chapter.

Hypotheses
H1: Firms that have higher levels of ***Internal Resources*** are likely to have a lower ***PAET***. • H1a: Firms that have higher levels of ***Internal Commercial CA Resources*** are likely to have a lower ***PAET***. • H1b: Firms that have higher levels of ***Internal Technological Resources*** are likely to have a lower ***PAET***. • H1c: Firms that have higher levels of ***Internal Commercial IP Resources*** are likely

Hypotheses
to have a lower ***PAET***. • H1d: Firms that have higher levels of ***Internal Human Capital*** are likely to have a lower ***PAET***.
H2: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Innovation Outcome*** have higher levels of ***Internal Resources***. • H2a: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have higher levels of ***Internal Technological Resources***. • H2b: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have higher levels of ***Internal Human Capital***. • H2c: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have higher levels of ***Internal Technological Resources***. • H2d: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have higher levels of ***Internal Human Capital***.
H3: Among firms that have high levels of ***Innovation Outcome*** with external technologies, those that report better commercial adoption *Performance* have higher levels of ***Internal Resources***. • H3a: Among firms that have high levels of ***Product Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance*** **(*Product)*** have higher levels of ***Internal Commercial CA Resources***. • H3b: Among firms that have high levels of ***Product Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance*** **(*Product)*** have higher levels of ***Internal Commercial IP Resources***. • H3c: Among firms that have high levels of ***Process Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Process)*** have higher levels of ***Internal Commercial CA Resources***. • H3d: Among firms that have high levels of ***Process Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance*** **(*Process)*** have higher levels of ***Internal Commercial IP Resources.***
H4: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Innovation Outcome*** have greater access to ***External Resources***. • H4a: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have greater access to ***External Commercial Officer Resources.*** • H4b: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have greater access to ***External***

Hypotheses
Human Capital. • H4c: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have greater access to ***External Technological Resources***. • H4d: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have greater access to ***External Commercial IP Resources***. • H4e: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have greater access to ***External Commercial Officer Resources.*** • H4f: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have greater access to ***External Human Capital***. • H4g: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have greater access to ***External Technological Resources***. • H4h: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have greater access to ***External Commercial IP Resources***.
H5: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Innovation Outcome*** have superior ***NPD Collaboration Capability***. • H5a: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have superior ***NPD Absorptive Capacity*.** • H5b: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have superior ***NPD Communication Capability***. • H5c: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have superior ***NPD Collaborative Problem-solving Capability***. • H5d: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have superior ***NPD Absorptive Capacity***. • H5e: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have superior ***NPD Communication Capability***. • H5f: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have superior ***NPD Collaborative Problem-solving Capability***.
H6: Among firms that have high levels of ***Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance*** have superior ***NPD Collaboration Capability***. • H6a: Among firms that have high levels of ***Product Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Product)*** have superior ***NPD Absorptive Capacity***.

Hypotheses
• H6b: Among firms that have high levels of ***Product Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Product)*** have superior ***NPD Communication Capability***. • H6c: Among firms that have high levels of ***Product Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Product)*** have superior ***NPD Collaborative Problem-solving Capability***. • H6d: Among firms that have high levels of ***Process Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Process)*** have superior ***NPD Absorptive Capacity***. • H6e: Among firms that have high levels of ***Process Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Process)*** have superior ***NPD Communication Capability***. • H6f: Among firms that have high levels of ***Process Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Process)*** have superior ***NPD Collaborative Problem-solving Capability***.
H7: ***Innovation Outcome*** mediates the relationship between ***PAET*** and commercial adoption ***Performance***. • H7a: ***Product Innovation Outcome*** mediates the relationship between ***PAET*** and commercial adoption ***Performance (Product)***. • H7b: ***Process Innovation Outcome*** mediates the relationship between ***PAET*** and commercial adoption ***Performance (Process)***.

Table 3-4: Summary of Hypotheses

3.3 Conclusion

This chapter has explained the research questions which aim to investigate the determinants affecting firms' propensity to license technologies developed by PRIs, and the factors influencing a firm's *PAET*, as well as the factors that affect the relationship between the firm's *PAET* and its *Innovation Outcome*, and that between its *Innovation Outcome* and its commercial adoption *Performance*. These research questions address some of the literature gaps highlighted in the previous chapter and contribute not only to the literature on NIS, national innovative capacity, Triple Helix, knowledge production and university-industry collaboration, but also to the literature on external technology acquisition, open innovation and NPD performance at firm level. In this chapter, we have applied the underlying theories and models reviewed in Chapter 2 to develop important constructs and formulate hypotheses to answer the research questions: RBT, KBT, PFI, TCE,

Dynamic Capabilities Theory, absorptive capacity theory, CDM model and collaboration concept in the inter-firm partnership NPD model. These theories and models have been supported by prior empirical studies and provide the theoretical framework for this research to explain the relationship between a firm's *Internal Resources* as independent variable and its *PAET* as a dependent variable.

Based on the RBT, KBT, TCE and PFI theories, a firm's *Internal Resources* are defined by *Human Capital, Commercial CA Resources, Commercial IP Resources* and *Technological Resources*, as supported in prior studies from the university-industry collaboration literature (O'Shea et al., 2005; Mustar et al., 2006). The *External Resources* variables share similar resource types (*Human Capital, Commercial IP Resources, Commercial Officer Resources* and *Technological Resources)* as those for *Internal Resources*, corroborated by previous research using the same theories of RBT, KBT, TCE and PFI in the external technology acquisition and open innovation literature (Hemmert, 2004). Drawing upon the perspectives of dynamic capabilities, absorptive capacity, collaboration, trust and communication, we develop the dynamic capability construct of *NPD Collaboration Capability* to comprise three dynamic capability constructs of *Absorptive Capacity, Collaborative Problem-solving Capability* and *Communication Capability*. We also build the conceptual framework to account for the effect of a firm's *Internal Resources (Internal Technological Resources* and *Internal Human Capital)*, *External Resources* and *NPD Collaboration Capability* as moderating variables on the relationship between its *Propensity for External Acquisition* and its *Innovation Outcome*. We apply the framework to investigate the effect of a firm's *Internal Resources (Internal Commercial CA Resources* and *Internal Commercial IP Resources)* and its *NPD Collaboration Capability* as moderating variables on the relationship between its *Innovation Outcome* and commercial adoption *Performance*, based on the collaboration and alliance concepts, as well as the inter-firm partnership NPD model. Finally, this chapter has presented the research model depicting all the variables and their inter-relationships, and elaborated on seven research hypotheses that are tested in this empirical research.

The next chapter discusses the methodology and research design.

4 Methodology and Research Design

4.1 Introduction

The key objective of this research is to examine the firms that have licensed technologies from Public Research Institutes (PRIs) in Singapore and investigate the determinants affecting the firms' propensity to license technologies developed by PRIs, and the factors influencing their innovative outcomes and firm performance. As the Agency for Science and Technology (A*STAR) is the government agency that oversees PRIs in Singapore, this research studies the organisations that have licensed technologies from A*STAR.

This chapter provides justification for the paradigm and the quantitative research methodology that has been adopted. The following sections elaborate on the research measures and measurements, sampling strategy and the questionnaire which has been designed based on the literature review in Chapter 2. The chapter further discusses the data collection and concludes with the procedure for sound ethical practices.

4.2 Justification for the Paradigm and Methodology

Quantitative Research

To answer the research questions of which, and how, determinants affect firms' propensity to license technologies developed by PRIs, and the factors influencing their innovative outcomes and firm performance that are detailed in Section 3.1, a quantitative research method was used with hypothesis testing. As discussed in Section 2.2 of this literature review of national innovation system (NIS) and national innovative capacity, there is currently a lack of empirical research on the knowledge and innovation from PRIs as knowledge sources from the perspective of the existing rather than new firms as knowledge recipients. As there is a lack of quantitative studies in the extant literature on organisational knowledge and learning, this research contributes to the literature by focusing on how external knowledge sources in the form of R&D from PRIs and the in-house R&D could complement each other to moderate the relationship between a firm's propensity to

acquire external technology (PAET) and its innovative outcome in the form of product or process innovation, building on the perspectives of Resource-based Theory (RBT), Knowledge-based Theory (KBT), Transaction Cost Economics (TCE) (complementary assets and IP appropriability), Profiting from Innovation (PFI) and open innovation (e.g., Wernerfelt, 1984; Barney, 1991; Grant, 1996; Williamson, 1985; Teece, 1986; Chesbrough, 2006a; Vanhaverbeke, 2012). Further, this research makes a significant contribution by empirically investigating how new product development (NPD) dynamic capabilities comprising the dynamic capabilities of absorptive capacity, collaborative problem-solving capability and communication capability could interact with a firm's internal and external resources to moderate the relationship between innovative outcome and firm performance, drawing upon the perspectives of absorptive capacity, dynamic capabilities and the CDM model (Cohen and Levinthal, 1990; Teece et al., 1997; Crépon et al., 1998).

In this study, the licensing agreements are the units of analysis in non-contrived settings. This study aims to investigate the (a) factors impacting propensity to license, (b) factors affecting innovation outcome of licensed technology and (c) factors affecting commercial adoption performance of licensed technology.

To control for inter-nation and inter-PRI variation, this research concentrates on PRIs operating within the IP, science and technology policy and cultural framework managed by the same national agency of one country, that is, Singapore, with her distinct institutional factors. PRIs managed by the same national agency are assumed to be operating with the same propensity to out-license publicly-funded indigenous technologies to both existing and new ventures.

A survey was conducted on the organisations that have signed licensing agreements with technology transfer office (TTO) representing PRIs to either evaluate the technologies of interest from PRIs for a stipulated period of time ('evaluation licenses') or utilise the technologies developed by PRIs for in-house applications or commercial purposes for an agreed duration ('commercial licenses').

4.2.1 Measurements and Measure

This section provides an overview of the variables and their operational definitions, data sources and scale in preparation for data collection.

4.2.1.1 Dependent Variable

The dependent variable for this study is the firm's *Performance*. It is operationalised as the sales related to the exploitation of the technology that the firm licensed from PRIs. The percentage of total sales is used as a performance measure here rather than other measures such as return on investment (ROI) and total sales. As both ROI and total sales are more indicative of the overall performance of the firm which is attributable to a variety of other internal and external factors in addition to the effect of licensed technology, we have restricted the measure of *Performance* to the innovation outcome of the licensed technology only (Cassiman and Veugelers, 2006). The *Performance* variable comprises three items measured as a percentage of the total annual sales: (a) actual sales of new/improved products embodying the licensed technology in the latest fiscal year, (b) actual production volume using new/improved processes from the licensed technology in the latest fiscal year, and (c) the projected annual growth rate of sales revenue of the product(s) embodying the licensed technology in the next three years. The first two items relating to actual sales are measured on a nominal scale with six ordinal categories ranging from the category of the lowest value at 0 to that of the highest value at 21% or more of the total sales. The third item pertaining to projected sales growth is measured on a nominal scale with five ordinal categories ranging from the category of the lowest value at less than 5% to that of the highest value at 21% or more of the total sales.

These cut-off values were proposed based on the pilot study that was conducted in April-May 2010, as discussed in Section 4.3.2. The mid-values of these three items are computed and averaged before logarithmic transformation into a normal variable to facilitate analysis by hierarchical regression, as discussed in Section 5.4.3. Prior studies in the literature on university technology transfer and venture performance (Agrawal, 2006; Cassiman and Veugelers, 2006; Thornhill, 2006) have employed similar operationalisation of the firm's performance. The data for

these items were collected only from the firms that had signed commercial licenses with PRIs, as their licensing agreements had granted them the rights to commercialise the technologies in their products or processes within the stipulated regions for a specified duration. The firms that signed evaluation licenses were given the right to evaluate the technologies for a specified time interval, but not the right to use them for commercial purposes. Hence, the firms that took up evaluation licenses were not asked to provide any data for this *Performance* variable.

4.2.1.2 Independent Variables

A firm's *PAET* is an independent variable that was hypothesised to have an influence on the firm's *Performance* as a dependent variable. *PAET* is measured by a binary variable of 1 = yes and 0 = no for the question of 'Has your organisation ever licensed technology from any other organisation before?' The data for this variable were collected from the firms that took commercial licenses as well as those that signed evaluation licenses.

While the firm's *PAET* is an independent variable in its relationship with the firm's *Performance* as a dependent variable, the firm's *PAET* is also a dependent variable in its relationship with its *Internal Resources* which was posited in Hypothesis 1 to be an independent variable. *Internal Resources* are operationalised using four dimensions*: Technological Resources, Commercial CA Resources, Commercial IP Resources* and *Human Capital*.

The *Technological Resources* variable measures the firm's reliance on basic R&D. Adopting the definition by Cassiman and Veugelers (2006) of this dimension in terms of gauging the significance of knowledge provided by PRIs compared to that furnished by the suppliers and customers, this research measures the firm's internal reliance on basic R&D by two items on a five-point Likert scale anchored at 1 = Strongly Disagree to 5 = Strongly Agree.

The *Human Capital* of a firm is defined as the availability and quality of its internal R&D staff. It is measured by two items on a five-point Likert scale anchored at 1 = Strongly Disagree to 5 = Strongly Agree, as in prior studies in the literature on

technology acquisition (Hemmert, 2004) and on new high-technology venture creation (Deeds et al., 1998).

Commercial Resources have two dimensions. The first dimension is measured by *Commercial Complementary Asset (CA) Resources*, which refers to the complementary assets of an organisation for the exploitation of a firm's R&D works (Teece, 1986; O'Shea et al., 2005). These include the firm's resources for production, marketing and sales, as well as distribution of goods and services. This dimension is measured using six items, each with a five-point Likert scale anchored at 1 = Much weaker Than Competition to 5 = Much Stronger Than Competition. The second dimension of *Commercial Resources* is measured by *Commercial IP Resources,* which describes the effectiveness of the firm's mechanisms to protect its competitive advantage, such as secrecy and economies of scale. It is measured by two items using a five-point Likert scale anchored at 1 = Strongly Disagree to 5 = Strongly Agree. Prior research that used these two items was Cassiman and Veugelers (2006). The data source for this variable comprised both the firms that signed evaluation licenses to evaluate and those that contracted commercialisation licenses to commercialise the technologies developed by PRIs.

4.2.1.3 Mediating Variable

As discussed in Section 2.5.2.4, prior studies found support for the positive influence of R&D expenditure on firm productivity (Lichtenberg and Siegel, 1991; Mairesse and Mohnen, 2005; van Leeuwen and Klomp, 2006; Parisi et al., 2006). However, some researchers argue that while R&D expenditure is a significant factor, it is just an innovation input that should not directly affect a firm's performance; rather, the latter is influenced by innovation output, such as process innovation, product innovation or both. Hence, this research investigates *Innovation Outcome* that is operationally defined by the firm's embodiment of externally licensed technology from PRIs into any of its product (that is, *Product Innovation Outcome*) or process (that is, *Process Innovation Outcome*). The two dimensions of the *Innovation Outcome* variable, namely *Product Innovation Outcome* and *Process Innovation Outcome* are measured with four items each on a five-point Likert scale anchored at 1 = Strongly Disagree to 5 = Strongly Agree, as advocated in prior

studies in the literature on knowledge production function (Pakes and Griliches, 1984) and the CDM approach (Crépon et al., 1998). The *Innovation Outcome* is expected to play the role of a mediating variable that mediates the relationship between the firm's *PAET* as an independent variable and its *Performance* as a dependent variable, as postulated in Hypothesis 7. As only the firms that signed commercial licensing agreements with PRIs are granted the right to embody the licensed technologies into their products or processes, these firms were the targeted sources for collecting *Innovation Outcome* data. In other words, the firms that had contracted evaluation licensing agreements with PRIs would not be asked for such data.

4.2.1.4 Moderating Variables

Although a firm's *Internal Resources* are regarded as independent variable in its relationship with its *PAET* (Hypothesis 1), the *Internal Resources* variable (*Internal Technological Resources* and *Internal Human Capital*) is also hypothesised as a moderating variable that moderates the relationship between its *PAET* and its *Innovation Outcome* (Hypothesis 2). In a similar vein, the *Internal Resources* variable (*Internal Commercial CA Resources* and *Internal Commercial IP Resources*) is posited to play the role of moderating variable on the relationship between the firm's *Innovation Outcome* and its commercial adoption *Performance* (Hypothesis 3).

As discussed in Section 3.2.5, the *External Resources* variable is similar to the *Internal Resources* variable in comprising four dimensions*: External Human Capital, External Technological Resources, External Commercial Officer Resources* and *External Commercial IP Resources*. The *External Human Capital* is operationally defined as the availability and quality of the R&D staff from PRIs assisting in the transfer of technological knowledge to the firm's internal staff. This dimension is measured using two items on a five-point Likert scale anchored at 1 = Strongly Disagree to 5 = Strongly Agree. This measurement was adapted from the approaches used in prior studies of university spin-offs (O'Shea et al., 2005; Powers and McDougall, 2005) and on the topic of technology acquisition from external private firms (Hemmert, 2004). The *External Technological Resources* is

defined as the readiness level of the external technology that was licensed by the firm and is measured by one item on a five-point Likert scale anchored at 1 = Strongly Disagree to 5 = Strongly Agree. This characteristic of *Technology Readiness Level* was highlighted by Markman et al. (2009) as a factor that the TTO should consider in their commercialisation strategy to license the technologies developed by universities to the industry. This research follows their suggestion by employing the *Technology Readiness Level* as a measure of *External Technological Resources* to capture the firm's assessment of its quality.

The *External Commercial Resources* available to a firm comprise two dimensions. The first dimension is defined by the *External Commercial Officer Resources,* which measures the availability and quality of the technology commercialisation personnel from the TTO who perform the commercial aspects of the technology licensing. In their study of university spin-offs, O'Shea et al. (2005) used the number of full-time equivalents in the TTOs to measure the commercial resources, arguing that this 'is an important determinant to successful technology transfer' (O'Shea et al., 2005, p. 998). While this would be a convenient measure, this research makes contribution to the literature on public research commercialisation by taking one step further to measure the firm's assessment of the availability and quality of the technology commercialisation officers with whom it interacted. This dimension is measured in two items on a five-point Likert scale anchored at 1 = Strongly Disagree to 5 = Strongly Agree.

The second dimension of *External Commercial Resources* is defined as the *External Commercial IP Resources* which measures the effectiveness of IP protection. Cassiman and Veugelers (2006, p. 75) defined this term as 'Industry average (NACE2*)[26] of measure of effectiveness of patents as means to protect innovation (firm-level measure on a scale of 1 = unimportant to 5 = crucia1)'. This research modifies their definition of effectiveness of IP protection to be the firm's willingness to commit resources to IP protection so as to gain competitive advantage. The *External Commercial IP Resources* is measured using one item on a five-point Likert scale anchored at 1 = Strongly Disagree to 5 = Strongly Agree.

[26] NACE2 refers to Nomenclature Statistique des Activités économiques dans la Communauté Européenne, which measures economic activities in the European Community.

The *External Resources* variable was postulated to moderate the relationship between the firm's *PAET* and its commercial adoption *Performance*. The data source for the *External Resources* variable comprised both the firms that signed evaluation licenses and those that contracted commercialisation licenses.

The *NPD Collaboration Capability* variable has three dimensions: *Absorptive Capacity*, *Communication Capability* and *Collaborative Problem-solving Capability*. The first dimension of *Absorptive Capacity* adopted the extended definition by Ettlie and Pavlou, (2006, p. 122) as inter-firm 'ability to identify, assimilate, transform and exploit external knowledge'. It is measured using two items on a five-point Likert scale anchored at 1 = Strongly Disagree to 5 = Strongly Agree. Drawing upon the conceptual model and results of Bstieler (2006, p. 99), this research defines the second dimension, *Communication Capability*, as the firm's ability to perform accurate, open and timely information exchange among parties. It is measured using one item on a five-point Likert scale anchored at 1 = Strongly Disagree to 5 = Strongly Agree. The third dimension which is *Collaborative Problem-solving Capability* is defined based on the work of Li et al. (2007, p. 202). It is measured with five items on a five-point Likert scale anchored at 1 = Strongly Disagree to 5 = Strongly Agree. The *NPD Collaboration Capability* variable is expected to moderate the relationship between the firm's *PAET* and its *Innovation Outcome* (Hypothesis 5), as well as the relationship between its *Innovation Outcome* and its commercial adoption *Performance* (Hypothesis 6). As in the case with *Innovation Outcome* variable, only the firms that signed commercial licensing agreements with PRIs are granted the right to embody the licensed technologies into their products or processes, these firms were the targeted sources for collecting *NPD Collaboration Capability* data. In other words, the firms that had contracted evaluation licensing agreements with PRIs were not requested to furnish such data.

4.2.1.5 Control Variables

In this research, we control for alternative explanations for the firms' *PAET*, *Innovation Outcome* and commercial adoption *Performance*. Seven control

variables (*Spin-off, Firm Size, Market Barriers, Technology Barriers, Firm Age, Industrial Sector* and *Innovation Orientation*) are used and discussed below.

Spin-off

Agrawal (2006) argued that the licensed technology would have a more significant effect on the innovation outcome and commercial adoption performance of a start-up than that of an existing firm, even though the latter would be better endowed with resources in NPD than the former. This research contends that in spin-offs, the founders in most cases are the inventors who developed the licensed technologies. The spin-offs would therefore have a more seamless transfer of technology and knowledge from PRIs to the newly created firm. In this regard, there is a possibility that the external and internal human capital resources might be rated more highly among the spin-offs than among the existing firms. Hence, the *Spin-off* is a binary variable that indicates whether the firm was founded on the basis of the technology that licensed from the PRI. It is used to control for the variations between spin-offs and existing firms due to the above reasons.

Firm Size

Prior studies (Agrawal, 2006, p. 71) have asserted that firms that are bigger in terms of staff strength and higher net fixed assets are deemed to have more resources than firms of smaller staff strength and lower net fixed assets to develop and take advantage of absorptive capacity (Cohen and Levinthal, 1990). On the other hand, small firms and their absence of bureaucratic organisation structures would allow them to be more agile and responsive to changes in technology and market, especially in high-technology industries where knowledge workers are in high demand (Acs and Audretsch, 1993; Agrawal, 2006, p. 71). This research therefore uses the *Number of Firm's Employees* and its *Net Fixed Assets* to control for the firm size. Both values are measured in logarithmic forms.

Market Barriers and Technology Barriers

According to Cassiman and Veugelers (2006), there may be external technology and market barriers that could hinder a firm's innovation process and outcome. In this research, the *Market Barriers* are captured as a control variable that is defined

by their impact as barrier to innovation. *Technology Barriers*, on the other hand, are defined as the impact of 'lack of technological opportunities as barrier to innovation' (Cassiman and Veugelers, 2006, p. 75). *Market Barriers* and *Technology Barriers* are measured using three items and two items, respectively, on a five-point Likert scale anchored at 1 = Low Impact to 5 = High Impact.

Firm Age

Firms that have been established for a longer time may have accumulated more resources and much experience that could positively influence their NPD process (Hall et al., 2009). To control for this variation, the firm's age in terms of the number of years that the firm has been established is used in this research. The *Age* of the firm is squared as part of data preparation for data analysis.

Industrial Sector and Innovation Orientation

Some high-technology industrial sectors such as information and communication technology sector might be prone to technological changes, leading to higher risk of technological obsolescence than other industrial sectors and influencing the firm's innovation outcome and performance. Similarly, certain innovation orientations such as biomedical technology in drug development would face a longer development cycle time, impacting the firm's commercialisation success. The variation in research orientation and development cycle time across different industrial sectors is supported by Kwanghui Lim's study (2004, p. 291) of semiconductor and pharmaceutical industrial sectors globally in 1981-1997. Lim found that the pharmaceutical industry enjoys strong IP appropriability and orientates towards basic research, while the semiconductor industry has weaker patent protection and focuses on applied research. To control for these variations, *Industrial Sector* and *Innovation Orientation* are defined as control variables. The *Industrial Sector* indicates the sector that the firm operates in and is measured by one item on a nominal scale with six categories. The *Innovation Orientation*, on the other hand, refers to the technology areas that the firm operates in and is measured by one item each on a nominal scale with four categories. The categories for both variables are based on those employed by PRIs and also clearly understood by the firms that licensed the technologies from these institutes.

Table 4-1 provides a summary of different variable types, data sources, scale and previous studies using similar operational definition and measurement methods.

Types of variables	Variables	Operational Definition	Data source	Scale	References
Moderating	***NPD Collaboration Capability***				
	Absorptive Capacity	Ability to identify, assimilate, transform and exploit external knowledge	Comm Licensees	2-item on a five-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree	Ettlie and Pavlou, 2006, p. 122
	Communication Capability	Ability to perform accurate, open and timely information exchange among parties	Comm Licensees	1-item on a five-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree	Bstieler, 2006, p. 99
	Collaborative Problem-solving capability	Ability to seek new ideas, evaluate and choose from alternatives, design and develop product, implement plan and launch product	Comm Licensees	5-item on a five-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree	Li et al., 2007, p. 202

Table 4-1: Operational Definition, Data Source and Scale of Variables

Types of variables	Variables	Operational Definition	Data source	Scale	References
Independent/ Moderating	***Internal Resources***				
	Human Capital	Availability and quality of R&D staff	Comm Licensees Eval Licensees	2-item on a five-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree	Deeds et al., 1998 Hemmert, 2004
	Technological Resources	Reliance on basic R&D	Comm Licensees Eval Licensees	2-item on a five-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree	Roberts and Hauptman, 1986 Rothwell, 1992 Cassiman and Veugelers, 2006
	Commercial Complementary Asset (CA) Resources	Complementary assets (manufacturing, marketing and sales capabilities)	Comm Licensees Eval Licensees	6-item on a five-point Likert scale anchored at 1 = Much Weaker Than Competition to 5 = Much Stronger Than Competition	Teece, 1986, 2006
	Commercial IP Resources	Effectiveness of strategic protection	Comm Licensees Eval Licensees	2-item on a five-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree	Cassiman and Veugelers, 2006

Table 4-1: Operational Definition, Data Source and Scale of Variables (Cont'd)

Types of variables	Variables	Operational Definition	Data source	Scale	References
Independent/ Moderating	***External Resources***				
	Human capital	Availability and quality of external R&D personnel	Comm Licensees Eval Licensees	2-item on a five-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree	Hemmert, 2004 O'Shea et al., 2005 Powers and McDougall, 2005
	Technological Resources	Readiness level of external technology	Comm Licensees Eval Licensees	1-item on a five-point Likert scale anchored at 1=Very Dissatisfied to 5=Very Satisfied	Markman et al., 2009
	Commercial Officer Resources	Availability and quality of technology commercialisation personnel	Comm Licensees Eval Licensees	2-item on a five-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree	O'Shea et al., 2005 Zahra et al., 2007
	Commercial IP Resources	Effectiveness of IP protection	Comm Licensees Eval Licensees	1-item on a five-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree	Cassiman and Veugelers, 2006

Table 4-1: Operational Definition, Data Source and Scale of Variables (Cont'd)

Types of variables	Variables	Operational Definition	Data source	Scale	References
Independent/ Dependent variable	***Propensity to acquire external technology (PAET)***	Whether the firm has previously licensed technology from any other organisation	Comm Licensees Eval Licensees	Binary variable: 1 = yes, 0 = no	Atuahene-Gima, 1993 Agrawal, 2006
Mediating variable	***Product Innovation Outcome*** ***Process Innovation Outcome***	Whether the firm has embodied externally licensed technology from PRIs into any of its product(s) or process(es) - Product Innovation Outcome - Process Innovation Outcome	Comm Licensees	4-item on a five-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree 4-item on a five-point Likert scale anchored at 1=Strongly Disagree to 5=Strongly Agree	Pakes and Griliches, 1984 Crépon et al., 1998
Dependent variable	***Performance***	Related to sales that used the licensed technology - Percentage of total actual sales for product innovation - Percentage of total actual production volume for process innovation - Projected sales for product innovation	Comm Licensees	2-item on a nominal scale with 6 ordinal categories 1-item on a nominal scale with 5 ordinal categories	Agrawal, 2006

Table 4-1: Operational Definition, Data Source and Scale of Variables (Cont'd)

Types of variables	Variables	Operational Definition	Data source	Scale	References
Control	***Spin-off***	Whether the firm was founded on the basis of the licensed technology	Comm Licensees	Binary variable: 1=yes, 0=no	Agrawal, 2006
	Firm Size	- Number of employees - Net Fixed Asset Investment	Comm Licensees Eval Licensees	Both values are measured in logs	Agrawal, 2006
	Market Barriers	Impact of market obstacles as barrier to innovation	Comm Licensees Eval Licensees	3-item on a five-point Likert scale anchored at 1= Low Impact to 5 = High Impact	Cassiman and Veugelers, 2006
	Technological Barriers	Impact of lack of technological opportunities as barrier to innovation	Comm Licensees Eval Licensees	2-item Likert-scale anchored on 1 = Low Impact to 5 = High impact.	Cassiman and Veugelers, 2006
	Firm Age	Number of years that the firm has been established	Comm Licensees Eval Licensees	Squared (age)	Hall et al., 2009
	Industrial Sector	Industrial sector that the firm operates in	Comm Licensees Eval Licensees	1-item on a nominal scale with 6 categories,	Lim (2004) Classification by PRIs
	Innovation Orientation	Technology areas that the firm operates in	Comm Licensees Eval Licensees	1-item on a nominal scale with 4 categories,	Lim (2004) Classification by PRIs

Table 4-1: Operational Definition, Data Source and Scale of Variables (Cont'd)

4.3 Research Procedure

This section provides an overview of the sampling strategy, the questionnaire design and the data collection method.

4.3.1 Sampling Strategy

Target Respondents

In Singapore, there are 14 PRIs and these report to a single government agency, A*STAR, to perform mission-oriented research in the biomedical, science and engineering clusters in 2010. Table 4-2 provides the names and profiles of these 14 A*STAR research institutes (A*STAR, 2012). From 2002 to 2009, approximately 300 licenses were granted from these PRIs to 220 organisations (A*STAR, 2009). Of the 300 licenses, 180 were commercial licenses while the remaining 120 were evaluation licenses. The sampling frame for this study was constructed from the database of the government agency. The target sample represented the population of 300 licenses and comprised all the organisations that had signed these licenses, namely the evaluation licensees and commercial licensees.

Evaluation Licensees

The evaluation licensees were the firms that had signed licenses to evaluate the technologies developed by PRIs for a stipulated period of time. By the end of the evaluation period, the evaluation licensees would decide whether or not to proceed to sign commercial license to adopt the technology as part of their product or process innovation for commercial adoption. From 2002 to 2009, there were 120 evaluation licenses taken up by 100 firms with the PRIs. This group of 120 evaluation licenses was examined to identify the determinants for their PAET. The questionnaire for the evaluation licensees may be found in Appendix C.

PRI	Profile
Bioinformatics Institute (BII)	BII was established in 2001 to train manpower and build capabilities in bioinformatics. It focuses on theoretical approaches aimed at understanding biomolecular mechanisms that underlie biological phenomena; the development of computational methods to support this discovery process; and experimental verification of predicted molecular and cellular functions of genes and proteins with biochemical methods.
Bioprocessing Technology Institute (BTI)	Established in 1990, BTI specialises in the generation of novel cell lines and biomolecules; optimization of therapeutics production in prokaryotic and eukaryotic systems; expansion and characterization of stem cells; product recovery, purification and analysis; and profiling of processes using "-omics" tools.
Genome Institute of Singapore (GIS)	Established in 2000, GIS is a centre for genomic discovery that pursues the integration of technology, genetics, and biology towards the goal of individualised medicine.
Institute of Bioengineering and Nanotechnology (IBN)	Since 2003, IBN conducts interdisciplinary research that brings together science, engineering and medicine in key areas such as drug and gene delivery; cell and tissue engineering; biodevices and diagnostics; and pharmaceuticals synthesis and green chemistry.
Institute of Medical Biology (IMB)	Established in 2007, IMB's mission is to study mechanisms of human disease in order to discover new and effective therapeutic strategies for an improved quality of life. Its growing portfolio of strategic research topics aims to promote translational research on the mechanisms of human diseases with a cell-to-tissue emphasis that can help identify new therapeutic strategies for disease amelioration, cure, and eradication.
Institute of Molecular and Cell Biology (IMCB)	Started in 1987, IMCB has established itself as a world-class research institute in biomedical sciences with a focus on six major fields: Cancer Biology, Cell Biology, Developmental Biology, Infectious Diseases, Structural Biology and Translational Research.
Singapore Immunology Network (SIgN)	Initiated in 2005, SIgN builds up research mass and coordinate basic, translational and clinical research needed to establish immunology as a core capability in Singapore. SIgN focuses on studying immune responses in disease-specific contexts to build up a strong platform in basic human immunology research for better translation into clinical applications.

Table 4-2: Profile of A*STAR Research Institutes (A*STAR, 2012)

PRI	Profile
Data Storage Institute (DSI)	Established in 1992, DIS aims to be a vital node in a global community of knowledge generation and innovation, nurturing research talent and capabilities for world-class R&D in next generation storage technologies. It has core competencies in network storage, non-volatile memory and high-density magnetic recording technologies.
Institute of Chemical and Engineering Sciences (ICES)	Established in 2002, ICES' research areas cover chemistry and chemical engineering science, using advanced analytical characterisation and measurement to develop new technology for the petrochemical, general chemical, fine chemical and pharmaceutical industries.
Institute of High Performance Computing (IHPC)	Established in April 1998, IHPC focuses its research on complex-coupled systems, mechanics and fluid dynamics, large-scale systems, scientific computing and software development, digital modelling, adaptive and collaborative computing, data mining and analyses, computational electronics and electromagnetics, computational material and chemistry.
Institute for Infocomm Research (I^2R)	Set up in 2002, I^2R performs R&D in information, communications and media (ICM) technologies to develop holistic solutions across the ICM value chain. Its research capabilities are in information technology, wireless and optical communication networks, interactive and digital media; signal processing and computing.
Institute of Materials Research and Engineering (IMRE)	Established in September 1997, IMRE seeks to create materials knowledge, develop human capital and to transform technology through innovative research. It has strong capabilities in materials analysis, characterisation, materials growth, patterning, fabrication, synthesis and integration.
Institute of Microelectronics (IME)	Since 1991, IME is an R&D bridge between academia and industry, It aims add value to Singapore's semiconductor industry by developing strategic competencies, innovative technologies and IP; enabling enterprises to be technologically competitive; and cultivating a technology talent pool for the industry. Its research areas are in integrated circuits design, advanced packaging, bioelectronics, MEMS, nanoelectronics and photonics.
Singapore Institute of Manufacturing Technology (SIMTech)	Established in 1993, SIMTech aims to develop high value manufacturing technology and human capital to contribute to the competitiveness of the Singapore industry. The focus areas of its research include Production and Logistics, Advanced Forming and Joining Technology, Machining Technology, Mechatronics, Precision Measurement, Advanced Automation and Product Design and Development.

Table 4-2: Profile of A*STAR Research Institutes (A*STAR, 2012) (Cont'd)

Commercial Licensees

From 2002 to 2009, 180 commercial licenses were signed with the PRIs by 120 firms. The questionnaire for the commercial licensees is provided in Appendix D.

A summary of the target sample, their description and data collection methods may be found in Table 4-3.

Target Sample	Description and Data Collection Methods
Evaluation Licensees	The evaluation licensees are the firms that have signed evaluation licenses to evaluate the technologies developed by PRIs for a stipulated period of time. The questionnaire for the evaluation licensees may be found in Appendix C.
Commercial Licensees	The commercial licensees are the firms that have signed commercial licenses to commercialise the technologies developed by PRIs for a stipulated period of time. The questionnaire for the commercial licensees is provided in Appendix D.

Table 4-3: Target Sample and Data Collection Methods

The target respondents were firms that came from various industrial sectors, ranging from electronics, chemicals, info communications, engineering, biomedical services and general manufacturing.

Unit of Analysis

One firm may have taken multiple commercial and evaluation licenses. For a particular firm, different licensing agreements describe the rights to use different technologies and their applications under certain terms and conditions for a certain period. It is at the licensing agreement level that the firm will decide the feasibility of commercialising the licensed technology and the commitment of their internal resources to attain the expected benefits of innovation arising from acquisition of the licensed technology. The licensing agreement is therefore a suitable unit of analysis. For firms that have signed multiple evaluation and/or commercial licenses, their responses to the respective licenses were collected as separate observations, as the unit of analysis is a licensing agreement.

4.3.2 Questionnaire Design

Pilot Study

The questionnaire design followed the guidelines and principles recommended by Cavana, Delahaye and Sekaran (2001). The questionnaires were tested in a pilot study between April and May 2010 on a group of 14 people to gather their feedback on the clarity and validity of the research instrument. The number of respondents participating in the pilot study satisfied Foddy's (1993) minimum guideline of five respondents. Among these 14 people who participated in the pilot study, four were from TTO, having subject matter expertise and experience in the commercial adoption of the technologies developed by the PRIs, while the remaining ten were representatives from the firms which had licensing agreements with the TTO. This researcher met with the four TTO commercialisation officers who represented four different technology clusters (innovation orientation) to seek their input on the questionnaire for the commercial licensees. In addition to obtaining the perspectives of the commercialisation officers, we requested for their nomination of ten firms that were representative of the following:

- three different status: (a) spin-off founded on the technology developed by the PRI, (b) SMEs and (c) MNCs;
- two different types of contractual relationship: (a) evaluation licensing agreement and (b) commercial licensing agreement;
- two different technology clusters (innovation orientation): (a) biomedical and life sciences technology cluster and (b) science and engineering technology cluster comprising: information and communication technology; engineering and manufacturing; materials, chemicals and electronics.

Based on the nomination and introduction by the TTO commercialisation officers, this researcher met two founders of their respective spin-offs which had signed commercial licenses with the TTO, with one founder from the biomedical and life sciences technology cluster and the other from the science and engineering technology cluster. Another two pilot participants were representatives of small medium enterprises which had signed commercial licenses, with one from the biomedical and life sciences cluster,

and the other from the science and engineering technology cluster. Two more pilot participants presented the views of multinational enterprises which had signed commercial licenses, with one from the biomedical and life sciences technology cluster, and the other from the science and engineering technology cluster. The perspectives of these six pilot participants representing the commercial licensees were sought on the questionnaires designed for the commercial licensees. Their views on the questionnaire were solicited for the evaluation licensees. Four firms from two different technology clusters (science and engineering versus biomedical) and two different firm sizes (SME versus MNC) which had signed evaluation licenses with the TTO were contacted to hear their opinions on the questionnaire designed for the evaluation licensees.

Refining the Questionnaires

Based on the feedback from the 14 participants of the pilot study, both the commercial and evaluation licensee questionnaires were re-worded to keep the number of questions to a minimum to avoid response fatigue. Most questions are closed to facilitate quick response and meaningful analysis. Notwithstanding this, some questions that relate to challenges encountered during commercial adoption or reasons for not signing for commercial licenses are open-ended to provide rich data. Biases in questions were avoided with careful sequencing of questions and helpful instructions to encourage response. The length of most questions was kept to 20 words or less. Where applicable, the interval Likert scale was adopted rather than the nominal or ordinal scale, to facilitate assessment of goodness of measures with the validity and reliability tests. The refining of the questionnaires was performed in accordance with Foddy's (1993) recommendation for piloting questions. More details are provided in Chapter 5.

After refining the questionnaires based on the feedback from the pilot test, the final version of the questionnaire was made up of seven parts. The first part consisted of questions about the *Internal Resources*, inquiring about the firm's *Internal Technological Resources, Internal Commercial CA Resources*, *Internal Commercial IP Resources* and *Internal Human Capital*, as illustrated in Table 4-4.

No	Questions	Scale
1	***Human Capital:*** 2 items Please select the extent to which you agree with the following statements about <u>your organisation resources in licensing technology</u> from the public research institute (PRI) - Our own R&D staff are knowledgeable and competent to assimilate and exploit internally the knowledge from PRI. - Our own R&D staff are available to assimilate and exploit knowledge from PRI.	Likert scale 1 = Strongly Disagree 5 = Strongly Agree
2	***Technological Resources***: 2 items Please select the extent to which you agree with the following statements about <u>your organisation's resources in licensing technology</u> from the public research institute (PRI) - Our organisation requires the technologies that are developed by the PRI. - For our organisation's innovation, knowledge from PRI is more important to us than knowledge from our suppliers and customers.	Likert scale 1 = Strongly Disagree 5 = Strongly Agree
3	***Commercial Resources (IP)***: 2 items Please select the extent to which you agree with the following statements about <u>your organisation's resources in licensing technology</u> from the public research institute (PRI) - The following are effective mechanisms in protecting my organisation's competitive advantage: i. secrecy ii. economies of scale	Likert scale 1 = Strongly Disagree 5 = Strongly Agree
4	***Commercial Resources (Complementary Assets)***: 6 items How would you rate the following <u>capability of your organisation in relation to your competition</u> - The quality of our market research - The range of our products - The cost of our production - The effectiveness of our marketing strategy - The quality of our customer service - The extensiveness of your distribution network	Likert scale 1=Much Weaker Than Competition 5 = Much Stronger Than Competition

Table 4-4: Questions about *Internal Resources*

The second part comprised items about the *External Resources*, covering the firm's *External Human Capital*, *External Technological Resources, External Commercial Officer Resources* and *External Commercial IP Resources*, as detailed in Table 4-5. Table 4-6 provides an overview of the third part of the questionnaire capturing the firm's *PAET*.

No	Questions	Scale
1	***Human Capital***: 2 items Please select the extent to which you agree with the following statements on the researcher/s of the public research Institutes (PRI) - The PRI researchers are knowledgeable and competent to transfer the licensed technologies to our organisation. - The PRI researchers are available to transfer the licensed technologies to our organisation.	Likert scale 1 = Strongly Disagree 5 = Strongly Agree
2	***Technological Resources***: 1 item On a scale of 1 to 5, how satisfied you are with the following attribute of the licensed technology for your organisation's R&D? - The technology readiness level	Likert scale 1 = Very Dissatisfied 5 = Very Satisfied
3	***Commercial Officer Resources***: 2 items Please select the extent to which you agree with the following statements on the technology commercialisation officer/s - The officer provides adequate advice and guidance on the licensing process. - The officer is always available to respond and attend to my queries and requests.	Likert scale 1 = Strongly Disagree 5 = Strongly Agree
4	***Commercial IP Resources***: 1 item Please select the extent to which you agree with the following statements about your organisation resources in licensing technology - Our organisation is willing to commit resources to IP protection to gain competitive advantage.	Likert scale 1 = Strongly Disagree 5 = Strongly Agree

Table 4-5: Questions about *External Resources*

No	Questions	Scale
1	***PAET:*** 1 item Has your organisation ever licensed technology from any other organisation before? a) Yes [ ] b) No [ ]	Binary scale

Table 4-6: Questions about *PAET*

The fourth part listed questions relating to the control variables such as the firm's status as a *Spin-off* or existing firm, *Firm Size, Firm Age, Industrial Sector, Innovation Orientation, Market Barriers* and *Technological Barriers*. Both the questionnaires for the evaluation licensees and the commercial licensees contained these first four parts. The remaining three parts pertain to technology commercialisation activities rather than technology evaluation activities. The technology commercialisation activities relate to the firm's *Innovation Outcome*, its *NPD Collaboration Capability* and its *Performance* in commercialising the technology licensed from PRIs. Therefore, these three parts were

found only in the questionnaire for the commercial licensees, but not in that for the evaluation licensees. The part containing questions relating to *Innovation Outcome* may be found in Table 4-7, while that for commercial adoption *Performance* in Table 4-8.

No	Questions	Scale
1	***Product Innovation Outcome***: 4 items The following are criteria used to assess the commercial outcome of the licensed technology. To what extent do you agree with the following statements? - The licensed technology opens new market(s). - The licensed technology increases market share. - The licensed technology improves quality of goods or services. - The licensed technology increases the range of goods or services.	Likert scale 1 = Strongly Disagree 5 = Strongly Agree
2	***Process Innovation Outcome***: 4 items The following are criteria used to assess the commercial outcome of the licensed technology. To what extent do you agree with the following statements? - The licensed technology reduces unit labour cost. - The licensed technology reduces materials per unit. - The licensed technology reduces lead time. - The licensed technology improves capacity.	Likert scale 1 = Strongly Disagree 5 = Strongly Agree

Table 4-7: Questions about *Innovation Outcome*

No	Questions	Scale
1	***Product Performance***: 1 item Please indicate your actual sales of new/improved products embodying the licensed technology in the latest fiscal year (in approximate % of total annual sales).	Ordinal scale a) 0 b) Less than 5% [ ] c) 5% - 10% [ ] d) 11% - 15% [ ] e) 16% - 20% [ ] f) 21% & above [ ]
2	***Process Performance***: 1 item Please indicate your actual production volume using new/ improved processes from the licensed technology in the latest fiscal year (in approximate % of annual production volume):	Ordinal scale a) 0 b) Less than 5% [ ] c) 5% - 10% [ ] d) 11% - 15% [ ] e) 16% - 20% [ ] f) 21% & above [ ]
3	***Projected Performance***: 1 item What is your projected annual growth rate of sales revenue of the product(s) embodying the licensed technology in the next 3 years (in approximate %)?	Ordinal scale a) Less than 5% [ ] b) 5% - 10% [ ] c) 11% - 15% [ ] d) 16% - 20% [ ] e) 21% & above [ ]

Table 4-8: Questions about commercial adoption *Performance*

The final part with questions depicting the *NPD Collaboration Capability* is listed in Table 4-9.

No	Questions	Scale
1	***Absorptive Capacity***: 2 items Please select the extent to which you agree with the following statements about your organisation's internal processes for transferring technology from PRI - We have internal processes to identify, assimilate and exploit external knowledge from the PRI. - We have internal processes to successfully exploit the new integrated knowledge from PRI into new products or processes.	Likert scale 1 = Strongly Disagree 5 = Strongly Agree
2	***Communication Capability***: 1 item - We ensure that the communication of our work between us and the PRI researchers is timely, accurate and adequate.	Likert scale 1 = Strongly Disagree 5 = Strongly Agree
3	***Collaborative Problem-solving Capability***: 5 items - We have internal processes to ensure adequate allocation of resources (e.g., information, time, reports) to work with the PRI researcher. - We ensure there is good understanding between the PRI researcher and our R&D staff of each other's roles and responsibilities. - Both the PRI researcher and our R&D staff work closely to ensure that there is smooth transfer of knowledge. - When there were conflicts during the NPD process, o we resolved them by ensuring accurate and complete information between us and the PRI researchers. o we resolved them by focusing on our common goals rather than differences.	Likert scale 1 = Strongly Disagree 5 = Strongly Agree

Table 4-9: Questions about *NPD Collaboration Capability*

4.3.3 Data Collection

Using the refined survey questionnaires discussed in Section 4.3.2, the researcher collected the data from July 2010 to November 2010 to identify and analyse the factors that account for variations in PAET, innovation outcome and performance among the evaluation and commercial licensees. From the sample frame of 300 licensing agreements, this study collected 253 responses, of which 250 were complete and usable. The incomplete responses were discarded. The questionnaires were distributed to the participants by post via a third party appointed by the Corporate Marketing and Communication Division of the TTO, which had granted the researcher permission in

September 2009 for this study. The respondents returned to the same Division their completed questionnaires by postal mail. For the participants who indicated preference for soft copy of the questionnaire, a soft copy was made available upon request and their responses were returned via email or hard copy by post to the Corporate Marketing and Communication Division. Such mixed modes of responses were employed to improve response rate (Dillman, Smyth and Christian, 2009).

The response rate of the survey was more than 80%, giving a good representation of the target population. The high response was achieved as the third party engaged by the Corporate Marketing and Communication Division contacted the respondents via telephone to give prior notice of the upcoming survey. A few days later, the respondents received by post the mail questionnaire together with the cover letter, the Information Sheet about the study and return envelope. The Division subsequently sent a thank you or reminder phone call to the participants a week later, followed by replacement questionnaire, cover letter and return envelope (Dillman et al., 2009). After two to four weeks, the Division contacted the participants to complete the questionnaire while speaking to them over the phone (Ettlie and Pavlou, 2006). As the questionnaires did not request identifying details, the anonymity of the participants was preserved, and a consent form was not required, since the return of the completed questionnaire indicated consent. The data collection was conducted in compliance with the stipulated guidelines for ethics protocol. More details on the procedure for sound ethical practices are discussed in the next section.

4.4 Procedure for Sound Ethical Practices

Sound ethical practices were observed during the research. The approval of the research proposal by the UNISA Ethics Committee was sought and granted in April 2010, pursuant to the submission of the following documents in compliance with the Ethics protocol:

1) Reference list, as updated in References chapter

2) Research tool
    a. Questionnaire for Evaluation Licensees as updated in Appendix C
    b. Questionnaire for Commercial Licensees as included in Appendix D
    c. Recruitment Material: Cover letter for the participants, as included in Appendix E
    d. Information Sheet for the participants, as included in Appendix F
    e. Correspondence with the TTO pertaining to their permission for the research to be conducted on their staff, licensees and potential licensees (which is not included for confidentiality reasons). The researcher had obtained written permission from the organisation in September 2009.

As highlighted in Section 4.3.3, the identified respondents were contacted and informed about the purpose and duration of the survey, as well as the researcher's code of data confidentiality. The respondents were notified of the voluntary nature of the survey. Their desire to terminate the data collection at any time was respected. The data collected were stored and managed in a secure manner by the researcher, and the respondents were assured that only aggregated data would be reported and published in this research.

4.5 Conclusion

This chapter has presented the research design and the justification for the paradigm and research methodology. It elaborated on the quantitative approach comprising survey research targeted at organisations that had signed commercial licensing agreements and evaluation licensing agreements with the TTO to acquire the technologies developed by PRIs. This chapter also discussed the sampling strategy and the questionnaire design, based on the literature review presented in Chapter 2. Prior to the survey, the questionnaires were pre-tested in a pilot study for validity and reliability. The questionnaires were subsequently refined based on the feedback of the pilot participants. This chapter further clarified the data collection approach and concluded with the procedure for sound ethical practices. The next chapter discusses descriptive statistics, data analysis and hypothesis testing.

5 Analysis of Data

5.1 Introduction

This chapter presents the regression analysis results on the independent, control, moderating, mediating and dependent variables to validate the seven hypotheses as detailed in Section 3.2. The binary logistic regression of *PAET* was performed to validate Hypothesis 1, stating that firms that have higher levels of *Internal Resources* are more likely to have a lower *PAET*. To validate Hypotheses 2, 4 and 5, the moderated hierarchical regression analysis was conducted (Lindley and Walker, 1993; Aguinis, 1995) to determine the moderation effect of the *Internal Resources, External Resource*s and *NPD Collaboration Capability* on the relationship between *PAET* and the *Innovation Outcome*. The same moderated hierarchical regression analysis was repeated to assess the moderation effect of the *Internal Resources* and *NPD Collaboration Capability* on the relationship between the *Innovation Outcome* and the commercial adoption *Performance*, to validate Hypotheses 3 and 6. Next, to confirm Hypothesis 7, which predicts the mediation of the relationship between *PAET* and *Performance* by *Innovation Outcome*, hierarchical regression was performed for the mediation analysis.

This chapter concludes with a summary of all the regression analysis results in response to each of the three research questions that were defined and elaborated in detail in Section 3.1.

5.2 Profile of Respondents

The survey received a total of 250 responses. More than 60% of the respondents (N = 153) are commercial licenses, while less than 40% (N = 97) are evaluation licenses, as shown in Table 5-1. About 42% of the licenses (N = 106) were signed in 2009-2010, while 58% of licenses (N = 144) were taken up before 2009. The percentage of evaluation licenses has also increased from 47% before 2009 to 53% in the recent years.

YEAR OF LICENSING AGREEMENT	Commercial Licenses		Evaluation Licenses	
	No.	%	No.	%
Before 2009	98	64	46	47
2009-2010	55	36	51	53
Total	153	100	97	100

Table 5-1: Responses by Year of Licensing

About one-third of the commercial and evaluation licenses are from the biomedical products and services industrial sector with a corresponding proportion of respondents with the biomedical and life sciences technological focus. Another one-third of both the commercial and evaluation licenses were made up of respondents from the information technology and communication industrial sector, with a similar percentage with the information and communication innovation orientation. The remaining one-third of both groups of licenses came from the electronics, engineering, chemicals, general manufacturing and other industries, as shown in Table 5-2.

INDUSTRIAL SECTOR OF ORGANISATION	Commercial Licenses		Evaluation Licenses	
	No.	%	No.	%
Biomedical products and services	48	31	29	30
Info communications	45	29	34	35
Electronics	33	22	8	8
Engineering	14	9	0	0
Chemicals	5	3	2	2
General manufacturing	5	3	7	7
Other	3	2	17	18
Total	153	100	97	100

Table 5-2: Responses by Industrial Sector

The commercial and evaluation licenses focusing on engineering and manufacturing, materials, chemicals, electronics and other technologies also make up to about one-third of the total number of respondents, as shown in Table 5-3.

INNOVATION ORIENTATION OF ORGANISATION	Commercial Licenses		Evaluation Licenses	
	No.	%	No.	%
Infocomm technology	51	33	38	39
Biomedical and life sciences	46	30	30	31
Engineering and manufacturing	42	27	7	7
Materials, chemical and electronics	10	7	7	7
Other	4	3	15	15
Total	153	100	97	100

Table 5-3: Responses by Innovation Orientation

60% of the commercial licenses have fixed asset investment of less than S$1 million, while the evaluation licenses that belong to this category make up 40%, showing that a significant proportion of the licenses are SMEs, as illustrated in Table 5-4.

Firm Size	Commercial Licenses		Evaluation Licenses	
	No.	%	No.	%
Below S$1 million	79	60	33	34
S$1 - S$3.9 million	28	21	16	16
S$4 - S$7.9 million	12	9	13	13
S$8 - S$11.9 million	4	3	5	5
S$12 – S$15 million	9	7	13	13
Above S$15 million	21	16	17	18
Total	153	100	97	82

Table 5-4: Responses by Firm Size (Fixed Asset Investment)

Some licensees approach A*STAR research institutes to license technologies to enhance the quality and range of goods or services, so as to open new markets or increase market share (product innovation). Others intend to license technologies from PRIs to reduce labour and material costs, shorten lead time or improve production capacity (process innovation). The typical challenges that these licensees, especially the SMEs, face in integrating technologies into their existing products or processes are lack of in-house R&D knowledge and capability for communication and transfer of knowledge from the PRIs. Even if these licensees are successful in achieving product or process innovation with the licensed technologies, the extensive funding and complementary asset resources required for the NPD process involving production, marketing, sales and distribution are obstacles to successful commercial adoption of technologies. In particular, the SMEs, having limited in-house resources, typically find management of IP and value-chain partners challenging. The motives and challenges of these licensees, comprising a significant proportion of SMEs, are therefore similar to those faced by innovative SMEs in earlier studies (de Vrande et al., 2009; Lee et al., 2010; Vanhaverbeke, 2012).

The profile of the respondents along the dimensions of industrial sector, innovation orientation, R&D intensity and firm size were found to be representative of the population of licensees in Singapore. It is important to ensure that a sample representative

of the population would mitigate the risk of systematic bias in the data collected, thus allowing the results to be generalised to the population (Cavana et al., 2001).

5.3 Validity and Reliability of Measurement

As this research includes only firms that license technologies from the PRIs managed under the umbrella of the same public research agency, there is an issue of potential selectivity bias. To address the issues, the empirical strategy of comparing evaluation and commercial licensees help to reduce selection bias, thereby improving the reliability of the research. In addition to selectivity bias, other issues such as face and content validity need to be addressed.

According to Cavana et al. (2001), face validity is concerned with the appearance of the questionnaire in measuring the theoretical constructs. To ensure that the two questionnaires measure the concepts under investigation, they were pre-tested with a total of ten licensees, of which four were evaluation licensees and the other six were commercial licensees. For each questionnaire, the researcher conducted pre-test interviews with one MNC and one SME from the science and engineering technology cluster, as well as one MNC and one SME from the biomedical technology cluster, which had taken up licenses for public research. In addition, one spin-off from the science and engineering technology cluster and another spin-off from the biomedical technology cluster were interviewed on the questionnaire for the commercial licensee. These firms were selected on the basis of appropriate representation of the target sample. Their feedback on the clarity and ease of understanding of the questionnaires was considered in improving the face validity, as discussed in detail in Section 4.3.2.

Content validity refers to the representativeness of the questionnaire in measuring the theoretical variables (Cavana et al., 2001). According to Cavana et al. (2001, p. 213), there are three possible ways to address content validity issues, namely, from: literature, qualitative research and the judgment of experts. To improve the content validity of this study, the literature and every item on the questionnaires was reviewed with four TTO

commercialisation officers with substantial experience in technology transfer activities in order to ascertain their adequacy in measuring the theoretical variables. With the expert judgment validation, the questionnaires were refined further, as detailed in Section 4.3.2.

As the data obtained from the questionnaires were mostly close-ended, they were analysed using a statistical software package (SPSS). To ensure that the data collected were reliable, the Cronbach's alpha coefficients were used to determine how well the items measuring a particular construct were correlated with one another. Cronbach's alpha coefficients were computed for the variables with multiple items for measurement of inter-item consistency reliability. According to Nunnally (1978), scales with Cronbach's alpha coefficients of 0.9 and above are said to be highly reliable, while measures with alpha coefficients of less than 0.7 are deemed to be acceptable. For measures that are newly developed for preliminary research, Nunnally (1967, p.226) recommended alpha levels of 0.5 to 0.6. Davis (1964, p. 24), on the other hand, suggested alpha level of above 0.75 for the study of individuals, 0.5 for a group of 25-50 and below 0.5 for a group of more than 50.

Internal Resources

Table 4-1 presents four *Internal Resources* variable set. The four variables and their respective Cronbach's alpha coefficients are as follows:

1) *Internal Commercial CA Resources* comprises six items relating to internal complementary assets (Teece, 1986, 2006), with Cronbach's alpha coefficient of 0.88.
2) *Internal Technological Resources* consists of two items representing reliance on basic R&D (Cassiman and Veugelers, 2006), with Cronbach's alpha coefficient of 0.71.
3) *Internal Human Capital* includes two items pertaining to the quality and availability of R&D staff (Hemmert, 2004), with Cronbach's alpha coefficient of 0.95.
4) *Internal Commercial IP Resources*, being made up of two items corresponding to effectiveness of strategic protection (Cassiman and Veugelers, 2006), with Cronbach's alpha coefficient of 0.58.

External Resources

As for the case of External Resources variable set, there are four variables and their respective Cronbach's alpha coefficients are as follows:

1) *External Commercial Officer Resources* comprises two items representing the TTO commercialisation officers (O'Shea et al., 2005; Zahra et al., 2007), with Cronbach's alpha coefficient of 0.93.
2) *External Human Capital* consists of two items relating to the quality and availability of the researchers from PRIs (O'Shea et al., 2005; Powers and McDougall, 2005), with Cronbach's alpha coefficient of 0.89.
3) *External Technological Resources* comprises one item representing the readiness level of external technology (Markman et al., 2009).
4) *External Commercial IP Resources* consists of one item representing the effectiveness of IP protection (Cassiman and Veugelers, 2006).

NPD Collaboration Capability

The *NPD Collaboration Capability* variable set has three variables and their respective Cronbach's alpha coefficients are as follows:

1) *NPD Absorptive Capacity* (Ettlie and Pavlou, 2006) comprises two items with Cronbach's alpha coefficient of 0.91.
2) *NPD Communication* (Bstieler, 2006) consists of one item.
3) *NPD Collaborative Problem-solving* (Li et al., 2007) has five items with Cronbach's alpha coefficient of 0.95.

Innovation Outcome

The *Innovation Outcome* variable set has two variables and their respective Cronbach's alpha coefficients are as follows:

1) *Product Innovation Outcome* comprises four items with Cronbach's alpha coefficient of 0.92. It is found to be normally distributed with a mean of 3.9 and standard deviation of 0.97.

2) *Process Innovation Outcome* consists of four items with Cronbach's alpha coefficient of 0.95. The normality test shows that it is normally distributed with a mean of 3.2 and standard deviation of 1.41.

Performance

The *Performance* variable comprises three items measured as: (a) percentage of total actual sales of new/improved products embodying the licensed technology in the latest fiscal year, (b) percentage of total actual production volume using new/improved processes from the licensed technology in the latest fiscal year, and (c) the projected annual growth rate of sales revenue of the product(s) embodying the licensed technology in the next three years. The three items yielded a Cronbach's alpha coefficient of 0.51. The logarithm of this *Performance* variable was found to be normally distributed with a mean of 1.9 and standard deviation of 0.98.

5.4 Results

5.4.1 Results of Hypothesis 1 Testing

5.4.1.1 Obtaining Descriptive and Inferential Statistics

Hypothesis 1 postulated that *firms that have higher levels of Internal Resources are likely to have a lower PAET*. In this hypothesis, the independent variables are four variables of *Internal Resources: Internal Commercial CA Resources, Internal Technological Resources, Internal Human Capital* and *Internal Commercial IP Resources,* while the dependent variable is the *PAET*. The descriptive statistics were used in the initial data analysis to describe the sample and to check for data errors such as missing or invalid data. The frequency distributions, measures of central tendencies and dispersions provided useful descriptions of the licensee samples in terms of the classification variables, such as industrial sector, innovation orientation (technology areas), firm size, or firm age. According to the descriptive statistics of these variables presented in Table 5-5, about 11% of the licensing agreements were signed by organisations that were spin-offs. The average age of the licensing organisation was about 34 years old with average strength of 50 and fixed asset investment in the range of S$1-S$3.9 million.

Apart from descriptive statistics, inferential statistics were also generated. Table 5-5 illustrates that bivariate correlation statistics between each of these *Internal Resources* variables with *PAET* are statistically significant. In particular, all the variables of *Internal Resources* have positive correlation coefficients with *PAET*, except the *Internal Technological Resource*s, indicating a negative correlation coefficient (correlation coefficient = - 0.146, $p < 0.05$).

Finding 1a: *The Internal Commercial CA Resources, Internal Commercial IP Resources and Internal Human Capital significantly and positively correlate with PAET, while Internal Technological Resources has a significant negative correlation with PAET.*

At the same time, certain control variables such as *Spin-off, Firm Age, Firm Size* in terms of employment and fixed asset investment significantly correlate with *PAET*.

5.4.1.2 Binary Logistic Regression

Given that the dependent variable of Hypothesis 1 was binary variable, the binary logistic regression was performed to ascertain the influence of each of the *Internal Resources* independent variables on a dichotomous outcome through assessing the occurrence probability of the events (Tharenou, Donohue and Cooper, 2007, p. 230). According to Tabachnick and Fidell (2001), the logistic regression examined the relationship between the independent variables and the log odds of the event outcome which is dichotomous in nature. By estimating the changes in the log odds of the dependent variable against the value of the dependent variable, the logistic regression describes the probabilistic relationship of the variables in a manner that is similar to the linear regression to facilitate analysis. The independent variables in a logistic regression may be categorical or continuous, but are not assumed to be normally distributed across all values of the dependent variable with equal covariant matrix, unlike discriminant function analysis (Peng and So, 2002, p. 35).

	Control Variables	**Mean**	**Std dev**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	Spin-off	0.11	0.32	1										
2	Firm Age (squared)	1155.05	3966.37	-0.102	1									
3	Firm Size – Employment (log)	1.70	1.06	-0.334**	0.459**	1								
4	Firm Size – Fixed Asset Investment (log)	6.37	0.69	-0.284**	0.372**	0.782**	1							
5	Market Barriers	2.35	1.00	-0.124*	-0.051	-0.168**	-0.075	1						
6	Technology Barriers	2.37	1.03	0.013	0.109	-0.08	0.029	0.659**	1					
	Dependent Variable													
7	PAET	0.35	0.48	-0.209**	0.258**	0.266**	0.334**	-0.003	0.088	1				
	Independent Variables													
8	Internal Commercial CA Resources	3.22	0.88	-0.269**	0.279**	0.397**	0.384**	0.188**	0.122	0.355**	1			
9	Internal Technological Resources	2.72	1.04	0.104	-0.085	-0.055	0.058	-0.005	-0.061	-0.146*	-0.398**	1		
10	Internal Commercial IP Resources	3.50	1.08	-0.136*	-0.142*	0.117	0.041	0.146*	-0.012	0.165**	0.427**	-0.340**	1	
11	Internal Human Capital	3.74	1.20	-0.114*	0.141*	0.110*	0.063	0.151**	0.133*	0.314**	0.517**	-0.388**	0.445**	1
	VIF			1.223	1.485	3.242	2.882	2.145	1.980		2.098	1.409	1.586	1.599
	VIF			1.204	1.322	3.145	2.658	2.085	1.922					

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

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

a. Listwise N=250

Table 5-5: Descriptive and Bivariate Correlation Statistics for *Internal Resources* and *PAET* variables

The same approach of binary logistic regression has been used in the literature on university-industry collaboration, such as the study of determinants affecting 'commercial output' of university research that was 'coded as a dichotomous variable' (Ambos, Mäkelä, Birkinshaw and D'Este, 2008, p. 1435). The results of the regression are discussed in Section 5.5.1.

Table 5-6 presents the results of binary logistic regression on *PAET*. While Model 1 is a baseline model that describes the variances contributed by the control variables, Model 2 examines the four variables of *Internal Resources* pertaining to Hypothesis 1. According to Field (2005, p. 172), 'it's important to collect enough data to obtain a reliable regression model'. He suggested some guidelines for the sample size with respect to 'the number of predictors', with minimum of 5-10 cases per predictor depending on 'the size of expected effect' (Field, 2005, pp. 173-174). Given that there are 250 cases and four predictors (four variables of *Internal Resources*) in Model 2, we have at least 62 cases per predictor, thereby satisfying the sample size/predictor ratio guidelines provided by Field (2005). Model 2 is an improvement over Model 1, where the pseudo R square values: Cox and Snell R Square and Nagelkerke R Square, as well as the percentage of correct classification showed an increase from Model 1 to Model 2.

Dependent Variable: Propensity to Acquire External Technology (PAET) (N=250)				
Variables	**Model 1**		**Model 2**	
	b	**S.E.**	**b**	**S.E.**
Constant	-5.89*	2.56	-9.29**	3.06
Control Variables				
Spin-off	-2.26**	0.85	-2.49**	0.96
Firm Age (squared)	0.00†	0.00	0.00*	0.00
Firm Size – Employment (log)	-0.22	0.30	-0.83*	0.38
Firm Size – Fixed Asset Investment (log)	0.72†	0.40	1.38**	0.48
Innovation Orientation = Infocomm technology	-2.24†	1.32	-3.13*	1.40
Innovation Orientation = Engineering and manufacturing	0.22	1.41	-0.26	1.45
Innovation Orientation = Materials, chemical and energy	0.82	1.72	-0.01	1.85
Innovation Orientation = Biomedical sciences and life sciences	-1.63	1.44	-2.54†	1.49
Industrial Sector = Electronics	1.45	1.40	1.57	1.42

Dependent Variable: Propensity to Acquire External Technology (PAET) (N=250)				
Variables	**Model 1**		**Model 2**	
	b	**S.E.**	**b**	**S.E.**
Industrial Sector= Chemicals	-21.26	13751.91	-20.90	13332.21
Industrial Sector = Info communications	2.36†	1.30	3.03*	1.36
Industrial Sector = Engineering	-0.60	1.60	0.13	1.64
Industrial Sector = Biomedical products and services	3.92**	1.46	4.66**	1.51
Industrial Sector = General manufacturing	-0.53	1.67	-0.80	1.77
Market Barriers	-0.46†	0.23	-0.73**	0.27
Technology Barriers	0.39	0.24	0.57*	0.27
Independent Variable				
Internal Commercial CA Resources			0.43	0.30
Internal Technological Resources			-0.63*	0.25
Internal Commercial IP Resources			0.05	0.21
Internal Human Capital			0.17	0.21
Cox and Snell R Square		0.33		0.38
Nagelkerke R Square		0.45		0.53
Model Chi-square		99.17		122.45
Significance		0.00		0.00
Classification correct		76.40%		82.40%
N=250				
† p < 0.1; * p < 0.05; ** p < 0.01				

Table 5-6: Binary Logistic Regression Results for PAET

Although the correlation statistics presented in Table 5-5 shows that all four *Internal Resources* significantly correlate with *PAET*, the binary logistic regression Model 2 results in Table 5-6 illustrate that only the *Internal Technological Resources* contribute significantly to the variance in the dependent variable, *PAET,* with a negative coefficient (b = -0.63) that is significant at $p < 0.05$. This means that *Internal Technological Resources* has a negative effect on *PAET*. In Model 2, the Nagelkerke R square of 0.53 means about 53% of variance in outcome is explained by the binary logistic model of including the *Internal Resources* variables (particularly the *Internal Technological Resources* variable). This shows an improvement over the Nagelkerke R square of 0.45 of the baseline Model 1. In a similar vein, the other pseudo R square, Cox and Snell R Square increases from 0.33 in Model 1 to 0.38 in Model 2. In Model 2, the Omnibus test shows chi-square with significance of $p < 0.05$, hence allowing us to reject the null

hypothesis that coefficients are zero, supporting the hypothesis that the *Internal Resources* contributes significantly to the variance in *PAET*.

The Classification Table of Model 2 shows that 142 licensing agreements were predicted correctly by the logistic regression model to have low *PAET*, while 65 were correctly predicted to have high *PAET*. The overall percentage of correct classification at 82.4% of the licensing agreements in Model 2 is an improvement over the percentage of 76.4% in Model 1. On the other hand, the other *Internal Resources* variables: *Internal Commercial CA Resources, Internal Human Capital* and *Internal Commercial IP Resources*, were found to have no statistically significant impact on *PAET,* despite their significant individual bivariate correlations with *PAET*. Finding 1b summarises the binary logistic regression results of *PAET* on all four *Internal Resources* variables.

Finding 1b: *The Internal Commercial CA Resources, Internal Commercial IP Resources and Internal Human Capital do not significantly contribute to the variance in PAET. Only Internal Technological Resources has a significant negative contribution to the variance in PAET.*

Combining Findings 1a and 1b, the results indicate no support for H1a, H1c and H1d, but show support for Hypothesis 1b, as presented in Figure 5-1.

Result No 1:

- *Firms that have higher levels of Internal Technological Resources are likely to have a lower PAET. Conversely, firms that have lower levels of Internal Technological Resources are likely to have a higher PAET. (H1b fully supported).*
- *While the Internal Commercial CA Resources, the Internal Commercial IP Resources and Internal Human Capital positively correlate with PAET individually, they do not contribute significantly to the variance in PAET, unlike Internal Technological Resources. (H1a, H1c, H1d not supported).*

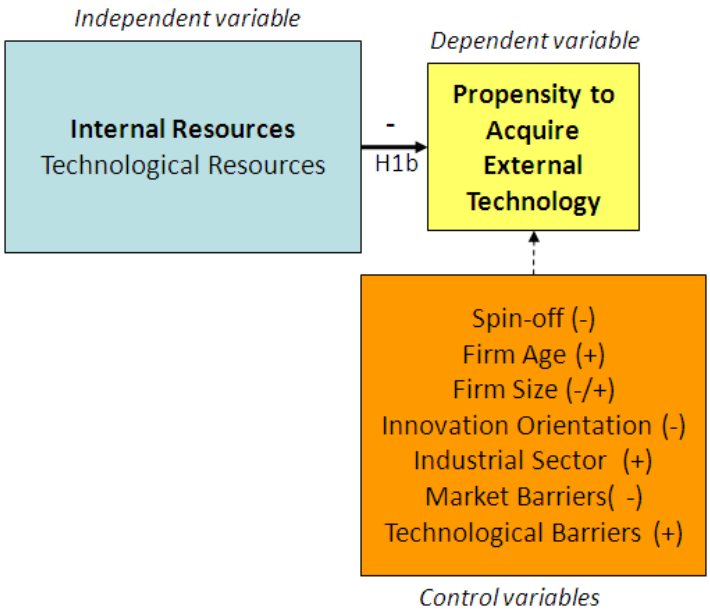

Figure 5-1: Result No 1 – Hypothesis 1 Finding

5.4.2 Results of Hypothesis 2 Testing

Of the 250 responses to the survey of this study, 153 companies took up commercial licenses. From the sub-population of 153 commercial licensees, all reported some form of product innovation. 110 of the commercial licensees also indicated that they had attained some form of process innovation, while the remaining 43 reverted that process innovation was not relevant for the technologies they had licensed. The results based on the responses of the 153 commercial licensees show support for Hypothesis 2, which posits that among firms that acquired external technologies, those that report higher levels of *Innovation Outcome* have higher levels of *Internal Resources*. In Hypothesis 2, the dependent variables are *Product Innovation outcome* and *Process Innovation Outcome,* as highlighted in Section 3.2.4. To test Hypothesis 2, the distributions of these two dependent variables were analysed. As *Product Innovation outcome* and *Process Innovation Outcome* variables were found to be normal, hierarchical regression was then performed on them predicting the moderating impact of each of the following two *Internal Resources* variables (moderating variables) on the relationships between *PAET* (independent variable) and *Product/Process Innovation Outcome* (dependent variables),

as recommended by Tharenou et al. (2007). The following two interactive variables between *Internal Resources* and *PAET* variables were created:

1) *PAET x Internal Technological Resources*, representing the interaction between PAET and reliance on basic R&D (Cassiman and Veugelers, 2006);
2) *PAET x Internal Human Capital*, pertaining to the interaction between PAET and the quality and availability of R&D staff (Hemmert, 2004).

To reduce the likelihood of multi-collinearity among the interaction terms, the *PAET* and *Internal Resources* variables were centralised by subtracting their values against their means before computing the interaction terms. The variance inflation factors (VIFs) for these variables and dimensions were less than Chatterjee and Price's (1991) suggested guideline of 10, indicating the low probability of multi-collinearity issue in the findings. A similar approach of reducing multi-collinearity among interaction terms is found in the study by Lee, Wong, Foo and Leung (2011).

Product Innovation Outcome

Table 5-7 presents the regression results on *Product Innovation Outcome* predicting the moderating impact of each of the four *Internal Resources* dimensions on the relationship between *PAET* and *Product Innovation Outcome*. Model 1 shows a baseline model illustrating the impact of the control variables. The regression results depict that the *Firm Size in* terms of fixed asset investment has a positive moderating effect ($p < 0.05$). As the *Innovation Orientation* and *Industrial Sector* were found to be closely related, the *Industrial Sector* variable was used to test for its relevance in moderating the relationship. As the regression results show that it has relatively little significance, the *Innovation Orientation* and *Industrial Sector* variables were excluded in the baseline model for parsimony of explanation (Tharenou et al., 2007).

Models 2 and 4 are main-effects models indicating how *Internal Technological Resources* and *Internal Human Capital Resources* affect *Product Innovation Outcome*.

Dependent Variable: Product Innovation Outcome (N=153)												
Variables	**Model 1**		**Model 2**		**Model 3**		**Model 4**		**Model 5**		**Model 16**	
	b	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**
(Constant)	1.91	0.98	1.40	1.03	2.53	1.14	1.47	1.02	1.49	1.02	1.70	1.08
Spin off	-0.01	0.12	0.04	0.12	0.03	0.12	0.01	0.12	0.01	0.12	0.07	0.11
Firm size log employment	-0.37**	0.14	-0.39**	0.14	-0.38**	0.14	-0.41**	0.14	-0.40**	0.14	-0.46**	0.14
Firm size log FAI	0.39*	0.18	0.48*	0.18	0.30	0.20	0.46*	0.18	0.46*	0.18	0.43*	0.19
Age squared	0.00*	0.00	0.00*	0.00	0.00**	0.00	0.00*	0.00	0.00*	0.00	0.00	0.00
Market barrier	0.07	0.11	0.07	0.11	0.05	0.11	0.04	0.11	0.04	0.11	0.01	0.10
Technology barrier	-0.11	0.11	-0.09	0.11	-0.08	0.11	-0.09	0.11	-0.10	0.11	-0.09	0.10
PAET			-0.05	0.09	0.03	0.10	-0.09	0.10	-0.07	0.11	-0.26*	0.11
Internal Tech Res			-0.15†	0.08	-0.06	0.09					0.11	0.10
Internal Human Capital							0.15*	0.07	0.13	0.10	0.07	0.10
Ext Comm Officer Res											0.47**	0.08
Ext Human Capital											0.42**	0.14
NPD Absorp Cap											-0.46*	0.17
NPD Comm Cap											0.37**	0.12
NPD Collab Prob-solv											0.13	0.21
PAET xInt Tech Res					0.21*	0.09					0.29*	0.11
PAET xInt Human									-0.03	0.10	0.08	0.11
PAET x Ext Human											0.37*	0.14
PAET x Ext Comm											0.19*	0.08
PAET x NPD Absorp Cap											-0.42*	0.17
PAET x NPD Comm Cap											0.25*	0.12
PAET x NPD Collab											0.17	0.21
R-Square Change	0.10		0.02		0.03		0.03		0.00		0.10	
Probability	0.02		0.18		0.03		0.12		0.74		0.00	

Table 5-7: Regression Results on Product Innovation Outcome (Models 1 to 5, and full Model 16)
Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

Models 3 and 5 are interactive effects models that assess the significance of interactive variables between *PAET* and these *Internal Resources* in contributing to the variance in *Product Innovation Outcome.* Model 16 is the full model that considers the effect of the control variables, independent variables, and hypothesised interactions, including those of *External Resources* and *NPD Collaboration Capability* highlighted in Section 5.3, in addition to *Internal Resources* variables, as the significance of each of the individual predictors should always be evaluated in the context of their unique contribution over and above other variables. Model 16 is important in explaining any significant variance in *Product Innovation Outcome* over and above the main-effects models and interactive effects models.

Models 2 to 5 demonstrate the effect of three predictor variables (*PAET*, *Internal Technological Resources* and *Internal Human Capital*) on 153 cases. Model 16 shows the effect of these three predictors and additional five predictors (*External Commercial Officer Resources, External Human Capital, NPD Absorptive Capacity, NPD Communication Capability* and *NPD Collaborative Problem-solving*). Having a range of 19 cases (Model 16) to 51 cases per predictor (Models 2 to 5) in these regression models satisfies Field's (2005) guidelines of minimum of 5-10 cases per predictor for reliable regression results.

The results of Model 4 reveal the effect of *Internal Human Capital* ($b = 0.15$, $p < 0.05$) on *Product Innovation Outcome*. However, it is found to be non-significant in the full model, Model 16, of Table 5-7. Of all the *Internal Resources* variables, only *Internal Technological Resources* was found in Models 3 and 16 to have a positive moderating impact on the relationship between *PAET* and *Product Innovation Outcome* ($b = 0.21$, $p < 0.05$ in Model 3; $b = 0.29$, $p < 0.05$ in Model 16). In Model 3, the R2 increased to 3% with significance of 0.03. With VIF at 1.66, which is below Chatterjee and Price's (1991) guideline of 10, the likelihood of multi-collinearity issues among the independent variables is therefore relatively low. The positive moderation by *Internal Technological Resources* is illustrated in Figure 5-2, where *Internal Technological Resources* increases the strength of relationship between *PAET* and *Product Innovation Outcome*.

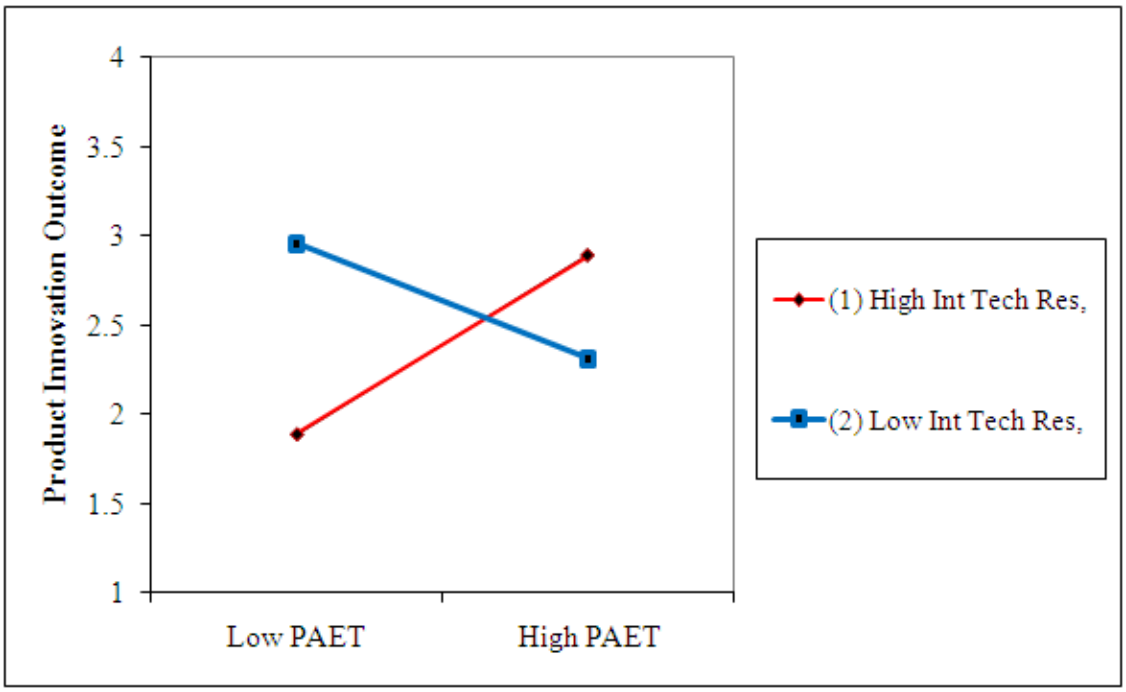

Figure 5-2: Moderation graph of *Internal Technological Resources* on *PAET-Product Innovation Outcome relation*

The above findings thus provide support for Hypothesis 2a but no support for Hypothesis 2b.

***Hypothesis 2a-2d Finding**:*

- *Among firms that have high levels of PAET, the firms that report higher levels of Product Innovation Outcome have higher levels of Internal Technological Resources (H2a fully supported).*
- *The Internal Human Capital does not have significant moderating effect on the relationship between PAET and Product Innovation Outcome (H2b not supported).*

The next Section of *Process Innovation Outcome* summarises the findings for Hypotheses 2c and 2d.

Process Innovation Outcome

The regression results on *Process Innovation Outcome* assessing the moderating impact of each of the two *Internal Resources* variables (*Internal Human Capital* and *Internal Technological Resources*) on the relationship between *PAET* and *Process Innovation Outcome* are presented in Table 5-8. Model 1 shows a baseline model illustrating the impact of the control variables on the dependent variable, *Process Innovation Outcom*e. The regression results of Model 1 indicate that *Firm Age* has a positive effect ($p < 0.01$) on *Process Innovation Outcome*. As in the case *of Product Innovation Outcome*, the *Industrial Sector* variable, as a proxy for both *Innovation Orientation* and *Industrial Sector* variables, was used to test for its relevance in the relationship between *PAET* and *Process Innovation Outcome*. As the proxy variable was found to be non-significant in hierarchical regression, the *Innovation Orientation* and *Industrial Sector* variables were excluded from the baseline model for parsimony of explanation (Tharenou et al., 2007). Models 2 and 4 are main-effect models that indicate how *Internal Technological Resources* and *Internal Human Capital* variables affect *Process Innovation Outcome.* Models 3 and 5 are interactive effects models that investigate how the interaction between each of the two *Internal Resources* variables and the independent variable, *PAET,* could contribute to the variance of the dependent variable, *Process Innovation Outcome*. Model 20 is the full model comprising all control variables, independent variables, and hypothesised interactions, including those of *External Resources* and *NPD Collaboration Capability*, in addition to *Internal Resources* variables to investigate their relative significance in explaining the variance of *Process Innovation Outcome* over and above the main-effects models and the interactive effects models. Models 2 to 5 demonstrate the effect of three predictor variables (*PAET*, *Internal Technological Resources* and *Internal Human Capital*) on 110 cases. Model 20 shows the effect of these three predictors and additional seven predictors (*External Commercial Officer Resources, External Human Capital, External Technological Resources, External Commercial IP Resources, NPD Absorptive Capacity, NPD Communication Capability* and *NPD Collaborative Problem-solving*).

Dependent Variable: Process Innovation Outcome (N=110)												
Variables	**Model 1**		**Model 2**		**Model 3**		**Model 4**		**Model 5**		**Model 20**	
	b	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**
(Constant)	3.06	1.61	2.39	1.52	2.11	1.57	2.40	1.63	2.46	1.64	-0.06	1.86
Spin off	-0.10	0.17	0.05	0.16	0.06	0.16	-0.02	0.16	-0.03	0.17	0.09	0.16
Firm size log employment	0.20	0.18	0.06	0.17	0.06	0.17	0.08	0.18	0.09	0.18	-0.11	0.21
Firm size log FAI	-0.04	0.29	0.12	0.27	0.16	0.28	0.13	0.30	0.12	0.30	0.55	0.34
Age squared	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Market Barrier	-0.02	0.16	0.04	0.15	0.07	0.15	0.01	0.16	0.01	0.16	0.14	0.17
Technology Barrier	0.06	0.15	0.08	0.14	0.06	0.14	0.06	0.15	0.04	0.15	0.01	0.16
PAET			0.21	0.13	0.14	0.16	0.30*	0.13	0.33*	0.14	-0.13	0.17
Internal Tech Res			-0.37**	0.12	-0.43**	0.15					-0.15	0.25
Internal Human Capital							0.14	0.10	0.09	0.13	-0.02	0.15
Ext Comm Officer Res											0.10	0.13
Ext Human Capital											0.05	0.25
Ext Tech Res											0.55**	0.15
Ext Comm IP Resource											0.29†	0.16
NPD Absorp Cap											0.02	0.24
NPD Comm Cap											-0.23	0.23
NPD Collab Prob-solv											0.25	0.34
PAET x Int Tech Res					-0.10	0.15					0.03	0.27
PAET x Int Human Capital									-0.07	0.12	0.02	0.16
PAET x Ext Human Capital											0.23	0.25
PAET x Ext Comm Res											-0.42**	0.12
PAET x Ext Tech Res											0.37*	0.15
PAET x Ext Comm IP Res											0.37*	0.16
PAET x NPD Absorp Cap											-0.10	0.24
PAET x NPD Comm Cap											-0.32	0.22
PAET x NPD Collab Prob-solv											0.32	0.34
R-Square Change	0.05		0.14		0.00		0.08		0.00		0.15	
Probability	0.45		0.00		0.48		0.01		0.58		0.01	

Table 5-8: Regression Results on Process Innovation Outcome (Models 1 to 5, and full Model 20)

Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

With a range of 11 cases (Model 20) to 36 cases per predictor (Models 2 to 5), these regression models satisfy Field's (2005) recommendations of minimum of 5-10 cases per predictor for reliable regression results. The full model, Model 20 of Table 5-8, shows that none of these *Internal Resources* variables had any significant positive moderating effect on the relationship between *PAET* and *Process Innovation Outcome*. These findings do not support Hypotheses 2c to 2d, which posited the *Internal Technological Resources* and *Internal Human Capital* to have significant positive moderating impact on the relation between *PAET* and *Process Innovation Outcome*. We will defer detailed discussion of these results until Section 5.5.2.

***Hypothesis 2c-2d Finding**:*

- *In the case of Process Innovation Outcome, none of the Internal Resources variables has a significant positive moderating impact on the relationship between PAET and Process Innovation Outcome (H2c-H2d not supported).*

Combining the findings for Hypotheses 2a to 2d, Result No 2 for Hypothesis 2 is as follows, as presented in Figure 5-3.

***Result No 2**:*

- *Among firms that have high levels of PAET, the firms that report higher levels of Product Innovation Outcome have higher levels of Internal Technological Resources (H2a fully supported).*
- *The Internal Human Capital has non-significant moderating effect on the relationship between PAET and Product Innovation Outcome (H2b not supported).*
- *None of the Internal Resources variables has a significant positive moderating impact on the relationship between PAET and Process Innovation Outcome (H2c and H2d not supported).*

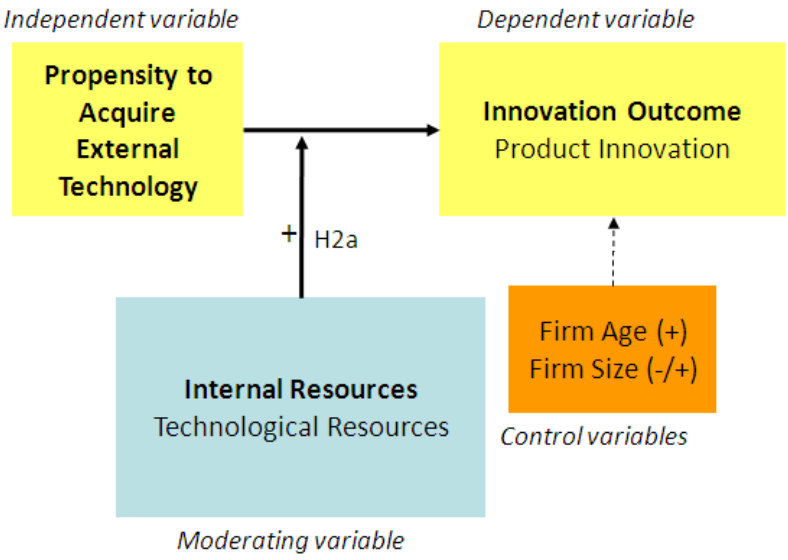

Figure 5-3: Result No 2 - Hypothesis 2 Finding

5.4.3 Results of Hypothesis 3 Testing

Of the 250 responses to the survey of this study, 153 took up commercial licenses and reported some form of product innovation based on the technologies that they had licensed from the PRIs. Of this sub-population of 153 commercial licenses, 131 had either commercialised or had plans to commercialise their product innovation that embodied the licensed technologies, while 91 worked on the commercial adoption of process innovation incorporating the licensed technologies. Hypothesis 3 states that among firms that have high levels of *Innovation Outcome* with external technologies, those that report better commercial adoption *Performance* have higher levels of *Internal Resources*. As the logarithm value of *Performance* shows a normal distribution, moderated hierarchical regression was performed to validate the hypothesis. The hierarchical regression was run on the dependent variable *Performance* using the two independent variables of *Innovation Outcome: Product Innovation Outcome* and *Process Innovation Outcome,* as well as the two *Internal Resources* moderating variables in a similar way as that for Hypothesis 2, as detailed in Section 5.4.2. The following four interactive variables between *Internal Resources* and *Innovation Outcome* variables were constructed:

1) *Product Innovation Outcome* x *Internal Commercial CA Resources*
2) *Product Innovation Outcome* x *Internal Commercial IP Resources*
3) *Process Innovation Outcome* x *Internal Commercial CA Resources*
4) *Process Innovation Outcome* x *Internal Commercial IP Resources*

To reduce the likelihood of multi-collinearity among the dimensions of *Internal Resources* and *Innovation Outcome* variables, the dimensions were centralised by subtracting their values against their means before computing the interaction terms. The VIFs for these variables and dimensions were less than Chatterjee and Price's (1991) suggested cut-off value of 10, indicating the low probability of multi-collinearity issue on the findings.

Product Innovation Outcome

Based on 131 responses that had reported active commercial adoption of the technologies they had licensed from PRIs, we ran moderated hierarchical regression on the *Performance* data they had submitted. Table 5-9 presents the regression results of *Performance* predicting the moderating impact of each of the two *Internal Resources* variables on the relationship between *Product Innovation Outcome* and *Performance*. Model 1 shows a baseline model examining the impact of the control variables. The regression results depict that being a *Spin-off* has a positive and significant effect ($p < 0.05$) on the relationship, while the *Firm Size* in terms of fixed asset investment has the opposite effect ($p < 0.05$). Models 2 and 4 are main-effects models that demonstrate how the two *Internal Resources* variables *(Internal Commercial CA Resources* and *Internal Commercial IP Resources)* and *Product Innovation Outcome* variables affect *Performance*. Models 3 and 5 illustrate the effects of the interactive variables between the two *Internal Resources* and *Product Innovation Outcome* on *Performance*. Model 12 of Table 5-9 is the full model which includes all the control variables, independent variables (*Product Innovation Outcome*), hypothesised moderating variables (*Internal Resources* and *NPD Collaboration Capability*) and their interaction terms.

Dependent Variable: Performance (Product Innovation) (N=131)												
Variables	**Model 1**		**Model 2**		**Model 3**		**Model 4**		**Model 5**		**Model 12**	
	b	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**
(Constant)	5.15	1.08	5.19	0.95	5.44	0.97	5.64	1.00	5.63	1.01	5.20	1.10
Spin off	0.29*	0.12	0.28*	0.11	0.30**	0.11	0.31**	0.11	0.32**	0.11	0.34*	0.12
Firm Size log employment	0.06	0.14	0.29*	0.13	0.34*	0.14	0.27*	0.14	0.27†	0.14	0.36*	0.15
Firm Size log FAI	-0.52**	0.19	-0.61**	0.16	-0.66**	0.17	-0.66**	0.17	-0.66**	0.18	-0.63**	0.19
Age squared	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Market Barrier	-0.10	0.12	-0.08	0.10	-0.05	0.10	-0.10	0.10	-0.10	0.10	-0.04	0.11
Technology Barrier	-0.01	0.11	0.05	0.10	0.03	0.10	0.05	0.10	0.04	0.10	-0.02	0.10
Infocomm Industry	0.22	0.22	0.42*	0.20	0.43*	0.20	0.41*	0.20	0.40†	0.21	0.52*	0.20
Other Industries (Engineering, Manufacturing, Chemicals, Electronics)	0.15	0.21	0.31*	0.19	0.29	0.19	0.27	0.20	0.27	0.20	0.31	0.21
Prod Innov Outcome			0.49**	0.08	0.52**	0.09	0.49**	0.09	0.49**	0.09	0.51**	0.09
Internal Commercial CA Res			-0.23*	0.10	-0.23*	0.10					-0.25*	0.12
Internal Commercial IP Res							-0.08	0.07	-0.08	0.08	0.03	0.08
NPD Absorp Cap											-0.05	0.10
NPD Comm Cap											0.39*	0.14
NPD Collab Prob-solv											-0.35†	0.16
Prod Innov Outcome x Int Comm CA Res					-0.10	0.08					0.04	0.12
Prod Innov Outcome x Int Comm IP Res									-0.01	0.08	0.11	0.09
Prod Innov Outcome x NPD Absorp Cap											0.28†	0.15
Prod Innov Outcome x NPD Comm Cap											-0.18	0.21
Prod Innov Outcome x NPD Collab Prob-solv											-0.25	0.26
R-Square Change	0.25		0.17		0.01		0.16		0.00		0.03	
Probability	0.00		0.00		0.22		0.00		0.86		0.21	

Table 5-9: Regression Results on Performance (Product Innovation) (Models 1 to 5, and full Model 12)
Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

Models 2 to 5 demonstrate the effect of three predictor variables (*Product Innovation Outcome*, *Internal Commercial CA Resources*, and *Internal Commercial IP Resources*) on 131 cases. Model 12 shows the effect of these three predictors and additional three predictors (*NPD Absorptive Capacity, NPD Communication Capability* and *NPD Collaborative Problem-solving*). These regression models utilise 21 cases per predictor (Model 12) to 43 cases per predictor (Models 2 to 5), thereby satisfying Field's (2005) guidelines of minimum of 5-10 cases per predictor for reliable regression results.

Models 2 to 5 generally show the positive effect of *Spin-offs*, *Firm Size* in terms of staff strength and the *Infocomm Industry*, but indicate that the *Internal Resources* have non-significant effect on the interaction between *Product Innovation Outcome* and *Performance*. On the other hand, Model 12 illustrates that the *Internal Commercial CA Resources* and *Commercial IP Resources* do not have significant moderating effect on the relationship between *Product Innovation Outcome* and *Performance*.

As the *Spin-off* dimension is significant, it is likely that their report of unusually high growth in commercial adoption *Performance* from a low initial sales volume might have skewed the results of Model 12. To control for the *Spin-off* effect, 25 spin-off cases were removed before performing moderated hierarchical regression on the remaining 106 cases of existing firms. The regression results after controlling for *Spin-off* are presented in Model 13 of Table 5-10. The results show that the *Internal Commercial CA Resources* does not have a significant moderating impact on the *Product Innovation Outcome-Performance* relation. However, Model 13 reveals the significance of *Internal Commercial IP Resources* as a moderating variable over and above the other predictors ($b = 0.19$, $p < 0.1$). In Table G-1 of Appendix G, Model 3, which shows the interaction effects of *Internal Commercial CA Resources* and *Internal Commercial IP Resources* with *Product Innovation Outcome* on *Performance*, presents similar results for *Internal Commercial IP Resources* ($b = 0.22$, $p < 0.05$). In this model, the R2 increased to 5% with significance of $p < 0.05$. With VIF at 1.96, which is below the cut-off value of 10 as recommended by Chatterjee and Price (1991), the likelihood of multi-collinearity issues among the independent variables is therefore relatively low. The positive moderation by

Internal Commercial IP Resources is illustrated in Figure 5-4, where *Internal Commercial IP Resources* increases the strength of relationship between *Product Innovation Outcome* and *Performance.* These findings show significant support for H3b, as consistent with the theory of PFI (Teece, 1986). As for the *Internal Commercial CA Resources* variable, it was indicated to be relatively non-significant compared to *Internal Commercial IP Resources,* as shown in Table 5-10, thereby providing no support for H3a. More details for the regression results after controlling for *Spin-off* effect may be found in Table G-1 of Appendix G.

***Hypothesis 3a-3b Finding**:*

- *Among firms that have high levels of Product Innovation Outcome with external technologies, those that report better commercial adoption Performance have higher levels of Internal Commercial IP Resources (H3b fully supported).*
- *The Internal Commercial CA Resources variable does not have a significant moderating effect on the relationship between Product Innovation Outcome and Performance (3a not supported).*

Dependent Variable = Performance (Product Innovation) N=106		
Variables	**Model 13**	
	b	**SE**
(Constant)	4.69	1.29
Spin-off	Not Applicable	
Firm Size log employment	0.58**	0.18
Firm Size log FAI	-0.68**	0.22
Age squared	0.00	0.00
Market Barrier	0.04	0.11
Technology Barrier	0.06	0.11
Infocomm Industry	1.05**	0.27
Other Industries (Engineering, Manufacturing, Chemicals, Electronics)	0.38	0.25
Prod Innov Outcome	0.62**	0.11
Internal Commercial CA Res	-0.41**	0.12
Internal Commercial IP Res	0.02	0.10
NPD Absorp Cap	-0.06	0.11
NPD Comm Cap	0.60**	0.16
NPD Collab Prob-solv	-0.53**	0.17
Prod Innov Outcome x Int Comm CA Res	0.01	0.12
Prod Innov Outcome x Int Comm IP Res	0.19†	0.11
Prod Innov Outcome x NPD Absorp Cap	0.29†	0.16

Dependent Variable = Performance (Product Innovation) N=106		
Variables	**Model 13**	
	b	**SE**
Prod Innov Outcome x NPD Comm Cap	-0.27	0.28
Prod Innov Outcome x NPD Collab Prob-solv	-0.22	0.32
R-Square Change	0.02	
Probability	0.19	

Table 5-10: Regression Results on Performance (Product Innovation) (full Model 13 after controlling for *Spin-off* effect)
Notes: b values are unstandardised regression coefficients. SE values are standard errors. † p < 0.10; * p < 0.05; ** p < 0.01

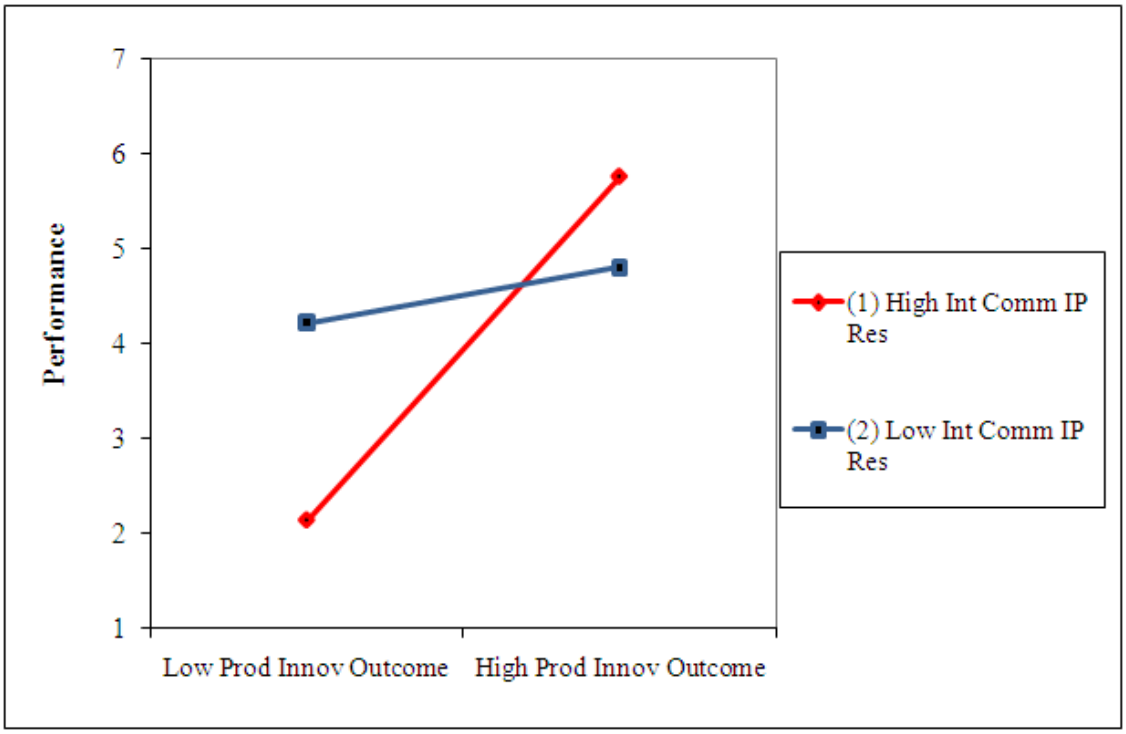

Figure 5-4: Moderation graph of *Internal Commercial IP Resources* on *Product Innovation Outcome-Performance* relation

Process Innovation Outcome

As highlighted earlier, 91 of the 250 survey responses indicated achievement of some form of process innovation. Based on these 91 responses, we ran moderated hierarchical regression of their reported *Performance* data on the independent variable, *Process Innovation Outcome* and hypothesised interaction with the *Internal Resources* variables. The regression results are presented in Table 5-11.

Dependent Variable: Performance (Process Innovation) (N=91)												
Variables	**Model 1**		**Model 2**		**Model 3**		**Model 4**		**Model 5**		**Model 12**	
	B	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**
(Constant)	4.36	1.31	4.36	1.34	4.67	1.30	3.86	1.39	3.61	1.39	3.72	1.58
Spin off	0.34*	0.15	0.35*	0.16	0.35*	0.15	0.38*	0.15	0.33*	0.16	0.27†	0.16
Firm size log employment	0.13	0.16	0.13	0.16	0.08	0.16	0.07	0.17	0.07	0.17	-0.09	0.19
Firm size log FAI	-0.40†	0.23	-0.40†	0.24	-0.43	0.23	-0.31	0.25	-0.26	0.25	-0.22	0.28
Firm Age squared	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Market Barrier	-0.05	0.14	-0.05	0.15	-0.07	0.14	-0.08	0.15	-0.09	0.15	-0.27	0.18
Technology Barrier	-0.05	0.13	-0.05	0.14	-0.04	0.13	-0.03	0.14	-0.01	0.14	0.09	0.15
Biomedical Industry	-0.26	0.28	-0.26	0.29	-0.27	0.28	-0.24	0.28	-0.33	0.29	-0.40	0.30
Other Industries (Engineering, Manufacturing, Chemicals, Electronics)	0.09	0.23	0.09	0.24	0.15	0.23	0.13	0.24	0.04	0.24	0.07	0.25
Proc Innov Outcome			0.00	0.09	-0.01	0.09	-0.01	0.09	-0.03	0.09	-0.03	0.09
Internal Commercial CA Res			0.01	0.15	0.15	0.15					0.17	0.18
Internal Commercial IP resource							0.12	0.11	0.06	0.11	0.02	0.13
NPD Absorp Cap											0.02	0.12
NPD Comm Cap											0.02	0.21
NPD Collab Prob-solv											-0.07	0.24
Proc Innov Outcome x Int Comm CA Res					-0.24*	0.10					-0.35*	0.12
Proc Innov Outcome x Int Comm IP Res									0.14	0.09	0.34**	0.11
Proc Innov Outcome x NPD Absorp Cap											0.09	0.13
Proc Innov Outcome x NPD Comm Cap											-0.38†	0.20
Proc Innov Outcome x NPD Collab Prob-solv											0.11	0.19
R-Square Change	0.15		0.00		0.07		0.01		0.02		0.18	
Probability	0.09		1.00		0.01		0.54		0.13		0.00	

Table 5-11: Regression Results on Performance (Process Innovation) (Models 1 to 5, and full Model 12)
Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

Model 1 in Table 5-11 shows a baseline model illustrating the impact of the control variables. The regression results indicate that being spin-offs have a positive effect ($p < 0.05$). Models 2 to 5 indicate how the two *Internal Resources* variables (*Internal Commercial CA Resources* and *Internal Commercial IP Resources*) and their interaction with *Process Innovation Outcome* affect the dependent variable, *Performance*. Model 12 in Table 5-11 is the full regression model showing the main and interaction effects on *Performance* comprising all control variables, *Process Innovation Outcome*, *Internal Resources* and *NPD Collaboration Capability* variables.

Models 2 to 5 demonstrate the effect of three predictor variables (*Process Innovation Outcome*, *Internal Commercial CA Resources* and *Internal Commercial IP Resources*) on 91 cases. Model 12 shows the effect of these three predictors and additional three predictors (*NPD Absorptive Capacity, NPD Communication Capability* and *NPD Collaborative Problem-solving*). These regression models utilise 15 cases per predictor (Model 12) to 30 cases per predictor (Models 2 to 5), thereby satisfying Field's (2005) guidelines of minimum of 5-10 cases per predictor for reliable regression results.

Model 12 shows that the *Internal Commercial IP Resource*s has a positive moderating effect on the interaction between *Process Innovation Outcome* and *Performance* ($b = 0.34$, $p < 0.01$). In Model 12, the R2 change increased to 18% with significance of $p < 0.01$. With VIF at 2.08, which is below Chatterjee and Price's (1991) recommended cut-off value of 10, the likelihood of multi-collinearity issues among the independent variables is therefore relatively low. The positive moderation by *Internal Commercial IP Resources* is illustrated in Figure 5-5, where *Internal Commercial IP Resources* increases the strength of relationship between *Process Innovation Outcome* and *Performance*.

However, Model 12 also shows that *Internal Commercial CA Resources* has a negative moderating impact ($b = -0.35$, $b < 0.05$). Given that the significant effect of *Spin-off* control variable, it is likely that that their exceptionally high report of growth in commercial adoption *Performance* might have skewed the results of Model 12. We removed the 14 spin-off cases out of the 91 responses to examine the full-model

regression results of the remaining 73 cases, as presented in Model 13 of Table 5-12. The Model 13 results show that the *Internal Commercial CA Resources* variable does not show a significant negative moderating effect on the *Process Innovation Outcome-Performance* relation, thereby showing no support for H3c. More details of the regression results after controlling for spin-off effect are listed in Table G-2 of Appendix G.

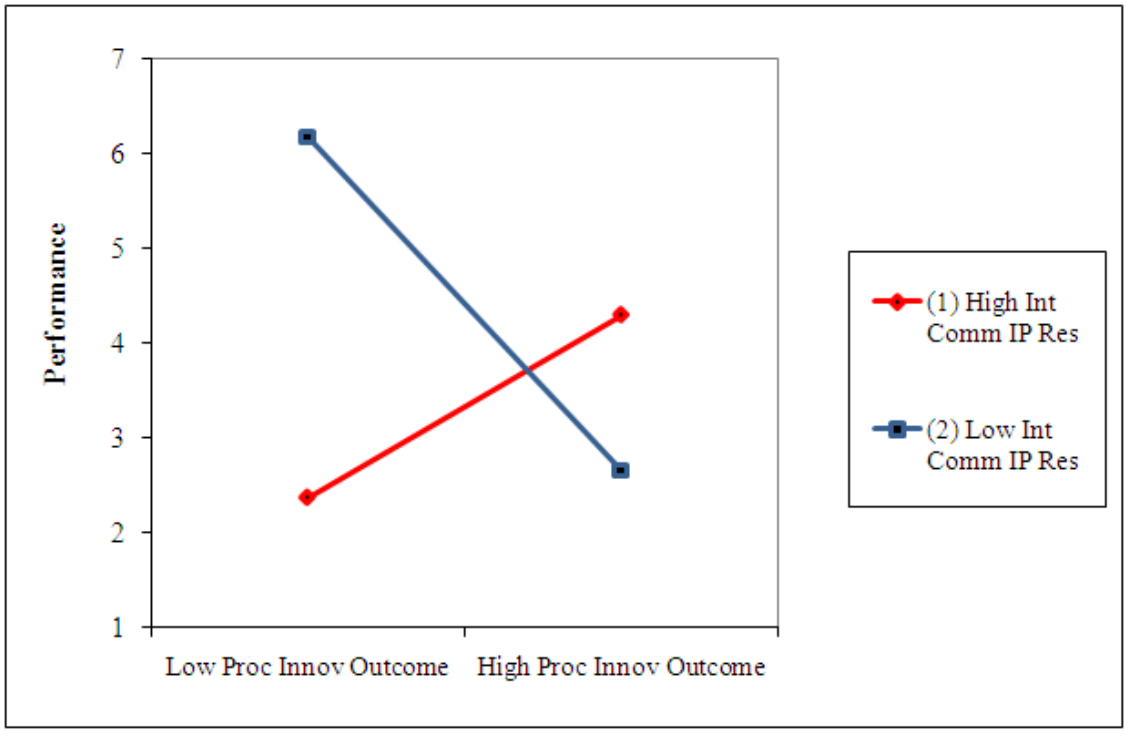

Figure 5-5: Moderation graph of *Internal Commercial IP Resources* on *Process Innovation Outcome-Performance* relation

Dependent Variable = Performance (Process Innovation) N=73		
Variables	**Model 13**	
	b	**SE**
(Constant)	5.17	2.18
Firm Size log employment	0.26	0.28
Firm Size log FAI	-0.57	0.40
Age squared	0.00	0.00
Market Barrier	-0.01	0.23
Technology Barrier	-0.05	0.19
Biomedical Industry	-0.62	0.46
Other Industries (Engineering, Manufacturing, Chemicals, Electronics)	-0.04	0.32
Proc Innov Outcome	0.17	0.16
Internal Commercial CA Res	0.02	0.25

Internal Commercial IP Res	-0.01	0.19
NPD Absorp Cap	0.01	0.15
NPD Comm Cap	0.24	0.30
NPD Collab Prob-solv	-0.48	0.34
Proc Innov Outcome x Int Comm CA Res	-0.19	0.19
Proc Innov Outcome x Int Comm IP Res	0.27†	0.14†
Proc Innov Outcome x NPD Absorp Cap	0.02	0.20
Proc Innov Outcome x NPD Comm Cap	-0.21	0.32
Proc Innov Outcome x NPD Collab Prob-solv	-0.09	0.26
R-Square Change	0.02	
Probability	0.61	

Notes: b values are unstandardised regression coefficients. SE values are standard errors. † p < 0.10; * p < 0.05; ** p < 0.01

Table 5-12: Regression Results on Performance (Process Innovation) (full Model 13 after controlling for *Spin-off* effect)

The regression findings of Model 12 (Table 5-11) and Model 13 (Table 5-12) on *Process Innovation Outcome* provide support for Hypothesis 3d, which states that among firms that have high levels of *Process Innovation Outcome* with external technologies, those that report better commercial adoption *Performance* have higher levels of *Internal Commercial IP Resources*.

***Hypotheses 3c-3d Finding**:*

- *Among firms that have high levels of Process Innovation Outcome with external technologies, those that report better commercial adoption Performance have higher levels of Internal Commercial IP Resources (H3d fully supported).*
- *The Internal Commercial CA Resources has non-significant moderating effect on the relationship between Process Innovation Outcome and Performance (H3c not supported)*

Combining the findings for Hypotheses 3a to 3d, Result No 3 for Hypothesis 3 is as follows, as presented in Figure 5-6. These results will be discussed in Section 5.5.3.

Result No 3:

- *Among firms that have high levels of Product/Process Innovation Outcome with external technologies, those that report better commercial adoption Performance have higher levels of Internal Commercial IP Resources. (H3b, H3d fully supported)*
- *The Internal Commercial CA Resources have non-significant moderating effect on the relationships between Product/Process Innovation Outcome and Performance (H3a and H3c not supported)*

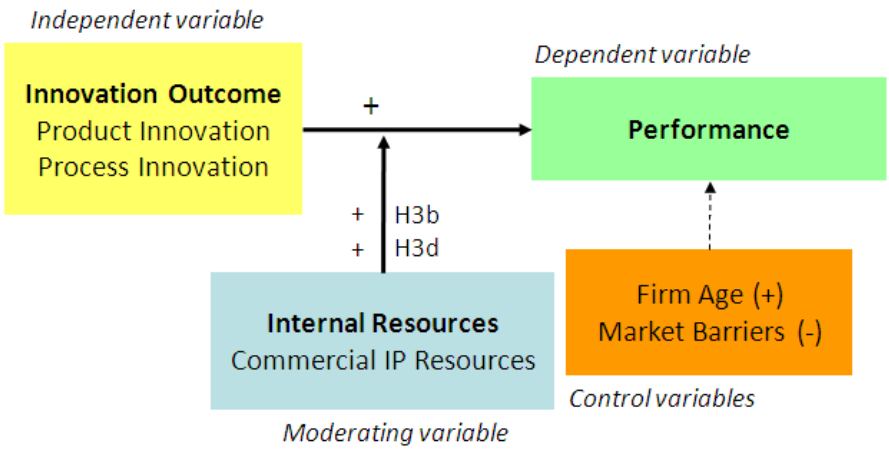

Figure 5-6: Result No 3 – Hypothesis 3 Finding

5.4.4 Results of Hypothesis 4 Testing

Hypothesis 4 predicts that among firms that have high levels of *PAET*, those that report higher levels of *Innovation Outcome* are those that have greater access to *External Resources*. In testing this hypothesis, the two dependent variables of *Innovation Outcome: Product Innovation Outcome* and *Process Innovation Outcome,* were examined using moderated hierarchical regression in a similar way as that for Hypothesis 2 detailed in Section 5.4.2. These dependent variables were each regressed onto the independent variable, *PAET*, and the four moderator variables of *External Resources* discussed in Section 5.3: *External Commercial Officer Resources, External Human Capital, External Technological Resources* and *External Commercial IP Resources*. The *External Resources* variables were centralised by subtracting their values against their means

before computing the following four interaction terms, so as to reduce the likelihood of multi-collinearity among them:

1) *PAET x External Commercial Officer Resources*, relating to the interaction between PAET and TTO commercialisation officers (O'Shea et al., 2005; Zahra et al., 2007);
2) *PAET x External Human Capital*, representing the interaction between PAET and the quality and availability of the researchers from PRIs (O'Shea et al., 2005; Powers and McDougall, 2005);
3) *PAET x External Technological Resources,* corresponding to the interaction between PAET and the readiness level of external technology (Markman et al., 2009);
4) *PAET x External Commercial IP Resources*, pertaining to the interaction between PAET and the effectiveness of IP protection (Cassiman and Veugelers, 2006).

The VIFs for these variables and dimensions were less than Chatterjee and Price's (1991) suggested cut-off value of 10, indicating the low probability of multi-collinearity issue on the findings.

Product Innovation Outcome

As highlighted in Sections 5.4.2 and 5.4.3, 153 out of 250 responses reported some form of product innovation using external technologies licensed from PRIs. Based on the 153 responses, the preliminary results of regressing *Product Innovation Outcome* on the four *External Resources* variables showed that the two *External Resources* variables: *External Technological Resources* and *External Commercial IP Resources* were not statistically significant. Hence, the moderated hierarchical regression was run using the remaining two *External Resources* variables: *External Commercial Resources* and *External Human Capital.* Model 1 of Table 5-7 shows the baseline model summarising the effect of the control variables on *Product Innovation Outcome*. In Table 5-13, Models 6 and 8 are main-effects models assessing the direct effect of *External Commercial Officer Resources* and *External Human Capital* on *Product Innovation Outcome*.

Dependent Variable: Product Innovation Outcome (N=153)										
Variables	**Model 6**		**Model 7**		**Model 8**		**Model 9**		**Model 16**	
	b	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**
(Constant)	1.34	0.91	1.39	0.91	1.13	1.02	1.27	1.08	1.70	1.08
Spin off	0.02	0.11	0.01	0.11	0.00	0.12	0.00	0.12	0.07	0.11
Firm size log employment	-0.42**	0.12	-0.43**	0.12	-0.42**	0.14	-0.41**	0.14	-0.46**	0.14
Firm size log FAI	0.49**	0.16	0.48**	0.16	0.52**	0.18	0.50*	0.19	0.43*	0.19
Age squared	0.00	0.00	0.00*	0.00	0.00*	0.00	0.00*	0.00	0.00	0.00
Market Barrier	0.00	0.10	-0.02	0.10	0.05	0.11	0.05	0.11	0.01	0.10
Technology Barrier	-0.12	0.10	-0.11	0.10	-0.08	0.11	-0.08	0.11	-0.09	0.10
PAET	-0.19*	0.09	-0.21*	0.09	-0.04	0.09	-0.03	0.10	-0.26*	0.11
Internal Tech Res									0.11	0.10
Internal Human Capital									0.07	0.10
Ext Comm Officer Res	0.40**	0.07	0.43**	0.07					0.47**	0.08
Ext Human Capital					0.24**	0.08	0.21*	0.10	0.42**	0.14
NPD Absorp Cap									-0.46*	0.17
NPD Comm Cap									0.37**	0.12
NPD Collab Prob-solv									0.13	0.21
PAET x Int Tech Res									0.29**	0.11
PAET x Int Human Capital									0.08	0.11
PAET x Ext Human Capital							-0.04	0.10	0.37*	0.14
PAET x Ext Comm Officer Res			0.09	0.07					0.19*	0.08
PAET x NPD Absorp Cap									-0.42*	0.17
PAET x NPD Comm Cap									0.25*	0.12
PAET x NPD Collab Prob-solv									0.17	0.21
R-Square Change	0.18		0.01		0.05		0.00		0.10	
Probability	0.00		0.18		0.02		0.69		0.00	

Table 5-13: Regression Results on Product Innovation Outcome (Models 6 to 9, and full Model 16)
Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

Models 7 and 9 of Table 5-13 are interactive effects model presenting the results of regressing *Product Innovation Outcome* on the interaction terms between these two *External Resources* variables and *PAET*. The full model, Model 16, of Table 5-13 considers the main and interactive effects of all variables (including *Internal Resources, NPD Collaboration Capability* variables and their interactive effects with *PAET*).

Models 6 to 9 show the effect of three predictor variables (*PAET*, *External Commercial Officer Resources* and *External Human Capital*) on 153 cases. Model 16 shows the effect of these three predictors and additional five predictors (*Internal Technological Resources*, *Internal Human Capital, NPD Absorptive Capacity, NPD Communication Capability* and *NPD Collaborative Problem-solving*). Having a range of 19 cases (Model 16) to 51 cases per predictor (Models 6 to 9), these regression models satisfy Field's (2005) suggestion of minimum of 5-10 cases per predictor for reliable regression results. In Table 5-13, Models 7 and 9 present the significance of *External Commercial Officer Resources* ($b = 0.43$, $p < 0.01$) and *External Human Capital* ($b = 0.21$, $p < 0.05$) respectively on *Product Innovation Outcome.*

The full model, Model 16, of Table 5-13, shows a R2 change of 10% with a significance of $p = 0.00$. In particular, Model 16 results illustrate the significant contribution by *External Commercial Officer Resources* in positively moderating the interaction between *PAET* and *Product Innovation Outcome* ($b = 0.19$, $p < 0.05$). Model 16 also shows that the *External Human Capital* has significantly positive moderating effect on the PAET-Product Innovation Outcome relationship ($b = 0.37$, $p < 0.05$). With relatively low value of VIF at 1.57 (*External Commercial Officer Resources*) and 4.51 (*External Human Capital*) that are below 10 (Chatterjee and Price, 1991), there is little likelihood of the findings being affected by the multi-collinearity. Figures 5-7 and 5-8 show how *External Commercial Officer Resources* and *External Human Capital* positively moderate the relationship between *PAET* and *Product Innovation Outcome*.

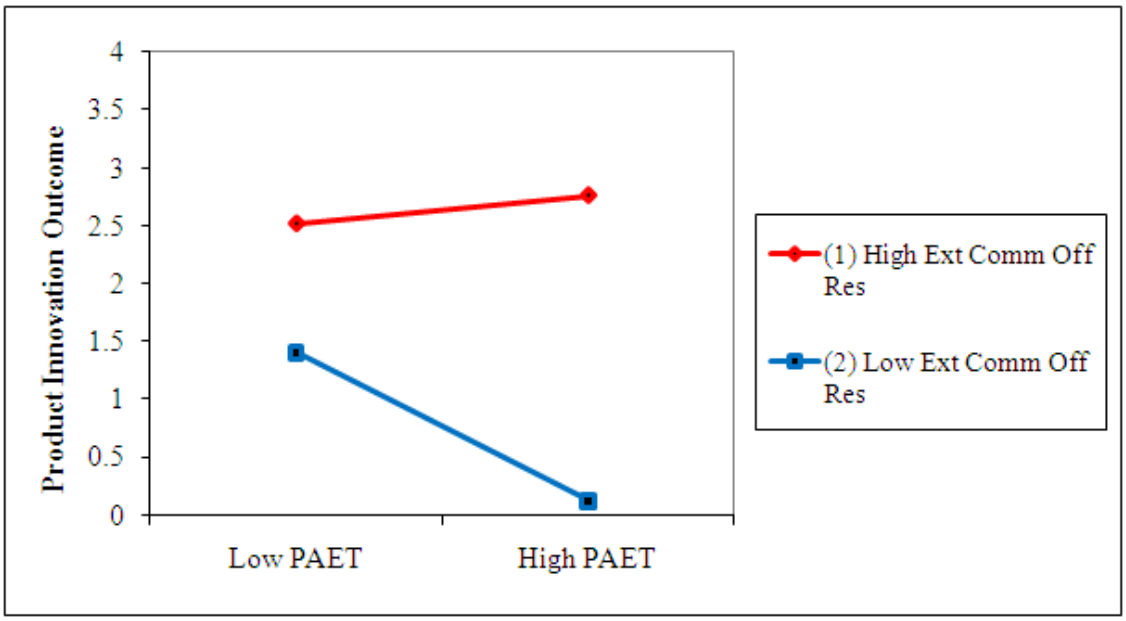

Figure 5-7: Moderation graph of *External Commercial Officer Resources* on *PAET-Product Innovation Outcome* relation

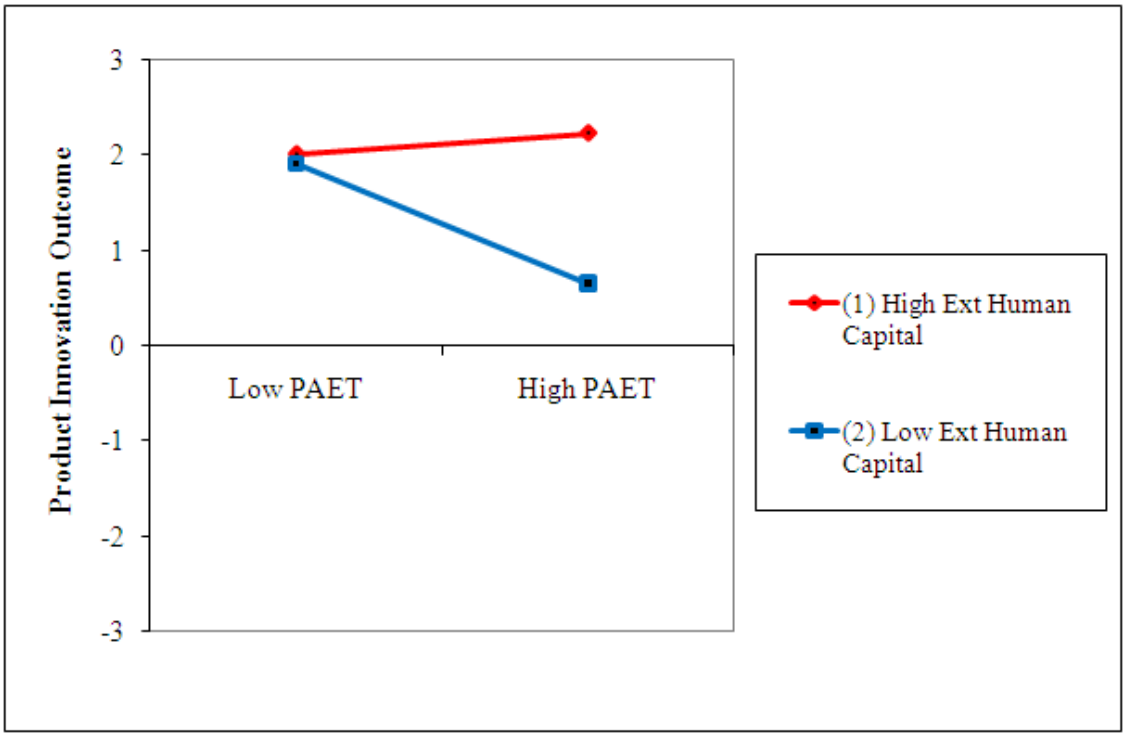

Figure 5-8: Moderation graph of *External Human Capital* on *PAET-Product Innovation Outcome* relation

These above findings thus provide support for Hypotheses 4a and 4b, which state that among firms that have high levels of *PAET*, those that report higher levels of *Product*

Innovation Outcome have greater access to *External Commercial Officer Resources* and *External Human Capital*. The findings, however, found the other *External Resources* variables non-significant, hence providing no support for Hypotheses 4c and 4d.

Hypothesis 4a-4d Finding:

- *Among firms that have high levels of PAET, those that report higher levels of Product Innovation Outcome have greater access to External Commercial Officer Resources (H4a fully supported).*
- *Among firms that have high levels of PAET, those that report higher levels of Product Innovation Outcome have greater access to External Human Capital Resources (H4b fully supported).*
- *The External Technological Resources and External Commercial IP Resources do not have significant moderating effect on the relationship between PAET and Product Innovation Outcome (H4c, H4d not supported).*

Process Innovation Outcome

Based on 110 out of 250 responses that reported some form of process innovation associated with the technologies licensed from PRIs, we performed moderated hierarchical regression on *Process Innovation Outcome* to predict the moderating impact of each of the four *External Resources* variables on the relationship between *PAET* and *Process Innovation Outcome*. The baseline model comprising the control variables was presented in Table 5-8 and discussed in Section 5.4.2. In Table 5-14, Models 6, 8, 10 and 12 are main-effects models demonstrating the effects of each of the *External Resources* variables and *PAET* on *Process Innovation Outcome*. Models 7, 9, 11 and 13 of Table 5-14 are interactive effects models examining the impact of interaction terms between *External Resources* and *PAET* on the dependent variable (*Process Innovation Outcome*). Model 20 of Table 5-14 is the full model demonstrating the main and interaction effects of all relevant variables (including *Internal Resources, External Resources* and *NPD Collaboration Capability* variables) on *Process Innovation Outcome*.

Dependent Variable: Process Innovation Outcome (N=110)																		
Variables	**Model 6**		**Model 7**		**Model 8**		**Model 9**		**Model 10**		**Model 11**		**Model 12**		**Model 13**		**Model 20**	
	b	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**
(Constant)	2.01	1.61	2.72	1.55	2.47	1.60	2.44	1.61	2.09	1.47	1.48	1.52	2.86	1.57	2.87	1.57	-0.06	1.86
Spin off	-0.01	0.16	0.05	0.16	-0.03	0.16	-0.03	0.16	-0.05	0.15	-0.06	0.15	-0.01	0.17	-0.01	0.17	0.09	0.16
Firm size log	0.06	0.18	0.10	0.17	0.09	0.18	0.08	0.18	0.10	0.17	0.07	0.17	0.11	0.18	0.11	0.18	-0.11	0.21
Firm size log FAI	0.20	0.29	0.10	0.28	0.10	0.29	0.11	0.29	0.16	0.27	0.27	0.27	0.04	0.28	0.03	0.28	0.55	0.34
Age squared	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Market Barrier	-0.02	0.15	0.03	0.15	0.04	0.15	0.04	0.15	-0.01	0.14	0.01	0.14	0.06	0.15	0.09	0.16	0.14	0.17
Technology	0.05	0.14	0.04	0.14	0.05	0.15	0.05	0.15	0.13	0.14	0.12	0.14	0.01	0.15	-0.01	0.15	0.01	0.16
PAET	0.27*	0.13	0.33*	0.13	0.30*	0.13	0.27†	0.15	0.29*	0.12	0.26*	0.12	0.31*	0.13	0.24	0.15	-0.13	0.17
Internal Tech Res																	-0.15	0.25
Internal Human																	-0.02	0.15
Ext Comm	0.25*	0.11	0.12	0.11													0.10	0.13
Ext Human					0.20	0.12	0.25	0.17									0.05	0.25
Ext Tech Res									0.38**	0.09	0.49**	0.12					0.55**	0.15
Ext Comm IP Res													0.12	0.10	0.18	0.11	0.29†	0.16
NPD Absorp Cap																	0.02	0.24
NPD Comm Cap																	-0.23	0.23
NPD Collab																	0.25	0.34
PAET x Int Tech																	0.03	0.27
PAET x Int Human Capital																	0.02	0.16
PAET x Ext Human Capital							0.07	0.17									0.23	0.25
PAET x Ext Comm Officer			-0.34**	0.11													-0.42**	0.12
PAET xExt Tech Res											0.17	0.12					0.37*	0.15
PAET x Ext_Comm IP															0.13	0.11	0.37*	0.16
PAET x NPD																	-0.10	0.24
PAET x NPD																	-0.32	0.22
PAET x NPD																	0.32	0.34
R-Square Change	0.10		0.08		0.08		0.00		0.19		0.02		0.07		0.01		0.15	
Probability	0.00		0.00		0.01		0.68		0.00		0.15		0.02		0.27		0.01	

Table 5-14: Regression Results on Process Innovation Outcome (Models 6 to 13, and full Model 20)

Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

Models 6 to 13 demonstrate the effect of five predictor variables (*PAET*, *External Commercial Officer Resources, External Human Capital, External Technological Resources* and *External Commercial IP Resources*) on 110 cases. Model 20 shows the effect of these five predictors and additional five predictors (*Internal Technological Resources*, *Internal Human Capital, NPD Absorptive Capacity, NPD Communication Capability* and *NPD Collaborative Problem-solving*). With a range of 11 cases (Model 20) to 22 cases per predictor (Models 6 to 13), these regression models satisfy Field's (2005) recommendations of minimum of 5-10 cases per predictor for reliable regression results. The regression results of Model 20 indicate that the *External Commercial Officer Resources* has a negative moderating effect on the *PAET-Process Innovation Outcome* relationship ($b = -0.42$, $p < 0.01$). Figure 5-9 shows the nature of moderation effect by *External Commercial Officer Resources* on the relationship.

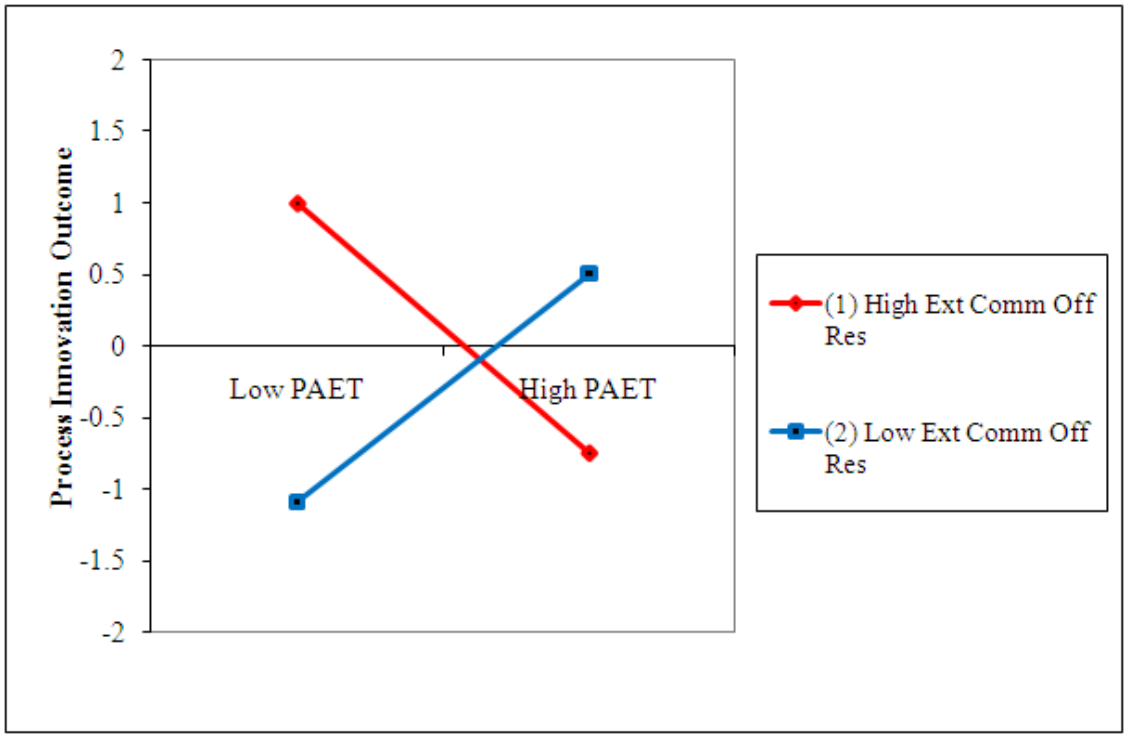

Figure 5-9: Moderation graph of *External Commercial Officer Resources* on *PAET-Process Innovation Outcome* relation

Model 20, on the other hand, shows that the *External Technological Resources* (b = 0.37, p < 0.05, VIF = 3.69) and *External Commercial IP Resources* (b = 0.37, p < 0.05, VIF = 4.62) have a positive moderating effect on the relationship between *PAET* and *Process Innovation Outcome*. The R2 of Model 20 increased to 15% with significance of p < 0.05.

The positive moderation effects of *External Technological Resources* and *External Commercial IP Resources* are illustrated in Figure 5-10 and Figure 5-11 respectively.

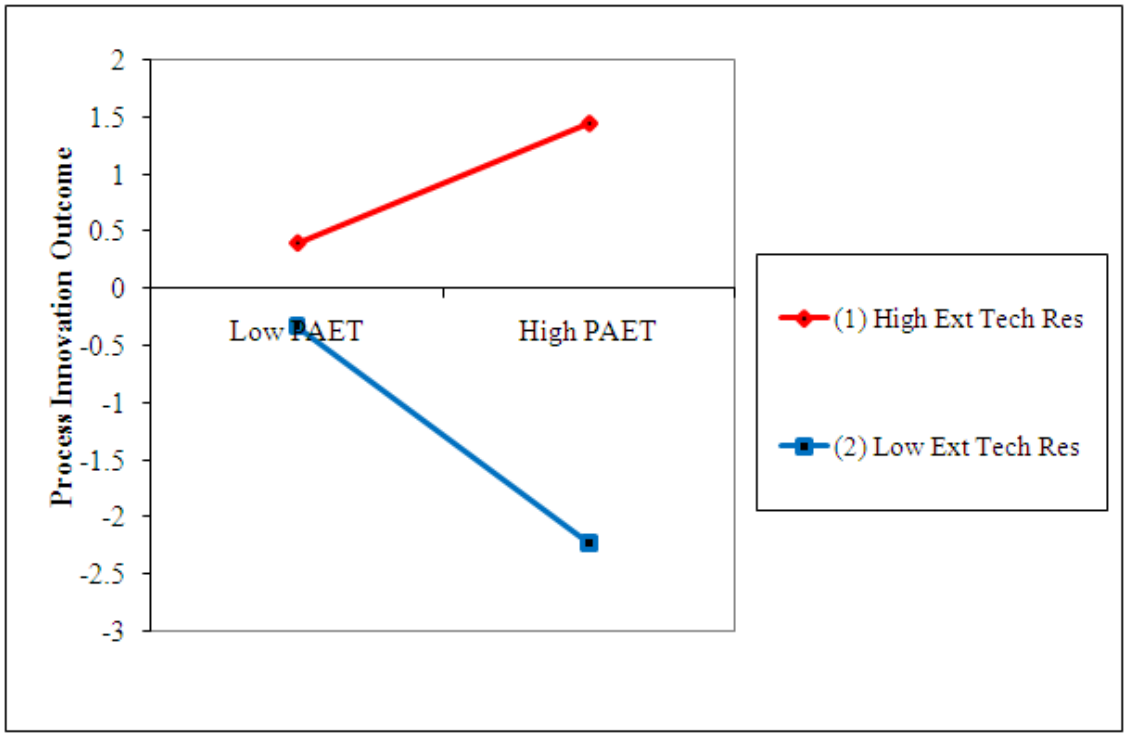

Figure 5-10: Moderation graph of *External Technological Resources* on *PAET-Process Innovation Outcome* relation

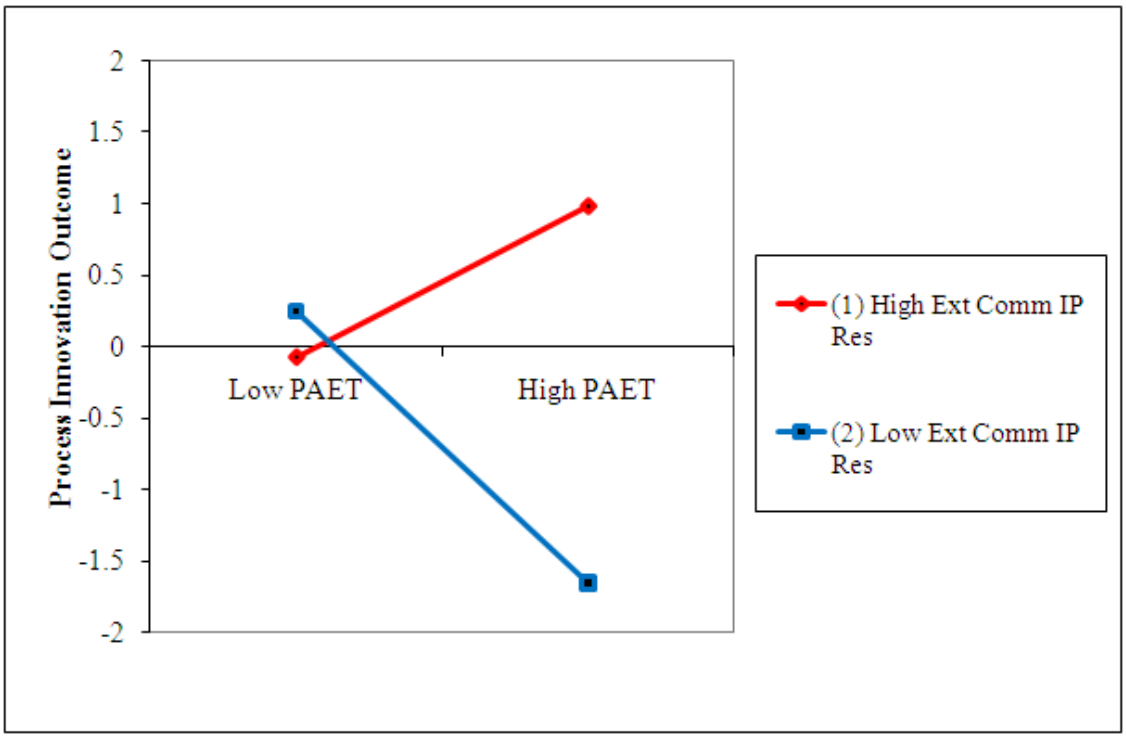

Figure 5-11: Moderation graph of *External Commercial IP Resources* on *PAET-Process Innovation Outcome* relation

These findings on *External Technological Resources* and *External Commercial IP Resources* therefore show support for Hypotheses 4g and 4h, which state that among firms that have high levels of *PAET*, those that report higher levels of *Process Innovation Outcome* have greater access to *External Technological Resources* and *External Commercial IP Resources,* respectively. Finding on Hypotheses 4e to 4h is as follows.

Hypotheses 4e-4h Finding:

- *Among firms that have high levels of PAET, those that report higher levels of Process Innovation Outcome have greater access to External Technological Resources and External Commercial IP Resources.(4g and 4h fully supported)*
- *The External Commercial Officer Resources and External Human Capital do not have significant moderating effect on the relationship between PAET and Process Innovation Outcome (4e and 4f not supported)*

Combining the findings for Hypotheses 4a to 4h, the Result No 4 for Hypothesis 4 is as follows and presented in Figure 5-12. The results are discussed in Section 5.5.2.

***Result No 4**:*

- *Among firms that have high levels of PAET, those that report higher levels of Product Innovation Outcome have greater access to External Commercial Officer and External Human Capital Resources (H4a, H4b fully supported).*
- *The External Technological Resources and External Commercial IP Resources do not have significant moderating effect on the relationship between PAET and Product Innovation Outcome. (H4c, H4d not supported)*
- *Among firms that have high levels of PAET, those that report higher levels of Process Innovation Outcome have greater access to External Technological Resources and External Commercial IP Resources.(4g and 4h fully supported)*
- *The External Commercial Officer Resources and External Human Capital do not have significant moderating effect on the relationship between PAET and Process Innovation Outcome (4e and 4f not supported)*

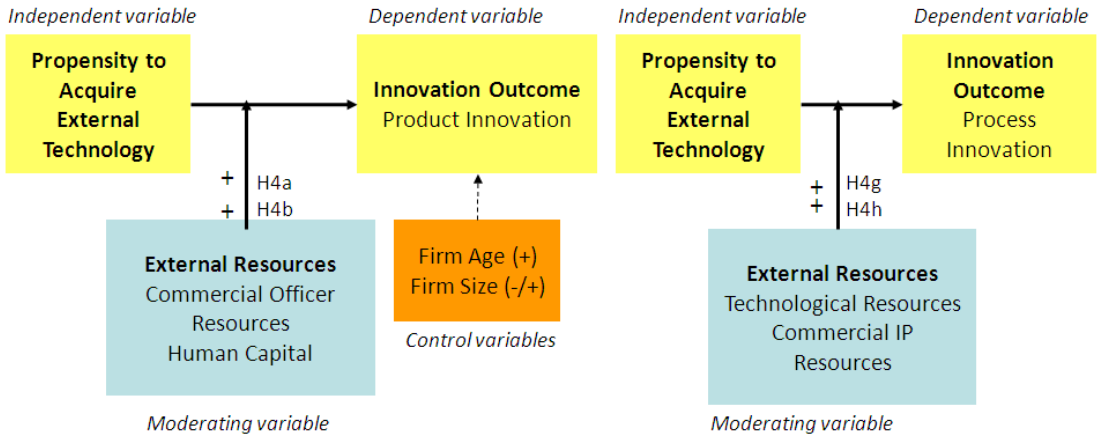

Figure 5-12: Result No 4 - Hypothesis 4 Finding

5.4.5 Results of Hypothesis 5 Testing

Hypothesis 5 states that among firms that have high levels of *PAET*, those that report higher levels of *Innovation Outcome* have superior *NPD Collaboration Capability*. In testing this hypothesis, hierarchical regression was performed on the two variables of innovation outcome: *Product Innovation Outcome* and *Process Innovation Outcome* in a similar way as that for Hypotheses 2 and 4 detailed in Sections 5.4.2 and 5.4.4, respectively. As discussed in Section 5.3, the following three variables of *NPD Collaboration Capability* and their respective interactive variables with *PAET* were examined for their role in moderating the interaction of *PAET* with *Product Innovation Outcome* and *Process Innovation Outcome*:

1) *NPD Absorptive Capacity* (Ettlie and Pavlou, 2006)
2) *NPD Communication Capability* (Bstieler, 2006)
3) *NPD Collaborative Problem-solving* (Li et al., 2007)
4) *NPD Absorptive Capacity* x *PAET*
5) *NPD Communication Capability* x *PAET*
6) *NPD Collaborative Problem-solving* x *PAET*

As in the case of *Internal Resources* and *External Resources* variables, the interactive variables between *NPD Collaboration Capability* and *PAET* were computed after centralisation by subtracting their values against their mean so as to mitigate the risk of multi-collinearity among them.

Product Innovation Outcome

The baseline model, Model 1, illustrating the effect of only control variables on the dependent variable, *Product Innovation Outcome*, was presented in Table 5-7 and discussed in Section 5.4.2. The main-effects models (Models 10, 12 and 14), the interactive effects models (Models 11, 13 and 15) and the full model (Model 16) are presented in Table 5-15.

Dependent Variable: Product Innovation Outcome (N=153)														
Variables	**Model 10**		**Model 11**		**Model 12**		**Model 13**		**Model 14**		**Model 15**		**Model 16**	
	b	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**
(Constant)	1.69	1.11	1.94	1.17	1.28	1.04	1.27	1.09	1.13	1.06	1.31	1.14	1.70	1.08
Spin off	-0.01	0.12	-0.01	0.12	0.04	0.12	0.04	0.12	0.03	0.12	0.03	0.12	0.07	0.11
Firm size log employment	-0.39**	0.15	-0.37*	0.15	-0.44**	0.14	-0.44**	0.14	-0.47**	0.15	-0.45**	0.15	-0.46**	0.14
Firm size log FAI	0.43*	0.20	0.39†	0.21	0.51**	0.19	0.51**	0.19	0.54**	0.19	0.51*	0.20	0.43*	0.19
Age squared	0.00*	0.00	0.00*	0.00	0.00*	0.00	0.00*	0.00	0.00*	0.00	0.00*	0.00	0.00	0.00
Market Barrier	0.06	0.11	0.06	0.11	0.10	0.11	0.10	0.11	0.06	0.11	0.05	0.11	0.01	0.10
Technology Barrier	-0.11	0.11	-0.11	0.11	-0.15	0.11	-0.15	0.11	-0.12	0.11	-0.12	0.11	-0.09	0.10
PAET	-0.03	0.10	-0.01	0.10	-0.06	0.09	-0.06	0.10	-0.09	0.10	-0.06	0.11	-0.26*	0.11
Internal Tech Res													0.11	0.10
Internal Human Capital													0.07	0.10
Ext Comm Officer Res													0.47**	0.08
Ext Human Capital													0.42**	0.14
NPD Absorp Cap	0.03	0.08	-0.01	0.10									-0.46*	0.17
NPD Comm Cap					0.18*	0.08	0.18†	0.10					0.37**	0.12
NPD Collab Prob-solv									0.18*	0.09	0.14	0.13	0.13	0.21
PAET xInt Tech Res													0.29**	0.11
PAET xInt Human Capital													0.08	0.11
PAET x Ext Human Capital													0.37*	0.14
PAET x Ext Comm Officer Res													0.19*	0.08
PAET x NPD Absorp Cap			-0.06	0.09									-0.42*	0.17
PAET x NPD Comm Cap							0.00	0.09					0.25*	0.12
PAET x NPD Collab Prob-solv											-0.05	0.12	0.17	0.21
R-Square Change	0.00		0.00		0.03		0.00		0.03		0.00		0.10	
Probability	0.91		0.51		0.10		0.97		0.13		0.67		0.00	

Table 5-15: Regression Results on Product Innovation Outcome (Models 10 to 15, and full Model 16)
Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

Models 10 to 15 demonstrate the effect of four predictor variables (*PAET*, *NPD Absorptive Capacity, NPD Communication Capability* and *NPD Collaborative Problem-solving*) on 153 cases. Model 20 shows the effect of these four predictors and additional four predictors (*Internal Technological Resources*, *Internal Human Capital, External Commercial Officer Resources* and *External Human Capital,*). With a range of 19 cases (Model 16) to 38 cases per predictor (Models 10 to 15), these regression models satisfy Field's (2005) guidelines of minimum of 5-10 cases per predictor for reliable regression results.

Models 12 and 14 indicate the significance of *NPD Communication Capability* ($b = 0.18$, $p < 0.05$) and *NPD Collaborative Problem-solving Capability* ($b = 0.18$, $p < 0.05$), respectively, on *Product Innovation Outcome*. The full model, Model 16, shows the effect of all control variables, independent variables (*PAET*), hypothesised moderation variables (*Internal Resources, External Resources* and *NPD Collaboration Capability*) and their interaction variables with *PAET* on *Product Innovation Outcome*, over and above the Model 1 and Models 10 to 15. Model 12 and 13 show that *NPD Communication Capability* has positive effect as independent variable on *Product Innovation Outcome* ($b = 0.18$, $p < 0.05$ in Model 12; $b = 0.18$, $p < 0.10$ in Model 13), while Model 14 shows that *NPD Collaborative Problem-solving Capability* as a significant positive independent variable ($b = 0.18$, $p < 0.05$).

Model 16 illustrates the significant contribution by *NPD Absorptive Capacity* in negatively moderating the *PAET-Product Innovation Outcome* relation ($b = -0.42$, $p < 0.05$), and the significant negative effect of *Firm Size* (employment) on *Product Innovation Outcome* ($b = -0.46$, $p < 0.01$). The negative moderating effects of *NPD Absorptive Capacity* are shown in Figure 5-13. On the other hand, *NPD Communication Capability* is found in Model 16 to positively moderate the interaction between *PAET* and the *Product Innovation Outcome* ($b = 0.25$, $p <0.05$). With relatively low VIF at 3.66 that is below Chatterjee and Price's (1991) recommended cut-off value of 10, there is little probability of multi-collinearity affecting the findings. The full model shows a R2 change of 10% with a significance of $p < 0.01$.

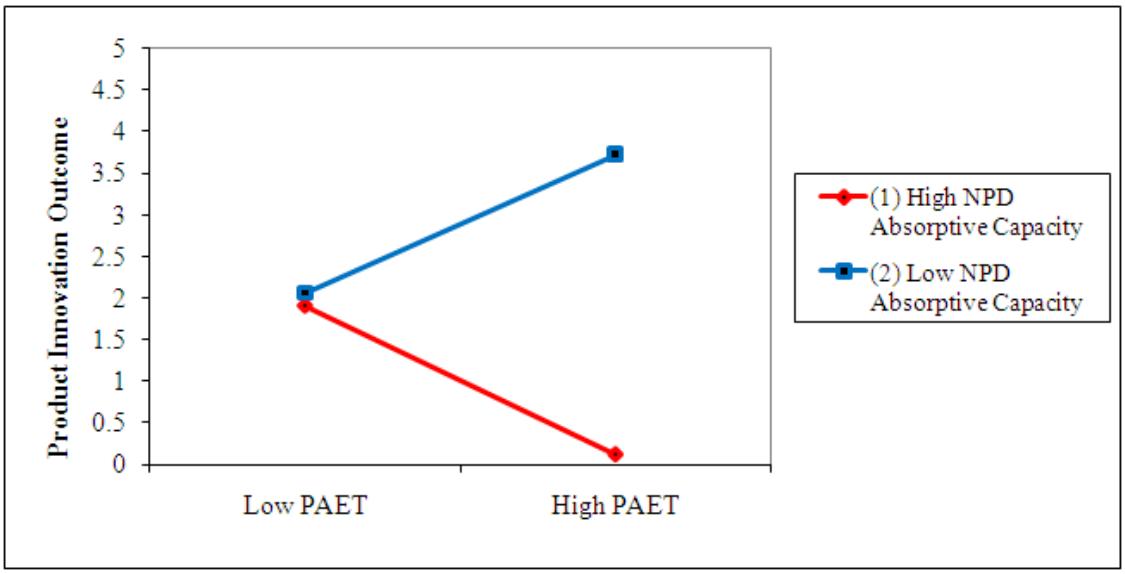

Figure 5-13: Moderation graph of *NPD Absorptive Capacity* on *PAET-Product Innovation Outcome* relation

The positive moderation by *NPD Communication Capability* is illustrated in Figure 5-14, where *NPD Communication Capability* increases the strength of relationship between *PAET* and *Product Innovation Outcome*.

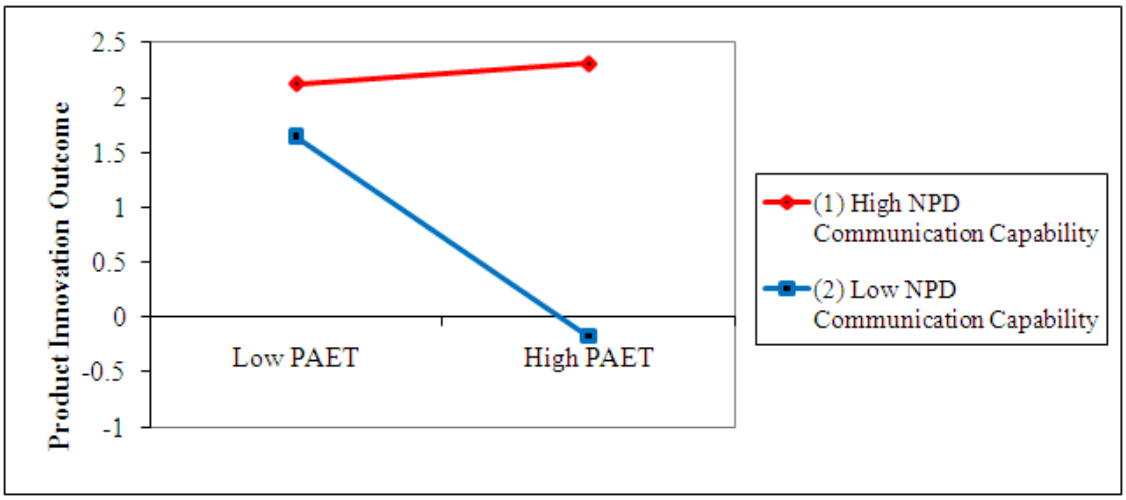

Figure 5-14: Moderation graph of *NPD Communication Capability* on *PAET-Product Innovation Outcome* relation

These above findings thus provide support for Hypothesis 5b, which states that among firms that have high levels of PAET, those that report higher levels of *Product Innovation Outcome* have superior *NPD Communication Capability*. As for the other *NPD Collaboration Capability* variables, there is no support for their related Hypotheses 5a

and 5c. The lack of support is discussed in Section 5.5.2. Result No 5 is summarised as follows:

***Hypothesis 5a-5c Finding**:*

- *Among firms that have high levels of PAET, those that report higher levels of product innovation outcome have superior NPD Communication Capability (H5b fully supported).*
- *The NPD Absorptive Capacity and NPD Problem-solving Capability have non-significant positive moderating effect on the relationship between PAET and Product Innovation Outcome (H5a, H5c not supported).*

Process Innovation Outcome

The baseline model, Model 1, illustrating the effect of only control variables on the dependent variable, *Process Innovation Outcome*, was presented in Table 5-8 and discussed in Section 5.4.2. The main-effects models (Models 14, 16 and 18), the interactive effects models (Models 15, 17 and 19) and the full model (Model 20) are presented in Table 5-16. The full model, Model 20, shows the effect of all control variables, independent variables (*PAET*), hypothesised moderation variables (*Internal Resources, External Resources* and *NPD Collaboration Capability*) and their interaction variables with *PAET* on *Process Innovation Outcome*, over and above the Model 1 and Models 14 to 19. Models 14 to 19 demonstrate the effect of four predictor variables (*PAET*, *NPD Absorptive Capacity, NPD Communication Capability* and *NPD Collaborative Problem-solving*) on 110 cases. Model 20 shows the effect of these four predictors and additional four predictors (*Internal Technological Resources*, *Internal Human Capital, External Commercial Officer Resources* and *External Human Capital,*). With a range of 13 cases (Model 20) to 28 cases per predictor (Models 14 to 19), these regression models satisfy Field's (2005) guidelines of minimum of 5-10 cases per predictor for reliable regression results.

Dependent Variable: Process Innovation Outcome (N=110)														
Variables	**Model 14**		**Model 15**		**Model 16**		**Model 17**		**Model 18**		**Model 19**		**Model 20**	
	b	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**
(Constant)	2.36	1.71	2.25	1.74	2.41	1.56	2.17	1.57	1.90	1.63	1.55	1.73	-0.06	1.86
Spin off	-0.04	0.16	-0.04	0.17	0.02	0.16	0.03	0.16	0.02	0.16	0.03	0.17	0.09	0.16
Firm size log employment	0.05	0.20	0.04	0.20	0.04	0.18	0.02	0.18	-0.02	0.19	-0.05	0.20	-0.11	0.21
Firm size log FAI	0.14	0.31	0.16	0.32	0.13	0.28	0.17	0.28	0.24	0.30	0.29	0.31	0.55	0.34
Age squared	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Market Barrier	0.02	0.16	0.02	0.16	0.11	0.15	0.12	0.15	0.03	0.15	0.04	0.15	0.14	0.17
Technology Barrier	0.02	0.15	0.02	0.15	-0.05	0.15	-0.04	0.15	0.03	0.14	0.03	0.14	0.01	0.16
PAET	0.30*	0.14	0.28†	0.15	0.28*	0.13	0.23†	0.14	0.27*	0.13	0.23	0.15	-0.13	0.17
Internal Tech Res													-0.15	0.25
Internal Human Capital													-0.02	0.15
Ext Comm Officer Res													0.10	0.13
Ext Human Capital													0.05	0.25
Ext Tech Res													0.55**	0.15
Ext Comm IP Res													0.29†	0.16
NPD Absorp Cap	0.11	0.11	0.14	0.13									0.02	0.24
NPD Comm Cap					0.26*	0.11	0.34*	0.13					-0.23	0.23
NPD Collab Prob-solv									0.27*	0.12	0.34*	0.17	0.25	0.34
PAET x Int Tech Res													0.03	0.27
PAET x Int Human Capital													0.02	0.16
PAET x Ext Human Capital													0.23	0.25
PAET x Ext Comm Officer Res													-0.42**	0.12
PAET xExt Tech Res													0.37*	0.15
PAET x Ext_Comm IP Res													0.37*	0.16
PAET x NPD Absorp Cap			0.05	0.12									-0.10	0.24
PAET x NPD Comm Cap							0.12	0.12					-0.32	0.22
PAET x NPD Collab Prob-solv											0.09	0.15	0.32	0.34
R-Square Change	0.07		0.00		0.11		0.01		0.10		0.00		0.15	
Probability	0.02		0.71		0.00		0.29		0.00		0.54		0.01	

Table 5-16: Regression Results on Process Innovation Outcome (Models 14 to 19, and full Model 20)

Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

Models 16 and 18 in Table 5-16 indicate the significance of *NPD Communication Capability* (b = 0.26, p < 0.05) and *NPD Collaborative Problem-solving Capability* (b = 0.27, p < 0.05), respectively, as predictors of *Process Innovation Outcome.* However, the full model 20 shows that the three variables of *NPD Collaboration Capability* were not significant compared to other factors, such as *External Commercial IP Resources* (b = 0.37, p < 0.05) and *External Technological Resources* (b = 0.37, p < 0.05), in moderating the relationship between *PAET* and *Process Innovation Outcome*. These findings on *Process Innovation Outcome* therefore do not show support for Hypothesis 5d-5f. Discussion for this lack of support is provided in Section 5.5.2.

Hypothesis 5d-5f Finding*:*

- *None of the NPD Collaboration Capability variables has significant moderating effect on the relationship between PAET and Product Innovation Outcome (H5d-H5f not supported)*

Combining the findings for Hypotheses 5a to 5f, Result No 5 for Hypothesis 5 is as follows and presented in Figure 5-15.

Result No 5:

- *Among firms that have high levels of PAET, those that report higher levels of Product Innovation Outcome have superior NPD Communication Capability (H5b fully supported).*
- *The NPD Absorptive Capacity and NPD Problem-solving Capability have non-significant moderating effect on the relationship between PAET and Product Innovation Outcome (H5a, H5c not supported)*
- *None of the NPD Collaboration Capability variables has significant positive moderating impact on the relationship between PAET and Process Innovation Outcome (H5d, H5e, H5f not supported)*

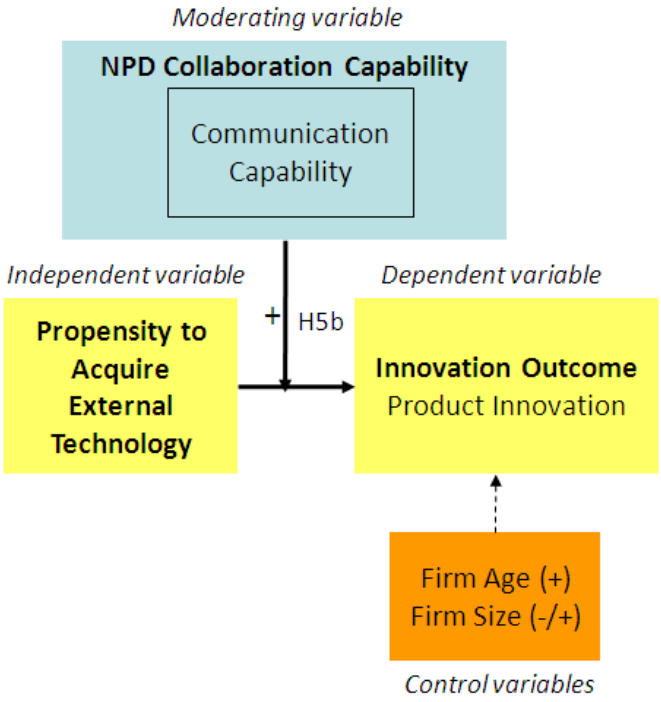

Figure 5-15: Result No 5 – Hypothesis 5 Finding

The interpretation of these results is deferred to Section 5.5.2.

5.4.6 Results of Hypothesis 6 Testing

Hypothesis 6 predicts that among firms that have high levels of *Innovation Outcome* with external technologies, those that report better commercial adoption *Performance* have superior *NPD Collaboration Capability*. In validating this hypothesis, moderated hierarchical regression was performed on *Performance* using the two variables of *Innovation Outcome*: *Product Innovation Outcome* and *Process Innovation Outcome* in a similar way as that for Hypothesis 3 discussed in Section 5.4.3, where *Performance* was regressed on the two variables of *Innovation Outcome* and the two variables of *Internal Resources (Internal Commercial CA Resources* and *Internal Commercial IP Resources)*. In this case, the three variables of *NPD Collaboration Capability* and their six interactive variables with *Product/Process Innovation Outcome* were examined for their role in predicting the variance in the dependent variable, *Performance*:

1) *NPD Absorptive Capacity*
2) *NPD Communication Capability*

3) *NPD Collaborative Problem-solving*
4) *NPD Absorptive Capacity* x *Product Innovation Outcome*
5) *NPD Communication Capability* x *Product Innovation Outcome*
6) *NPD Collaborative Problem-solving* x *Product Innovation Outcome*
7) *NPD Absorptive Capacity* x *Process Innovation Outcome*
8) *NPD Communication Capability* x *Process Innovation Outcome*
9) *NPD Collaborative Problem-solving* x *Process Innovation Outcome*

To mitigate the risk of multi-collinearity among the three variables of NPD *Collaboration Capability*, they were centralised by subtracting their values against their means before computing the interaction terms.

Product Innovation Outcome

Table 5-9 presents the baseline model, Model 1 assessing the effects of control variables only. Table 5-17 lists the regression results of *Performance* predicting the impact of each of the three *NPD Collaboration Capability* variables (main-effects Models 6, 8 and 10) and their interactive terms with *Product/Process Innovation Outcome* (Models 7, 9 and 11) on the dependent variable, *Performance*.

The full model, Model 12, considers the main and interaction effects of all variables (comprising *NPD Collaboration Capability* and *Internal Resources*).

Models 6 to 11 demonstrate the effect of four predictor variables (*Product Innovation Outcome*, *NPD Absorptive Capacity, NPD Communication Capability* and *NPD Collaborative Problem-solving*) on 131 cases. Model 12 shows the effect of these four predictors and additional two predictors (*Internal Commercial CA Resources* and *Internal Commercial IP Resources*). These regression models utilise 21 cases per predictor (Model 12) to 32 cases per predictor (Models 6 to 11), thereby satisfying Field's (2005) guidelines of minimum of 5-10 cases per predictor for reliable regression results.

Dependent Variable: Performance (Product Innovation) (N=131)														
Variables	**Model 6**		**Model 7**		**Model 8**		**Model 9**		**Model 10**		**Model 11**		**Model 12**	
	b	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**
(Constant)	5.48	1.02	5.24	1.12	5.34	0.99	5.71	1.03	5.82	0.99	6.28	1.04	5.20	1.10
Spin off	0.34**	0.11	0.33**	0.11	0.34**	0.11	0.38**	0.11	0.31**	0.11	0.35**	0.11	0.34*	0.12
Firm Size log employment	0.24†	0.14	0.21	0.15	0.22	0.13	0.28†	0.14	0.31*	0.14	0.39**	0.15	0.36*	0.15
Firm Size log FAI	-0.64**	0.18	-0.59**	0.20	-0.61**	0.17	-0.68**	0.18	-0.71**	0.17	-0.80**	0.18	-0.63**	0.19
Age squared	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Market Barrier	-0.10	0.10	-0.11	0.11	-0.11	0.10	-0.10	0.10	-0.10	0.10	-0.07	0.10	-0.04	0.11
Technology Barrier	0.05	0.10	0.05	0.10	0.05	0.10	0.04	0.10	0.07	0.10	0.05	0.10	-0.02	0.10
Infocomm Industry	0.43*	0.20	0.44*	0.20	0.44*	0.20	0.46*	0.20	0.40†	0.20	0.40*	0.20	0.52*	0.20
Other Industries (Engineering, Manufacturing, Chemicals, Electronics)	0.33†	0.19	0.35†	0.20	0.34†	0.20	0.35†	0.20	0.36†	0.19	0.34†	0.19	0.31	0.21
Prod Innov Outcome	0.47**	0.08	0.45**	0.09	0.47**	0.08	0.51**	0.09	0.49**	0.08	0.53**	0.09	0.51**	0.09
Internal Commercial CA Res													-0.25*	0.12
Internal Commercial IP Res													0.03	0.08
NPD Absorp Cap	-0.03	0.07	-0.04	0.07									-0.05	0.10
NPD Comm Cap					-0.01	0.08	-0.02	0.08					0.39*	0.14
NPD Collab Prob-solv									-0.16†	0.08	-0.15†	0.08	-0.35†	0.16
Prod Innov Outcome x Int Comm CA Res													0.04	0.12
Prod Innov Outcome x Int Comm IP Res													0.11	0.09
Prod Innov Outcome x NPD Absorp Cap			0.05	0.09									0.28†	0.15
Prod Innov Outcome x NPD Comm Cap							-0.12	0.09					-0.18	0.21
Prod Innov Outcome x NPD Collab Prob-solv											-0.13	0.09	-0.25	0.26
R-Square Change	0.00		0.00		0.00		0.01		0.02		0.01		0.03	
Probability	0.60		0.59		0.86		0.20		0.05		0.17		0.21	

Table 5-17: Regression Results on Performance (Product Innovation) (Models 6 to 11, and full Model 12)
Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

The full model, Model 12, shows that the *NPD Communication Capability* has a significant positive impact on *Performance* (b = 0.39, p < 0.05), while the *NPD Absorptive Capacity* has a significant and positive moderating effect on the relationship (b = 0.28, p < 0.1) between *Performance* and *Product Innovation Outcome*. With relatively low VIF at 4.93 that is below Chatterjee and Price's (1991) recommended cut-off value of 10, there is little probability of multi-collinearity affecting the findings. The positive moderation by *NPD Absorptive Capacity* is illustrated in Figure 5-16, where *NPD Absorptive Capacity* increases the strength of the relationship between *Product Innovation Outcome* and *Performance*.

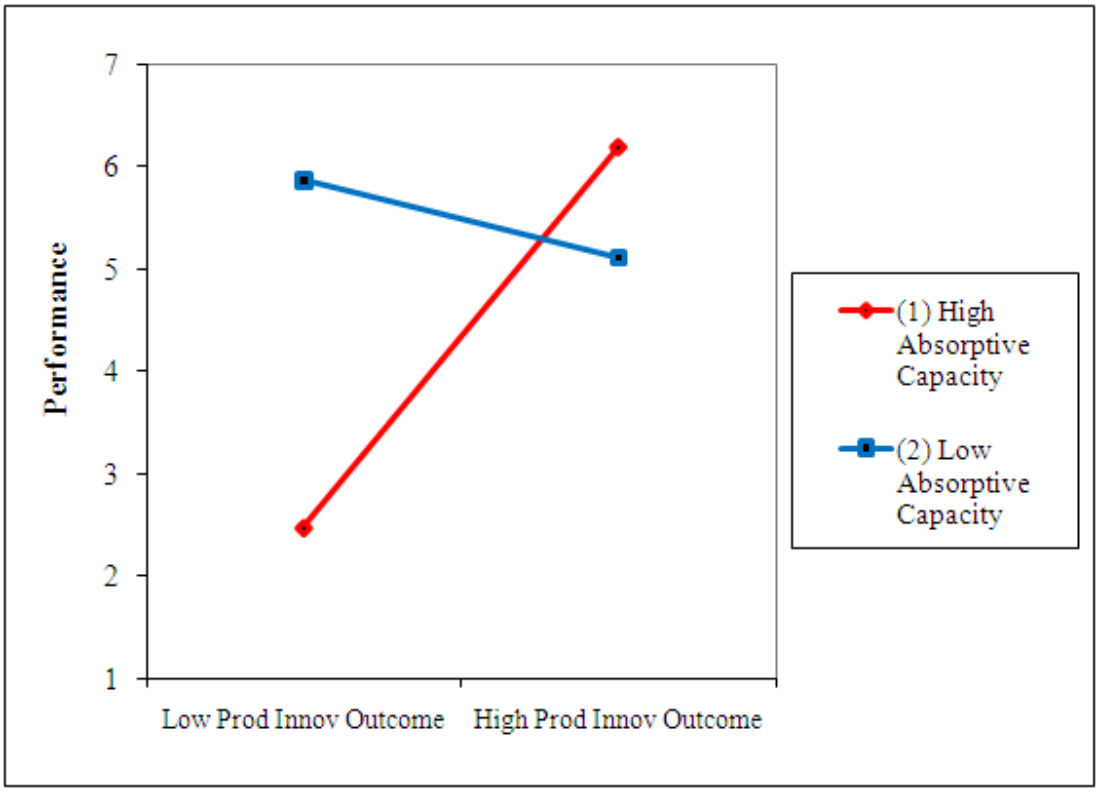

Figure 5-16: Moderation graph of *NPD Absorptive Capacity* on *Product Innovation Outcome-Performance* relation

The above findings thus provide support for Hypothesis 6a, that among firms having high levels of *Product Innovation Outcome* with external technologies, those that report better commercial adoption *Performance* have superior *NPD Absorptive Capacity*.

***Hypothesis 6a-6c Finding**:*

- *Among firms that have high levels of Product Innovation Outcome with external technologies, those that report better commercial adoption Performance have superior NPD Absorptive Capacity (H6a fully supported).*
- *The NPD Communication Capability and NPD Collaborative Problem-solving have non-significant moderating effect on the relationship between Product Innovation Outcome and Performance (H6b, H6c not supported).*

Process Innovation Outcome

As highlighted earlier in Section 5.4.3, 91 of the 250 survey responses indicated achievement of some form of process innovation. Based on these 91 responses, we ran moderated hierarchical regression of their reported *Performance* data on the independent variable, *Process Innovation Outcome* and hypothesised interaction with the *NPD Collaboration Capability* variables. Model 1 of Table 5-9 shows a baseline model examining the impact of the control variables. The results of regressing *Performance* on the three *NPD Collaboration Capability* variables (main-effects Models 6, 8 and 10) and their three interactive terms with *Process Innovation Outcome* (interactive effects Models 7, 9 and 11) are presented in Table 5-18. Model 12 is the full regression model showing the main and interaction effects on *Performance* comprising all control variables, *Process Innovation Outcome*, *Internal Resources* and *NPD Collaboration Capability* variables.

Models 6 to 11 demonstrate the effect of four predictor variables (*Product Innovation Outcome*, *NPD Absorptive Capacity, NPD Communication Capability* and *NPD Collaborative Problem-solving*) on 91 cases. Model 16 shows the effect of these four predictors and additional two predictors (*Internal Commercial CA Resources* and *Internal Commercial IP Resources*). These regression models utilise 15 cases per predictor (Model 12) to 22 cases per predictor (Models 6 to 11), thereby satisfying Field's (2005) guidelines of minimum of 5-10 cases per predictor for reliable regression results.

Dependent Variable: Performance (Process Innovation) (N=91)														
Variables	**Model 6**		**Model 7**		**Model 8**		**Model 9**		**Model 10**		**Model 11**		**Model 12**	
	b	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**	**b**	**SE**
(Constant)	4.44	1.41	5.18	1.44	4.27	1.33	3.91	1.38	4.45	1.38	3.66	1.46	3.72	1.58
Spin off	0.35*	0.15	0.26	0.16	0.35*	0.15	0.31*	0.16	0.34*	0.15	0.29†	0.15	0.27†	0.16
Firm size log employment	0.14	0.17	0.12	0.17	0.11	0.16	0.07	0.17	0.15	0.17	0.04	0.18	-0.09	0.19
Firm size log FAI	-0.41	0.26	-0.53	0.26	-0.37	0.24	-0.30	0.25	-0.42	0.25	-0.27	0.27	-0.22	0.28
Firm Age squared	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Market Barrier	-0.04	0.15	-0.09	0.15	-0.05	0.15	-0.06	0.15	-0.04	0.15	-0.09	0.15	-0.27	0.18
Technology Barrier	-0.05	0.14	-0.05	0.14	-0.06	0.14	-0.05	0.14	-0.06	0.14	-0.03	0.14	0.09	0.15
Biomedical Industry	-0.26	0.28	-0.23	0.28	-0.29	0.29	-0.30	0.29	-0.26	0.29	-0.27	0.28	-0.40	0.30
Other Industries (Engineering, Manufacturing, Chemicals, Electronics)	0.10	0.24	0.11	0.24	0.03	0.26	0.02	0.26	0.11	0.25	0.10	0.24	0.07	0.25
Proc Innov Outcome	0.01	0.09	0.02	0.09	-0.01	0.10	-0.01	0.10	0.02	0.10	0.01	0.10	-0.03	0.09
Internal Commercial CA Res													0.17	0.18
Internal Commercial IP resource													0.02	0.13
NPD Absorp Cap	-0.02	0.09	0.03	0.09									0.02	0.12
NPD Comm Cap					0.06	0.11	0.07	0.11					0.02	0.21
NPD Collab Prob-solv									-0.03	0.12	-0.02	0.12	-0.07	0.24
Proc Innov Outcome x Int Comm CA Res													-0.35*	0.12
Proc Innov Outcome x Int Comm IP Res													0.34**	0.11
Proc Innov Outcome x NPD Absorp Cap			-0.19	0.10									0.09	0.13
Proc Innov Outcome x NPD Comm Cap							0.11	0.11					-0.38†	0.20
Proc Innov Outcome x NPD Collab Prob-solv											0.19	0.12	0.11	0.19
R-Square Change	0.00		0.04		0.00		0.01		0.00		0.03		0.18	
Probability	0.98		0.06		0.85		0.32		0.96		0.13		0.00	

Table 5-18: Regression Results on Performance (Process Innovation) (Models 6 to 11, and full Model 12)
Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

Model 7 shows that *NPD Absorptive Capacity* has a significant negative moderating effect on the relationship (b = -0.19, p < 0.1). This model shows its significant contribution to the variance in *Performance*, by a R2 change of 4% with a significance of less than 0.1. In Model 12, the negative moderating effect of *NPD Absorptive Capacity* dissipated in the presence of the other variables, thereby showing no support for H6d. On the other hand, *NPD Communication Capability* was found to have a negative moderating effect with *Process Innovation Outcome* on *Performance* (b = -0.38, p < 0.1) in Model 12. Given the significant effect of *Spin-off* on *Performance*, it is likely that the spin-off founders that report high level of commercial adoption *Performance* have also given lower rating for the role of *NPD Communication Capability* in terms of communication with the researchers of PRIs, compared to the non-spin-offs. As former PRI researchers who had developed the technologies, the spin-off founders subsequently left to found their own companies and licensed from the PRIs the same technologies they had worked on and gained expertise in. Their familiarity with the technologies meant that there was relatively little need for them to communicate with the researchers of PRIs for knowledge transfer, contributing to the lower rating of *NPD Communication Capability* than non-spin-offs.

As the cases of spin-offs could potentially skew the regression results, we re-ran the moderated hierarchical regression on the remaining 73 cases after removing the 14 spin-off cases. After controlling for the *Spin-off* effect, the results presented in Model 13 of Table 5-12 show that the *NPD Communication Capability* was no longer significant as a negative moderating variable, and hence supporting the theory of dynamic capabilities. Similarly, Model 12 of Table 5-18 and Model 13 of Table 5-12 show that *NPD Collaborative Problem-solving* variable does not have significant moderating effect on the relationship between *Process Innovation Outcome* and *Performance*, thus rejecting H6e and H6f. The findings for H6d to H6f are as follows.

Hypotheses 6d-6f Finding:

- *NPD Absorptive Capacity, Communication Capability and NPD Collaborative Problem-solving variables do not have significant positive moderating effect on the*

relationship between Process Innovation Outcome and Performance (H6d to H6f not supported).

Combining the findings on Hypotheses 6a to 6f, Result No 6 is summarised below and presented in Figure 5-17. Discussion of these results is deferred to 5.5.3.

Result No 6:

- *Among firms that have high levels of Product Innovation Outcome with external technologies, those that report better commercial adoption Performance have superior NPD Absorptive Capacity (H6a fully supported).*
- *NPD Absorptive Capacity does not have significant positive moderating effect on the relationship between Process Innovation Outcome and Performance (H6d not supported).*
- *The NPD Communication Capability and NPD Collaborative Problem-solving have non-significant moderating effect on the relationship between Product/Process Innovation Outcome and Performance (H6b, H6c, H6e, H6f not supported).*

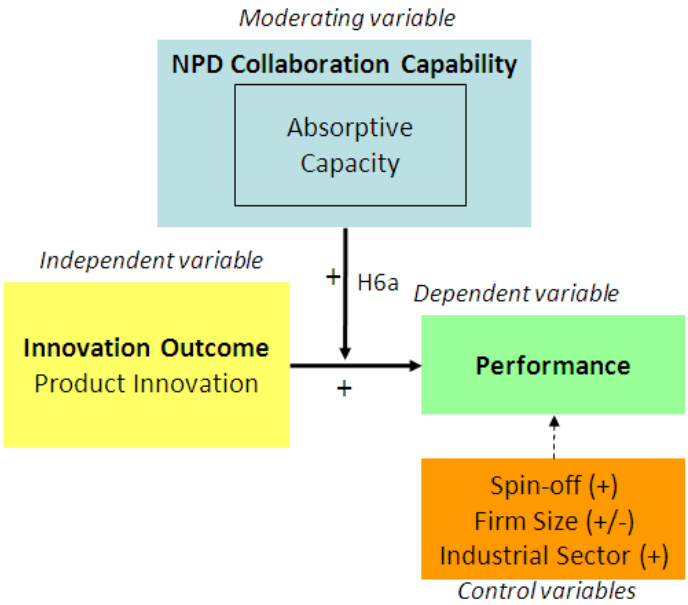

Figure 5-17: Result No 6 – Hypothesis 6 Finding

5.4.7 Results of Hypothesis 7 Testing

Hypothesis 7 predicts that *Innovation Outcome* mediates the relationship between *PAET* and commercial adoption *Performance*. To validate the hypothesis that a mediating relationship exists, mediation analysis was utilised. According to Tharenou et al. (2009), mediation analysis assesses if an independent variable gives rise to another variable, known as the mediator variable, which then transfers the influence of the independent variable to the dependent variable. In other words, the effect on the dependent variable by the independent variable is mediated by the mediator variable.

5.4.7.1 Mediation Analysis

This study analysed the relationship among the independent, mediator and dependent variables by using the following three steps of mediation analysis recommended by Baron and Kenny (1986) and supported by MacKinnon and Fairchild (2009):

1) The mediator variables (*Product Innovation Outcome* and *Process Innovation Outcome*), were regressed on the independent variable (*PAET*) to examine if they were statistically significantly related so as to determine if the independent variable was mediated by the mediating variable.
2) The dependent variable (*Performance*) was then regressed on the independent variable (*PAET)*. The statistical significance of the regression coefficient would be an indication of the significant relationship between the independent and dependent variable, which would be necessary if the mediating variables (*Product/Process Innovation Outcome*) mediated the influence of independent variable on the dependent variable.
3) As the final step, the regression was performed on the dependent variable (*Performance*) using both independent (*PAET*) and mediating (*Product/Process Innovation Outcome*) variables. The statistical significance of the mediating variable was crucial in this step to determine its mediation effect. If the mediating variable was statistically significant after controlling for the effect of the independent variable, the regression coefficient of the independent variable could either become statistically

non-significant (showing full mediation effects) or remain statistically significant but with decrease in magnitude compared to its regression coefficient in Step 2 (illustrating partial mediation effects).

The following four conditions must be satisfied to show the existence of a mediating relationship (Baron and Kenny, 1986, p.1177; MacKinnon and Fairchild, 2009, p.17):

1) The results of Step 1 must show that the independent variable (*PAET*) significantly affects the mediating variables (*Product Innovation Outcome* and *Process Innovation Outcome*).
2) The results of Step 2 must reveal that the independent variable (*PAET*) significantly affects the dependent variable (*Performance*).
3) The results of Step 3 must illustrate that the mediating variables (*Product Innovation Outcome* and *Process Innovation Outcome*) significantly affect the dependent variable (*Performance*).
4) The regression results of Step 3 should also indicate that the independent variable is either statistically non-significant (showing full mediation effects) or remain statistically significant but with decrease in magnitude compared to its regression coefficient in Step 2 (illustrating partial mediation effects).

5.4.7.2 Regressing Innovation Outcome on PAET

In the first step, the mediator variables, *Product Innovation Outcome* and *Process Innovation Outcome*, were regressed on the independent variable, *PAET*. Table 5-19 presents the regression results of the first step of Baron and Kenny's (1986) mediation analysis model. Models 1 and 4 show the baseline models comprising the control variables for regression analysis on *Product Innovation Outcome* and *Process Innovation Outcome,* respectively. In particular, the Model 1 results indicate that the *Firm Size* in terms of staff strength, the *Info Communication Industry* and *Other Industries* have a negative effect on the firm's *Product Innovation Outcome*, while *Firm Age* has a positive effect.

Step 1a: Regressing Product Innovation Outcome on PAET

Product Innovation Outcome was regressed on *PAET* in Step 1a. In Model 2, *Product Innovation Outcome* was regressed onto the control, *Internal Resources (Internal Technological Resources* and *Internal Human Capital), External Resources* and *NPD Collaboration Capability* variables. Model 3 presents the results of regressing *Product Innovation Outcome* onto *PAET* in addition to control variables, *Internal Resources, External Resources* (*External Commercial Officer Resources* and *External Human Capital* for reasons provided in Section 5.4.4) and *NPD Collaboration Capability*. While Model 2 tests the effect of 7 predictor variables on 153 cases, Model 3 shows the effect of 8 predictor variables. These regression models utilise 21 cases per predictor (Model 2) to 19 cases per predictor (Model 3), thereby satisfying Field's (2005) guidelines of minimum of 5-10 cases per predictor for reliable regression results. In Model 3, the *PAET* was found to be statistically significant ($b = -0.17$, $p < 0.10$), showing a R2 change of 2% at significance level of 0.06. These findings show that the first condition of mediating analysis test has been satisfied for *Product Innovation Outcome*.

Step 1b: Regressing Process Innovation Outcome on PAET

The above Step 1a was repeated in Step 1b for the other variable of *Innovation Outcome*: *Process Innovation Outcome*, as presented in Table 5-19. In Model 5, *Process Innovation Outcome* was regressed onto the control variables, *Internal Resources (Internal Technological Resources* and *Internal Human Capital)*, *External Resources (External Commercial Officer Resources*, *External Human Capital, External Technological Resources* and *External Commercial IP Resrouces*) and *NPD Collaboration Capability. Process Innovation Outcome* was regressed in Model 6 onto *PAET*, over and above the control and independent variables included in Model 5. Model 5 tests the effect of 9 predictor variables on 110 cases, while Model 6 shows the effect of 10 predictor variables. These regression models utilise 12 cases per predictor (Model 5) to 11 cases per predictor (Model 6), thereby satisfying Field's (2005) guidelines of minimum of 5-10 cases per predictor for reliable regression results.

Variables	Dependent Variable: Product Innovation Outcome (N=153)						Dependent Variable: Process Innovation Outcome (N=110)					
	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	b	SE	b	SE	B	SE	b	SE	b	SE	b	SE
(Constant)	1.91	0.98	1.85	0.96	1.24	1.01	3.06	1.61	0.73	1.70	1.13	1.72
Spin off	-0.01	0.12	0.08	0.11	0.07	0.11	-0.10	0.17	0.03	0.17	0.04	0.17
Firm Size log employment	-0.37**	0.14	-0.39**	0.14	-0.40**	0.13	0.20	0.18	-0.04	0.19	-0.02	0.19
Firm Size log FAI	0.39*	0.18	0.42*	0.18	0.50*	0.18	-0.04	0.29	0.41	0.31	0.35	0.31
Age squared	0.00*	0.00	0.00†	0.00	0.00†	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Market Barrier	0.07	0.11	0.11	0.10	0.07	0.10	-0.02	0.16	-0.05	0.16	0.00	0.16
Technology Barrier	-0.11	0.11	-0.18†	0.10	-0.16	0.10	0.06	0.15	0.10	0.15	0.08	0.15
Internal Tech Res			-0.03	0.08	-0.05	0.08			-0.18	0.14	-0.15	0.14
Internal Human Capital			0.02	0.08	0.03	0.08			-0.03	0.13	-0.02	0.13
NPD Absorp Cap			-0.11	0.11	-0.09	0.08			0.08	0.17	0.04	0.17
NPD Comm Cap			0.29*	0.12	0.28*	0.10			0.11	0.18	0.13	0.18
NPD Collab Prob-solv			-0.23	0.16	-0.19	0.12			0.01	0.25	0.00	0.25
Ext Comm Officer Res			0.37**	0.08	0.40**	0.16			0.18	0.12	0.15	0.13
Ext Human Capital			0.11	0.09	0.09	0.08			-0.11	0.16	-0.09	0.16
Ext Tech Res									0.29*	0.11	0.29*	0.11
Ext Comm IP Res									0.05	0.10	0.04	0.10
PAET					-0.17†	0.09					0.18	0.13
R-Square Change	0.10		0.21		0.02		0.05		0.23		0.01	
Probability	0.02		0.00		0.06		0.45		0.00		0.19	

Table 5-19: Regression Results on Product Innovation Outcome (Models 1 to 3) and Process Innovation Outcome (Models 4 to 6)
Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

In Model 6, *PAET* was found to be statistically non-significant. These findings illustrate that the independent variable, *PAET*, does not significantly affect the hypothesised mediating variable, *Process Innovation Outcome*.

In summary, these results of Step 1 satisfy the first condition of mediating analysis test for *Product Innovation Outcome*, as highlighted in Section 5.4.7.1, which requires the independent variable, *PAET*, to significantly affect the mediating variable, *Product Innovation Outcome*.

5.4.7.3 Regressing Performance on PAET

In the second step, the dependent variable, *Performance*, was regressed on the independent variable, *PAET*. Models 7 to 9 in Table 5-20 illustrate the regression results of the second step of Baron and Kenny's (1986) mediation analysis model. Model 7 presents the baseline models comprising the control variables for *Performance*, while Model 8 considers the effects of *Internal Resources (Internal Commercial CA Resources* and *Internal Commercial IP Resources)* and *NPD Collaboration Capability* variables in explaining the variance in *Performance*. In Model 9, *Performance* was regressed onto *PAET* in addition to the control variables, *Internal Resources*, *External Resources* and *NPD Collaboration Capability*.

Models 8 and 9 demonstrate the effect of five and six predictor variables on 91 cases, utilising 18 and 15 cases per predictor, respectively. These regression models thus satisfy Field's (2005) guidelines of minimum of 5-10 cases per predictor for reliable regression results.

The Model 9 results show that *PAET* was statistically significant ($b = -0.30$, $p < 0.01$), with a R2 increase of 7% at a significance level of $p < 0.01$. These results show that the second condition of mediating analysis test, as detailed in Section 5.4.7.1 (which requires the independent variable, *PAET*, to significantly influence the dependent variable, *Performance*) has been satisfied.

5.4.7.4 Regressing Performance on PAET, Product Innovation Outcome and Process Innovation Outcome

In the third step, the dependent variable, *Performance*, was regressed on both the independent variable, *PAET*, and the mediating variables, *Product Innovation Outcome* and the *Process Innovation Outcome*. Models 10 to 11 in Table 5-20 present the regression results of the third step of Baron and Kenny's (1986) mediation analysis model. In Model 10, *Performance* was regressed onto the control, *PAET, Product Innovation Outcome*, *Internal Resources* and *NPD Collaboration Capability*. Model 11 is the full model that presents the regression results of *Performance* onto *Process Innovation Outcome* in addition to all the variables considered in Model 10.

Models 10 and 11 demonstrate the effect of 7 and 8 predictor variables on 91 cases, utilising 13 and 11 cases per predictor, respectively. These regression models thus satisfy Field's (2005) guidelines of minimum of 5-10 cases per predictor for reliable regression results.

In both models, the *Product Innovation Outcome* is statistically significant ($b = 0.51$, $p < 0.01$ in Model 10; $b = 0.53$, $p < 0.01$ in Model 11). It is worth noting that Model 12 in Table 5-9, which is the full model comprising all the variables (*Internal Resources* and *NPD Collaboration Capability*) and their interactive effects, shows the same results for *Product Innovation Outcome* ($b = 0.51$, $p < 0.01$). In Model 11, *Process Innovation Outcome* was found to be statistically non-significant. These results of the third step therefore satisfy that the third condition of mediating analysis test, as elaborated in Section 5.4.7.1, for the case of *Product Innovation Outcome*, which has significant effect on the dependent variable, *Performance*.

Although *PAET* also has a significant effect on *Performance* in Model 11 of Table 5-20, its regression coefficient is increased to -0.25 ($p < 0.05$) from its initial value of -0.30 ($p < 0.01$) in Model 9. The increase in the magnitude of the unstandardised regression coefficient of *PAET* in Step 3 from its initial value in Step 2 satisfies the fourth condition of mediation analysis for partial mediation effects.

Variables	Dependent Variable: Performance (N=91)									
	Model 7		Model 8		Model 9		Model 10		Model 11	
	b	SE	b	SE	b	SE	b	SE	b	SE
(Constant)	4.48	1.28	4.04	1.56	3.65	1.51	3.58	1.33	3.59	1.34
Spin off	0.27**	0.13	0.29*	0.14	0.22	0.14	0.13	0.12	0.13	0.13
Firm Size log employment	0.13	0.15	0.12	0.18	0.13	0.17	0.29†	0.16	0.29†	0.16
Firm Size log FAI	-0.43†	0.23	-0.36	0.28	-0.33	0.27	-0.34	0.24	-0.34	0.24
Age squared	0.00	0.00	0.00	0.00	0.00*	0.00	0.00	0.00	0.00	0.00
Market Barrier	-0.12	0.13	-0.06	0.15	-0.15	0.15	-0.29*	0.13	-0.30*	0.13
Technology Barrier	-0.02	0.13	-0.08	0.14	-0.03	0.14	0.14	0.13	0.15	0.13
Internal Commercial CA Res			-0.12	0.16	-0.12	0.16	-0.14	0.14	-0.13	0.14
Internal Commercial IP Res			0.16	0.12	0.15	0.11	0.03	0.10	0.02	0.10
NPD Absorp Cap			-0.02	0.12	0.04	0.12	0.18	0.11	0.18	0.11
NPD Comm Cap			0.27	0.19	0.34†	0.18	0.17	0.16	0.17	0.17
NPD Collab Prob-solv			-0.23	0.23	-0.29	0.22	-0.31	0.19	-0.29	0.20
Prod Innov Outcome							0.51**	0.11	0.53**	0.11
Proc Innov Outcome									-0.05	0.09
PAET					-0.30**	0.11	-0.26*	0.10	-0.25*	0.10
R-Square Change	0.13		0.04		0.07		0.18		0.00	
Probability	0.05		0.06		0.01		0.00		0.54	

Table 5-20: Regression Results on Performance (Models 7 to 11)

Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

The results in Tables 5-19 and 5-20 show that all the four conditions of mediation analysis set out in Section 5.4.7.1 are satisfied, thereby supporting Hypothesis 7a in that *Product Innovation Outcome* partially mediates the relationship between *PAET* and commercial adoption *Performance*. Result No 7 is as follows and presented in Figure 5-18.

Result No 7:

- *Product Innovation Outcome partially mediates the relationship between PAET and commercial adoption Performance (H7a partially supported).*
- *Process Innovation Outcome does not mediate the relationship between PAET and commercial adoption Performance (H7b not supported).*

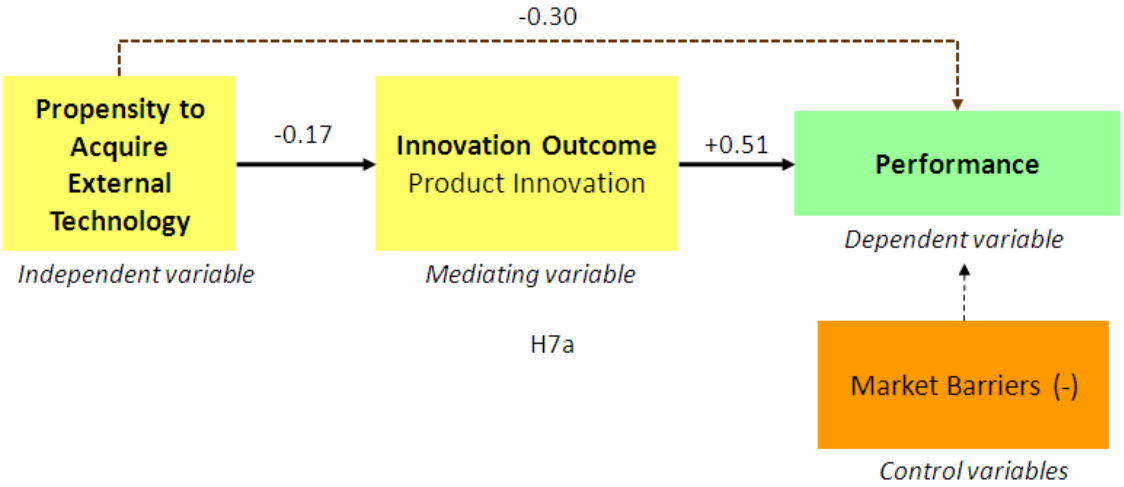

Figure 5-18: Result No 7 – Hypothesis 7 Finding

5.4.8 Summary of Regression Analysis Results for Hypothesis Testing

The above results have provided support for the hypotheses of this study. Table 5-21 presents a summary of the results.

Hypotheses	Finding
H1: Firms that have higher levels of ***Internal Resources*** are likely to have a lower ***PAET.*** • H1a: Firms that have higher levels of ***Internal Commercial CA Resources*** are likely to have a lower ***PAET***. • H1b: Firms that have higher levels of ***Internal Technological Resources*** are likely to have a lower ***PAET***. • H1c: Firms that have higher levels of ***Internal Commercial IP Resources*** are likely to have a lower ***PAET***. • H1d: Firms that have higher levels of ***Internal Human Capital*** are likely to have a lower ***PAET***.	Partially supported by Result No 1: • H1b fully supported • H1a, H1c and H1d not supported
H2: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Innovation Outcome*** have higher levels of ***Internal Resources.*** • H2a: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have higher levels of ***Internal Technological Resources***. • H2b: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have higher levels of ***Internal Human Capital***. • H2c: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have higher levels of ***Internal Technological Resources.*** • H2d: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have higher levels of ***Internal Human Capital***.	Partially supported by Result No 2: • H2a fully supported • H2b to H2d not supported
H3: Among firms that have high levels of ***Innovation Outcome*** with external technologies, those that report better commercial adoption *Performance* have higher levels of ***Internal Resources.*** • H3a: Among firms that have high levels of ***Product Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance*** **(*Product)*** have higher levels of ***Internal Commercial CA Resources.*** • H3b: Among firms that have high levels of ***Product Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance*** **(*Product)*** have higher levels of ***Internal Commercial IP Resources.*** • H3c: Among firms that have high levels of ***Process Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Process)*** have higher levels of ***Internal Commercial CA Resources.***	Partially supported by Result No 3: • H3b, H3d fully supported • H3a and H3c not supported

Hypotheses	Finding
• H3d: Among firms that have high levels of ***Process Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance*** **(*Process)*** have higher levels of ***Internal Commercial IP Resources.***	
H4: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Innovation Outcome*** **have** greater access to ***External Resources***. • H4a: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have greater access to ***External Commercial Officer Resources.*** • H4b: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have greater access to ***External Human Capital***. • H4c: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have greater access to ***External Technological Resources***. • H4d: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have greater access to ***External Commercial IP Resources***. • H4e: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have greater access to ***External Commercial Officer Resources***. • H4f: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have greater access to ***External Human Capital***. • H4g: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have greater access to ***External Technological Resources***. • H4h: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have greater access to ***External Commercial IP Resources***.	Partially supported by Result No 4: • H4a, H4b, H4g, H4h fully supported • H4c-H4f not supported
H5: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Innovation Outcome*** have superior ***NPD Collaboration Capability***. • H5a: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have superior ***NPD Absorptive Capacity.*** • H5b: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have superior ***NPD Communication Capability***. • H5c: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Product Innovation Outcome*** have	Partially supported by Result No 5: • H5b fully supported • H5a, H5c-5f not supported

Hypotheses	Finding
superior ***NPD Collaborative Problem-solving Capability***. • H5d: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have superior ***NPD Absorptive Capacity***. • H5e: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have superior ***NPD Communication Capability***. • H5f: Among firms that have high levels of ***PAET***, the firms that report higher levels of ***Process Innovation Outcome*** have superior ***NPD Collaborative Problem-solving Capability***.	
H6: Among firms that have high levels of ***Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance*** have superior ***NPD Collaboration Capability***. • H6a: Among firms that have high levels of ***Product Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Product)*** have superior ***NPD Absorptive Capacity***. • H6b: Among firms that have high levels of ***Product Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Product)*** have superior ***NPD Communication Capability***. • H6c: Among firms that have high levels of ***Product Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Product)*** have superior ***NPD Collaborative Problem-solving Capability***. • H6d: Among firms that have high levels of ***Process Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Process)*** have superior ***NPD Absorptive Capacity***. • H6e: Among firms that have high levels of ***Process Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Process)*** have superior ***NPD Communication Capability***. • H6f: Among firms that have high levels of ***Process Innovation Outcome*** with external technologies, those that report better commercial adoption ***Performance (Process)*** have superior ***NPD Collaborative Problem-solving Capability***.	Partially supported by Result No 6: • H6a fully supported • H6b to H6f not supported

Hypotheses	Finding
H7: ***Innovation Outcome*** mediates the relationship between ***PAET*** and commercial adoption ***Performance***. • H7a: ***Product Innovation Outcome*** mediates the relationship between ***PAET*** and commercial adoption ***Performance (Product)***. • H7b: ***Process Innovation Outcome*** mediates the relationship between ***PAET*** and commercial adoption ***Performance (Process)***.	Partially supported by Result No 7: • H7a partially supported • H7b not supported

Table 5-21: Summary of Regression Analysis Results for Hypothesis Testing

Based on the regression results of this research, the conceptual model hypothesised in Section 3.2 is updated here with the results provided in this section. Figure 5-19 presents the revised conceptual framework of this empirical study.

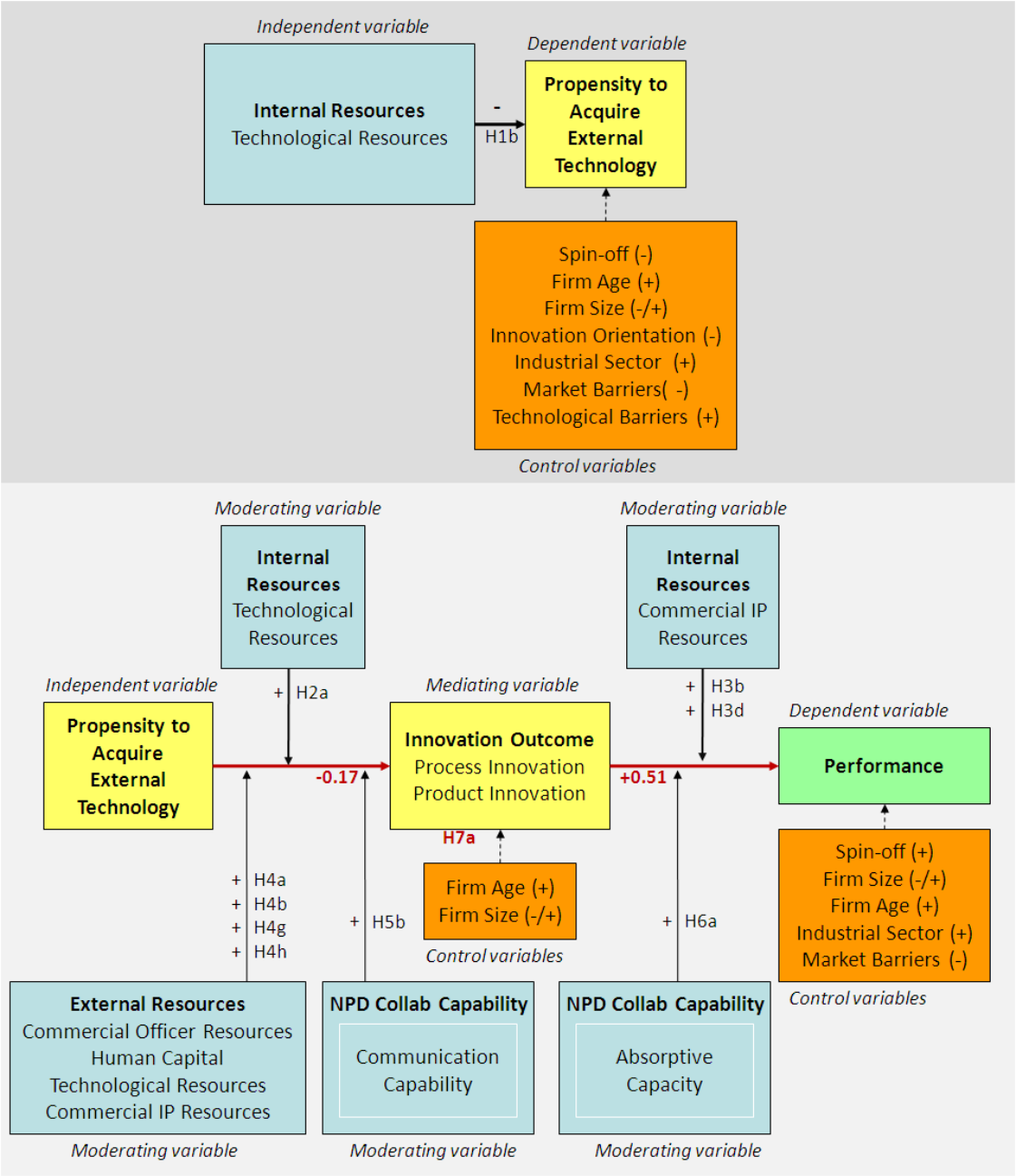

Figure 5-19: Conceptual Framework based on the regression results of this research

The next section provides a discussion of the results.

5.5 Discussion

This section discusses the empirical findings presented in Section 5.4 and focuses on the three research questions that were detailed in Section 3.1.

(a) What are the determinants of a firm's PAET from PRIs?
(b) For firms that acquire external technologies from PRIs, what factors influence their innovation outcome?
(c) For firms that acquire external technologies, what factors influence their commercial adoption performance?

5.5.1 Determinants of firm's PAET from PRIs

The first research question is: What are the determinants of a firm's PAET? Prior studies have focused on a firm's propensity to out-license technologies (Fosfuri, 2006) or to in-license from multi-national organisations (Lopez, 2008). Drawing on RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996), TCE theory (Williamson, 1985) and PFI theory (Teece, 1986), this study identifies and examines the critical factors that determine a firm's propensity to in-license from PRIs. As highlighted in Section 3.2.3, the firms' resources have been categorised by previous studies into four key types that new ventures and existing small businesses would require: technological resources, human capital, commercial resources (complementary assets) and commercial resources (IP appropriability) (Brush et al., 1997, 2001; O'Shea et al., 2005; Mustar et al., 2006). This research builds on their earlier works to define *Internal Resources* as *Human Capital*, *Commercial CA Resources*, *Commercial IP Resources* and *Technological Resources* to test Hypothesis 1 that firms that have higher levels of *Internal Resources* are likely to have a lower *PAET*. Based on the empirical results (Result No 1), this study has established that, among these *Internal Resources*, the firm's *Internal Technological Resources* in terms of its reliance on basic research is a significant determinant of its *PAET* in relation to technology licensing. This means that the higher the level of *Internal Technological Resources* that a firm has access to, the lower will be its *PAET*. Conversely, the lower the availability of *Internal Technological Resources* that a firm has, the higher will be its *PAET*.

This finding is corroborated by the study of Cassiman and Veugelers (2006, p. 68) who found that a firm's 'reliance on basic R&D – the importance of universities and research centres as an information source for the innovation process' has significant effect on the

'complementarity between internal and external innovation activities', as detailed in Section 2.4.1. Result No 1 is also supported by the findings of Atuahene-Gima (1993) that the firm's internal R&D was likely to negatively affect its decision to in-license technology. In addition, the empirical results of this study reveal that the firms in the information and communication, as well as biomedical industries also have a greater *PAET*. This increased tendency for external technology licensing by the firms in these high-technology industries could be attributed to the technological challenges of the industries. The fast pace of technological changes and the threat of competing technologies are some of the significant risks inherent in the high-technology industries, and external technology acquisition is increasingly being adopted as one of the firm's strategic response options of open innovation to mitigate the risks and shorten its time-to-market to remain competitive (Chesbrough, 2007b; Pavitt, 1984; Vanhaverbeke, 2012).

As for the other *Internal Resources* variables, namely, *Commercial CA Resources*, *Human Capital* and *Commercial IP Resources*, this study has found that they correlate significantly and positively with *PAET*. However, the binary logistic regression results show that, in comparison to *Internal Technological Resources*, they are non-significant predictors of *PAET*. Although prior studies have found these dimensions significant, their focus was primarily on determining their effect on the performance of firms, such as human capital on wealth of new ventures (Deeds et al., 1998) or on firm performance (Hemmert, 2004), and commercial resources on firm's performance (Teece, 2006; Cassiman and Veugelers, 2006). This research, by contrast, focuses on the effect of the firm's *Internal Resources* on its *PAET* from PRIs rather than on its *Performance* per se. Unlike prior studies, this study yields significant findings that show variation in the relative importance of the four *Internal Resources* dimensions, with the *Internal Technological Resources* showing statistical significance in determining the firm's *PAET*. The distinct finding of *Internal Technological Resources* over the other *Internal Resources* (such as *Commercial CA Resources*, *Human Capital* and *Commercial IP Resources*) as a predictor of a firm's *PAET* from PRIs is a significant contribution to the literature on commercialising research by PRI.

5.5.2 Innovation outcome of firms that decide to acquire external technologies from PRIs

The second research question is: For firms that acquire external technologies from PRIs, what factors influence their innovation outcome? In this study, a firm's *Innovation Outcome* measures whether the firm has embodied externally licensed technology from PRIs into any of its products or processes. Previous studies have analysed the impact of licensing foreign rather than publicly-funded technology on the innovation outcome of the firms in Chile (Lopez, 2008) and Japan (Kiyota and Okazaki, 2005). Other studies have analysed both firms and research institutes as external sources of technologies, whose availability and quality are pivotal for the innovation outcome of the importing firms (Hemmert, 2004). This research question draws attention to PRIs as sources of external knowledge and part of NIS (Etzkowitz et al., 2005), representing the academic sphere of Triple Helix (Leydesdorff and Etzkowitz, 1998). Building on the theoretical frameworks of RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996) and TCE (Williamson, 1985), as well as the perspectives of PFI (Teece, 1986), absorptive capacity (Cohen and Levinthal, 1990) and Dynamic Capabilities (Teece et al., 1997) theories, this study has examined the significance of three groups of factors with the testing of Hypotheses 2, 4 and 5 in explaining why some licensee firms are more successful than others in applying this external knowledge to develop product or process innovation, as detailed in Section 3.2:

1) *Internal Resources* comprising *Technological resources* and *Human Capital.* (Hypothesis 2)
2) *External Resources* consisting of *Human Capital, Commercial Officer Resources, Commercial IP resources* and *Technological Resources* (Hypothesis 4)
3) *NPD Collaboration Capability* made up of *Absorptive Capacity, Communication Capability* and *Collaborative Problem-solving* (Hypothesis 5)

Internal Resources, PAET and Innovation Outcome

The findings of this study (Result No 2) address Hypothesis 2 on the effect of *Internal Resources:* among firms that have high levels of *PAET*, those that report higher levels of

Innovation Outcome have greater availability of *Internal Resources*. Result No 2 confirms the significance of the moderating effect of the *Internal Technological Resources* over the other *Internal Resources* variable on the linkage between *PAET* and *Product Innovation Outcome,* providing support for Hypothesis 2a. This indicates that having greater availability of *Internal Technological Resources* has put the firms in a better position to embody the external technologies that they have licensed from PRIs into their existing or new products and achieve higher *Product Innovation Outcome*. This empirical result supports the claims by Pavitt (1984) that it is the internal R&D capabilities of the large firms that enable them to manage and internalise changes in technological life cycle (Rothwell, 1992).

On the other hand, the *Internal Technological Resources* was found to be non-significant in moderating the relationship between *PAET* and *Process Innovation Outcome*. Interestingly, *Process Innovation Outcome* was found to have a significant positive bivariate correlation with *PAET* ($r = 0.31$; $p < 0.01$) but a negative bivariate correlation with *Internal Technological Resources* ($r = -0.39$; $p < 0.01$). This could possibly be attributed to the fact that firms that have low levels of *Internal Technological Resources* may tend to have high levels of *PAET* to source for external IP that are more related to *Process Innovation Outcome*, rather than *Product Innovation Outcome*. This is consistent with Pavitt's (1984, p. 366) finding that there is a stronger positive association between 'patent intensity' as a form of internal technological resources and 'product innovation' particularly among smaller firms than that between 'patent intensity' and 'process innovation' among larger 'production-intensive' firms, as the latter firms have to commit relatively higher proportion of internal resources other than commercial IP resources to 'process innovation' such as production plant and equipment.

As for the other *Internal Resources* dimension, namely, *Human Capital,* it was shown in this study to have significant positive bivariate correlation with *Product Innovation Outcome* ($r = 0.20$; $p < 0.10$) and with *Process Innovation Outcome* ($r = 0.22$; $p < 0.05$). This observation is supported by extant studies that establish its significant role as independent variable. Deeds et al. (1998) and Hemmert (2004) found a significant

positive correlation between *Human Capital* as part of internal firm resources and firm performance.

External Resources, PAET and Innovation Outcome

With regard to the *External Resources*, Hypothesis 4 predicted that: among firms that have high levels of *PAET*, those that report higher levels of *Innovation Outcome* have greater access to *External Resources*. This study (Result No 4) validates Hypothesis 4a that the *External Commercial Officer Resources* play a significant role in positively moderating the relationship between *PAET* and *Product Innovation Outcome*. The skills and availability of technology commercialisation officer from technology transfer office (TTO) are found to be critical in facilitating the transfer of knowledge and technology from PRIs to the firms that decided to acquire the external technologies. Apart from having a good understanding of the potential commercial applications of the licensed technologies, TTO commercialisation officers are required to have knowledge of both competing and complementary technologies and patents, as well as experience in market evaluation. In addition, the TTO commercialisation officers are likely to encourage close linkages between firms and inventors of PRIs to enhance the firms' understanding and assimilation of the licensed technologies. This study confirms that firms that have greater access to these *External Commercial Officer Resources* are more likely to report higher levels of *Product Innovation Outcome*.

This finding is consistent with the study of O'Shea et al. (2005, p. 1003) who reported the significance of commercial officer resource on the number of university spin-offs. As for *Process Innovation Outcome*, it is worth noting that the interactive effect between *External Commercial Officer Resources* and *PAET* has a significant but negative effect on *Process Innovation Outcome*, although each of these two variables has a positive bivariate correlation with *Process Innovation Outcome*. A possible explanation for the positive significant correlation between *PAET* and *Process Innovation Outcome* could be that firms having a high level of *Process Innovation Outcome* tend to have high level of *PAET* in terms of having prior licensing experience (Atuahene-Gima, 1993; Crawford, 1985; Kim, 1988). Similarly, firms having greater access to *External Officer Commercial*

Resources tend to report higher levels of *Process Innovation Outcome* (O'Shea et al., 2005).

As for the negative *PAET-External Commercial Officer Resources* interactive effect on *Process Innovation Outcome*, it could be interpreted that among the cases of firms having high level of *PAET* and high level of *Process Innovation Outcome*, there could be a significant number of cases where the firms having prior licensing experience have a higher expectation of the availability and quality of the *External Commercial Officer Resources* for the *Process* type of I*nnovation Outcome,* as distinct from *Product Innovation Outcome*. This higher expectation of *External Commercial Resources* may be reflected in their relatively lower rating, hence contributing to the negative interactive effect between *PAET* and *External Officer Commercial Resources* on *Process Innovation Outcome*, in contrast to their positive interactive effect on the *Product* kind of *Innovation Outcome.* The difference in the significance of various *Resources* input between *Product* and *Process Innovation Outcome* has been highlighted in other studies, such as Hall et al. (2009), whose research of Italian SME found that the availability of equipment resources contributed significantly to process innovation but not to product innovation.

The *External Human Capital* dimension is also found to be significant as a moderating variable in positively moderating the relationship between *PAET* and *Product Innovation Outcome* in this study*,* thereby validating Hypothesis 4b. Although *External Human Capital* is not a significant moderating variable compared to other *External Resources* variables (*External Commercial IP Resources* and *External Technological Resources*) in the case of *Process Innovation Outcome*, it has significant positive bivariate relationship with *Process Innovation Outcome* ($r = 0.21$; $p < 0.05$). These results show that *External Human Capital* is significant for both *Product* and *Process Innovation Outcome,* whether as an independent or a moderating variable. This finding of the important role of human capital is consistent with the earlier works by O'Shea et al. (2005) and Powers and McDougall (2005), who found significant positive influence of faculty quality on university spin-off activity by providing critical knowledge to pursue radical innovations required for technology commercial adoption.

The results of this study (Result No 4) indicate that the *External Commercial IP Resources* are significant in positively moderating the interaction between *PAET* and *Process Innovation Outcome*, providing support for Hypothesis 4h. The *External Commercial IP Resources* refers to the firm's effectiveness of IP protection, as detailed in Section 3.2.5. Although Cassiman and Veugelers (2006) found only marginal significance of this construct on the innovation activities of complementing internal and external technologies, TCE asserts that appropriability of IP could impact the firm's incentives to engage in transaction of external technology acquisition (Mayer and Salomon, 2006). The IP protection regime has been found to be a significant determinant of the prioritisation of innovative activities (Teece, 1986). If the IP appropriability is strong, firms will prefer acquisition of external technology to in-house development; however, when the appropriability is weak, firms will prefer internal development to inward technology licensing (Cassiman and Veugelers, 2006). This study confirms that firms that have stronger IP appropriability (*External Commercial IP Resources*) are more likely to report higher levels of *Process Innovation Outcome*. This finding therefore supports the IP appropriability aspect of the TCE Theory (Williamson, 1985).

As for *External Technological Resources*, Result No 4 validated Hypothesis 4g: among firms that acquired external technologies from PRIs, those that report higher levels of *Process Innovation Outcome* are found to have access to external technologies of higher readiness level. This study establishes that the readiness of the external technology licensed from PRIs (*External Technological Resources*) has a significant moderating impact on the interaction between *PAET* and *Process Innovation Outcome*. The higher was the readiness level of the external technology, the less cost the firm incurred in developing the external technology to suitable industry standards for integration into its existing innovation processes. This would reduce the risk of integration failure, which, in turn, would influence positively their *Process Innovation Outcome*. This characteristic of technology readiness level was highlighted by Markman et al. (2009) as a factor that a TTO should consider in their commercialisation strategy to license technologies developed by universities to the industry.

Although both *External Commercial IP Resources* and *External Technological Resources* are found to be non-significant in moderating the linkage between *PAET* and *Product Innovation Outcome*, unlike the case of *Process Innovation Outcome*, these two *External Resources* variables have significant bivariate relationships with *Product Innovation Outcome* ($r = 0.11$, $p < 0.10$ for *External Commercial IP Resources*; $r = 0.19$, $p < 0.05$ for *External Technological Resources*), as supported by prior studies on the significance of building IP management and expertise among SMEs (Hang and Ng, 2004; Lee et al., 2010; Vanhaverbeke, 2012).

NPD Communication Capability, PAET and Innovation Outcome

Hypothesis 5 postulated that: among firms that high levels of *PAET*, those that report higher levels of *Innovation Outcome* have superior *NPD Collaboration Capability*. This study (Result No 5) indicates that *NPD Communication Capability* significantly moderated the relationship between the *PAET* and *Product Innovation Outcome*, thus supporting Hypothesis 5b. The construct of *NPD Communication Capability* refers to the firm's ability to exchange relevant, accurate and sufficient information in a timely fashion with another organisation in collaborative NPD. To effectively transfer the licensed technology and knowledge from PRIs to the firms, it is important to have open, timely and accurate exchange of information between the two organisations. Such interaction fosters a climate of a high level of trust between firms and PRIs (Ring and van de Ven, 1994). According to Bstieler (2006), such a climate of trust can positively influence inter-firm NPD. The significance of the *NPD Communication Capability* as a moderating variable found in this study is corroborated by the research of Bstieler (2006, p. 67), who found the positive impact of communication on trust formation, which, in turn, influenced positively 'partnership satisfaction, intentions for partnership continuity, financial performance of the product in the market, and time efficiency'.

NPD Absorptive Capacity, on the other hand, is found to have significant negative effect both as an independent variable and a moderating variable (in interacting with *PAET*) on *Product Innovation Outcome*. By contrast, both *NPD Absorptive Capacity* and *PAET* have no such negative effect on *Process Innovation Outcome*. In fact, *PAET* has a

positively significant effect on *Process Innovation Outcome*. Our interpretation of this finding is that firms that have high levels of *PAET* in terms of prior licensing experience tend to license technologies from PRIs under study for *Process Innovation Outcome* rather than *Product Innovation Outcome*. This could account for the positive association between *PAET* and *Process Innovation Outcome* and the negative association between *PAET* and *Product Innovation Outcome*. For firms that license the technologies for product innovation, it is observed that those that achieve high levels of *Product Innovation Outcome* tend to have a significantly smaller *Firm Size* (in terms of employment) and hence lower level of *NPD Absorptive Capacit*y (in terms of established internal organisational processes for assimilating and exploiting knowledge from PRIs into new products). The positive association between *Firm Size* and *Absorptive Capacity* is supported by Agrawal's (2006) study, which established that firms that are bigger in terms of employment have more resources to develop and take advantage of absorptive capacity. In understanding the apparent tendency for smaller firms to go for product innovation rather than process innovation, it is useful to refer to Hall et al.'s (2009) study findings that the amount of capital investment required for process innovation and its resulting impact was more significant compared to product innovation. In other words, in view of the difference in investment required, it is likely that firms of larger size tend to target process innovation, while firms of smaller size may be more likely to embark on product innovation projects. This finding is corroborated by Pavitt's (1984) observation of differences in the relationships that each innovation type (product innovation versus process innovation) has with the firm size and the industrial sector in which the firm operates.

As for *NPD Collaborative Problem-solving Capability,* it was found to have significant positive effect on both *Product* and *Process Innovation Outcomes*. This finding is consistent with the study of Li et al. (2007, p. 202), who found a statistically significant positive relationship between 'collaborative problem solving' and 'new product performance'.

5.5.3 Commercial adoption performance of firms that acquire external technologies from PRIs

The third research question is: For firms that acquire external technologies, what factors influence their commercial adoption performance? To address this research question, Hypotheses 3 and 6 were developed to predict how *Internal Resources* and *NPD Collaboration Capability* moderate respectively the relationship between *Innovative Outcome* and commercial adoption *Performance*, while Hypothesis 7 examines the mediating role of *Innovation Outcome* between *PAET* and *Performance*. In this study, commercial adoption *Performance* refers to the sales related to the exploitation of the technology that the firm licensed from PRIs. It comprises three items measured as: (a) the percentage of total actual sales that consist of new or improved products embodying the licensed technology in latest fiscal year, (b) the percentage of total actual production volume that consist of new or improved processes from the licensed technology in the latest fiscal year, and (c) the projected annual growth rate in percentage of sales revenue of the product(s) embodying the licensed technology in the next three years. Integrating the theoretical frameworks of RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996), TCE (Williamson, 1985), absorptive capacity (Cohen and Levinthal, 1990) and the CDM (Crépon et al., 1998), this study has examined the significance of the following factors highlighted in Section 5.3 to explain why some firms that introduce *Innovation Outcome* are more successful than are others in commercial adoption *Performance*:

1) *Internal Resources* comprising *Commercial CA Resources and Commercial IP Resources*.
2) *NPD Collaboration Capability* made up of *Absorptive Capacity*, *Communication Capability* and *Collaborative Problem-solving*.
3) *Innovation Outcome* consisting of *Product Innovation Outcome, Process Innovation Outcome*
4) *PAET* (Propensity to Acquire External Technology)

Internal Resources, Innovation Outcome and Performance

The findings of this study (Result No 3) support Hypothesis 3b and 3d which postulated that: among firms that have high levels of *Product/Process Innovation Outcome* with external technologies, those that report better commercial adoption *Performance* have higher levels of *Internal Commercial IP Resources.* Result No 3 confirms the significance of the moderating effect of *Internal Commercial IP Resources* on the linkage between *Product/Process Innovation Outcome* and commercial adoption *Performance*. This indicates that among the firms that achieve higher levels of *Product/Process Innovation Outcome*, those that have effective mechanisms in protecting their IP are more likely to report higher commercial adoption *Performance*. The firms that have effective ways of protecting their innovation activities and their outcomes by such means as secrecy or economies of scale are in a better position to sustain their competitive advantage to exploit their innovation to achieve higher commercial adoption *Performance*. This empirical result supports the study of Belgian manufacturing firms by Cassiman and Veugelers (2006) who asserted the significant impact of strategic protection effectiveness on the propensity of a firm to perform internal R&D.

Internal Commercial CA Resources has a non-significant moderating effect on the relationship between *Product Innovation Outcome* and *Performance.* On the other hand, *Internal Commercial CA Resources* has a negative moderating effect on the relationship between *Process innovation and Performance*. Given that the *Spin-off* control variable was statistically significant, it is likely that the spin-off cases which reported unusually high growth in commercial *Performance* from a low initial sales volume were more likely to have given a lower rating for their availability of internal complementary resources as start-ups (low rating of *Internal Commercial CA Resources*). After controlling for *Spin-off* effect, the results show that the *Internal Commercial CA Resources* do not have a significant negative moderating impact on the *Process Innovation Outcome-Performance* relation.

NPD Collaboration Capability, Innovation Outcome and Performance

Hypothesis 6 posited that: among firms that have high levels of *Innovation Outcome* with external technologies, those that report better commercial adoption *Performance* have superior *NPD Collaboration Capability*. This study (Result No 6) indicates that the *Absorptive Capacity* dimension of *NPD Collaboration Capability* significantly moderates the relationship between *Performance* and *Product Innovation Outcome*, supporting Hypothesis 6a. This research utilises Cohen and Levinthal's (1990, p. 128) definition of absorptive capacity as 'the firm's ability to recognise the value of new, external information, assimilate it, and apply it to commercial ends'. The findings of this study confirm that the greater the firm's *Absorptive Capacity*, the greater its ability to identify the value of new external knowledge, assimilate and exploit it commercially. This, in turn, positively affects the likelihood of its translation of high levels of *Product Innovation Outcome* into better commercial adoption *Performance*. This finding is corroborated by Ettlie and Pavlou (2006), who found significant positive association between absorptive capacity and inter-firm NPD partnership capabilities, which in turn correlated significantly with NPD performance.

This study produced mixed results with regard to the *NPD Communication Capability*. For example, this factor was found to have a positive direct impact on *Performance*, as consistent with the observation of Bstieler (2006), who established the significant role of communication capability as antecedent to trust formation, which then positively affected firm performance. On the other hand, this study found that the *NPD Communication Capability* had a negative moderating effect with *Process Innovation Outcome* on *Performance*. The negative moderating effect was found to be linked to the spin-off cases which tend to report unusually higher growth rates (*Performance*) and lower level of communication activities with the researchers of PRIs for knowledge transfer (*NPD Communication Capability)* than non-spin-offs. The higher level of *Performance* could be attributed to the low sales base in the initial stage of a spin-off. The low level of *NPD Communication Capability* could be due to the founders' familiarity with the technologies they had previously developed as former PRI inventors and subsequently licensed from the PRI for commercial adoption. After controlling for the *Spin-off* effect,

this study established that the *NPD Communication Capability* was non-significant as a moderating variable for existing firms.

PAET, Innovation Outcome and Performance

Hypothesis 7 predicted that: *Innovation Outcome* mediates the relationship between *PAET* and commercial adoption *Performance*. The results of this study (Result No 7) show that the following four conditions of mediation analysis were satisfied:

1) The independent variable, *PAET*, significantly affected the mediating variable, *Product Innovation Outcome;*
2) The independent variable, *PAET*, significantly affected the dependent variable, *Performance;*
3) The mediating variable, *Product Innovation Outcome*, significantly affected the dependent variable, *Performance;*
4) The effect of independent variable, *PAET*, on the dependent variable, *Performance*, decreased in magnitude when it was regressed simultaneously with the mediating variable, *Product Innovation Outcome*.

Result No 7 confirmed that the *Product Innovation Outcome* mediates the relationship between the *PAET* and commercial adoption *Performance*, while *Process Innovation Outcome* does not, thereby showing partial support for Hypothesis 7a. This means that the effect of the firm's *PAET* on its *Performance* has been transmitted by its *Product Innovation Outcome*. This finding is consistent with the CDM model that has been developed by the integration of knowledge production function and Cobb-Douglas production function to establish the mediating role of innovation output (in the form of product and process innovation) between innovation input and performance (in the form of productivity) (Crépon et al., 1998). It is also supported by prior studies (Parisi et al., 2006; Hall et al., 2009) built on the CDM model.

5.6 Conclusion

This chapter has presented an overview of the respondents' profile and data analysis procedure. To ensure that the data collected were reliable in terms of consistency and

stability, Cronbach's alpha coefficients were computed for the independent, moderating and mediating variables to measure inter-item consistency reliability. In addition, the descriptive statistics were used in the initial data analysis to describe the sample and to check for data errors such as missing or invalid data. The frequency distributions, measures of central tendencies and dispersions provided useful descriptions of the licensee samples in terms of the classification variables, such as industrial sector, innovation orientation, size, or age. In addition to the descriptive statistics, inferential statistics were also generated for the study's variables (Tharenou et al., 2007). This chapter also presented the regression analysis results on the independent, control, moderating, mediating and dependent variables to validate the seven hypotheses, as summarised in Table 5-21.

The binary logistic regression of *PAET* was performed and its results validated for Hypothesis 1, which states that firms that have higher levels of *Internal Resources* were hypothesised to be more likely to have a lower *PAET*. The first finding, Result No 1, was discussed:

Result No 1: Firms that have higher levels of Internal Technological Resources are likely to have a lower PAET. Conversely, firms that have lower levels of Internal Technological Resources are likely to have a higher PAET.

The moderated hierarchical regression analysis was conducted (Lindley and Walker, 1993; Aguinis, 1995) to test the moderation effect of the *Internal Resources*, *External Resources* and *NPD Collaboration Capability* on the relationship between *PAET* and the *Innovation Outcome*, as hypothesised in Hypotheses 2, 4 and 5, respectively. The following Results No 2, 4 and 5 were presented:

Result No 2: Among firms that have high levels of PAET, those that report higher levels of Product Innovation Outcome have higher levels of Internal Technological Resources.

Result No 4: Among firms that have high levels of PAET, those that report higher levels of Product Innovation Outcome have greater access to External Commercial Officer Resources and External Human Capital. Among firms that have high levels of PAET, those that report higher levels of Process Innovation Outcome have greater access to External Technological Resources and External Commercial IP Resources.

Result No 5: Among firms that have high levels of PAET, those that report higher levels of Product Innovation Outcome have superior NPD Communication Capability.

The same moderated hierarchical regression analysis was repeated to assess the moderation effect of the *Internal Resources* and *NPD Collaboration Capability* on the relationship between the *Innovation Outcome* and the commercial adoption *Performance*. The findings, Result No 3 and Result No 6, confirmed Hypotheses 3 and 6, respectively.

Result No 3: Among firms that have high levels of Product/Process Innovation Outcome with external technologies, those that report better commercial adoption Performance have higher levels of Internal Commercial IP Resources.

Result No 6: Among firms that have high levels of Product Innovation Outcome with external technologies, those that report better commercial adoption Performance have superior NPD Absorptive Capacity.

Finally, mediation analysis was performed using hierarchical regression of *Performance* on *PAET* and *Innovation Outcome* and Result No 7 confirmed Hypothesis 7.

Result No 7: Product Innovation Outcome mediates the relationship between PAET and commercial adoption Performance.

This chapter ended with a detailed discussion of the above seven empirical findings in response to each of the three research questions that were defined and elaborated upon in Section 3.1.

The next chapter presents the conclusions of this study with a summary of this research, highlighting the contributions and implications of the study, together with its limitations and suggestion of directions for future research.

6 Conclusions, Contributions and Implications

6.1 Introduction

This research aims to answer three key research questions: (a) What are the determinants affecting firms' propensity to license technologies developed by PRIs? (b) For firms that acquire external technologies from PRIs, what factors influence their innovation outcome? (c) For firms that acquire external technologies, what factors influence their commercial adoption performance? This study defined these research questions based on a rigorous review of the theoretical frameworks and prior empirical studies in the relevant literatures (Cavana et al., 2001) to identify gaps and possible areas of contribution.

Commencing with the literature on NIS, national innovative capacity and Triple Helix using the frameworks of endogenous growth theories, cluster theory, evolutionary and coevolutionary theories, this study shows that there is a lack of rigorous empirical research on examination of the linkage between NIS and firm innovation system (Yam et al., 2011). There is also a scarcity of studies on how firms as important actors in the systems were impacted by the other actors and related components of the innovation systems and the innovation process (Yam et al., 2011; Herrmann and Peine, 2011; Leydesdorff and Zawdie, 2010). Next, the examination of the literature on the knowledge production and its various linear and non-linear models shows a lack of dimensions on organisational learning, inter-organisational collaboration specifically in the form of external technology acquisition (van Gils et al., 2009), access to complementary assets and open innovation. A subsequent review of the literature on university-industry collaboration with reference to the theoretical perspectives of RBT (Wernerfelt, 1984; Barney, 1991) and KBT (Grant, 1996) shows a tendency to focus on new ventures based on university research rather than on existing firms that license technologies from PRIs. Finally, the literatures on external technology acquisition, firm-level open innovation, NPD and performance that frequently allude to theories of TCE (Williamson, 1985), PFI (Teece, 1986), absorptive capacity (Cohen and Levinthal, 1991) and dynamic capabilities

(Teece et al., 1997) tend to focus on the commercialisation of internal R&D or external technology acquisition from foreign firms or local large firms, rather than from publicly-funded research organisations.

A comprehensive review of the above literature revealed similar gaps in empirical research on the propensity of firms to acquire indigenous technologies from public-sector research centres and the innovation performance of these firms, possibly due to a lack of available data on such firms across a range of industries. To address these gaps, the objectives of this research were formulated and research questions framed to examine how internal R&D, among other internal resources would influence its propensity to acquire technology from PRIs. In addition, this study investigated how internal resources, external resources and NPD collaboration capability moderated the relationship between a firm's PAET and its innovative outcomes, as well as innovation performance, drawing upon RBT (Wernerfelt, 1984; Barney, 1991) and KBT (Grant, 1996). This study also integrated the literature of NIS, triple helix, knowledge production, commercial adoption of research by PRI, external technology acquisition, open innovation, NPD and dynamic capabilities underpinned by the theories of absorptive capacity (Cohen and Levinthal, 1990) and TCE (Williamson, 1985) to scrutinise how the firm's dynamic capabilities and internal resources could moderate the relationship between its innovative outcome and performance. From the review of the existing literature and theoretical frameworks, this study built on the multiple theoretical lenses of RBT, TCE, absorptive capacity and NPD to develop a conceptual model and generate seven hypotheses, as discussed in Section 3.2.

This research adopted a quantitative research methodology to test the hypotheses and validate the conceptual model. A survey was conducted from July to November 2010 on firms from a wide range of industries that had signed a total of 300 licensing agreements with the largest technology transfer office (TTO) representing the 14 PRIs of Singapore during the period from 2002 to 2009. In this study, the licensing agreements were the units of analysis in non-contrived settings. Based on the data collected from 250 complete and usable responses, this study analysed the profile of the respondents and the reliability and validity of the measures and data, using the Cronbach's alpha coefficients, descriptive and inferential statistics (Cavana et al., 2001).

This study went on to perform regression analysis on the control, independent, moderating, mediating and dependent variables and found significance for the seven hypotheses. The regression results were presented in Section 5.4 and the detailed discussion in Section 5.5.

Highlighting the contributions of this study, this final chapter summarises the findings for each hypothesis, forms conclusions about the research problem, discusses implications for theory, policy and practice, outlines the limitations, and suggests directions for future research.

6.2 Conclusion about the Research Problem and Key Contributions

Considering the results of this study, this section provides a conclusion about the research problem and highlights the key contributions of this study.

First, this research has helped to identify the determinants and their relative importance of affecting a firm's propensity to license technologies developed by PRIs. Among the various internal commercial, human and technological resources that the firm had typical access to, technological resources were found to be the most significant in influencing the firm's propensity to acquire external technologies from PRIs. This finding is supported by the results of Atuahene-Gima (1993) and Cassiman and Veugelers (2006), and has important implications for PRIs and TTOs, which are motivated to enhance the firms' propensity to license research by PRIs as part of their increasingly important role as external centres of knowledge forming part of the NIS to promote economic development (Mowery and Sampat, 2005a; Sharin, 2006; Lundvall, 2007).

Contribution 1: *The distinct finding of Internal Technological Resources over the other Internal Resources (such as Commercial CA Resources, Human Capital and Commercial IP Resources) as a predictor of a firm's PAET from PRIs is a significant contribution to the literature on commercialising research by PRI.*

Second, the empirical results of this study reveal that the firms in the information communication and biomedical industries also have a greater PAET. This increased tendency for external technology licensing by the firms in these high-technology industries could be attributed to the technological challenges of the industries. The fast pace of technological changes and the threat of competing technologies are some of the significant risks inherent in the high-technology industries, and external technology acquisition is increasingly being adopted as one of the firm's strategic response options of open innovation to mitigate the risks and shorten its time-to-market to remain competitive (Chesbrough, 2007b; Vanhaverbeke, 2012).

Contribution 2: *Firms in the information and communication, as well as biomedical industries have a greater PAET than firms in other industries.*

Third, the effect of external resources on PAET is not considered in the extant literature reviewed in Section 2.4 on external technology acquisition, particularly from PRIs. By contrast, this research points to the significance of this factor, specifically in how the external commercial officer resources and external technological resources (technology readiness level) positively influence the firm's propensity to license external research by PRI. This means that the higher the availability and quality of the technology commercialisation officer from the TTO representing PRIs, the higher will be the tendency of the firm to license the technology from PRIs. In a similar vein, the higher the readiness level of the external technology developed by PRIs, the greater will be the firm's propensity to license the technologies. The higher is the readiness level of the external technology, the less cost the firm will need to incur in developing the external technology to meet suitable industry standards for integration into its existing innovation processes. This is because having higher technological readiness level would reduce the risk of integration failure, which, in turn, would influence positively the licensees' process innovation outcome. This characteristic of technology readiness level was highlighted by Markman et al. (2009) as a factor that the TTO should consider in their commercialisation strategy to license the technologies developed by universities to the industry.

Contribution 3: *The distinct finding of the importance of External Technological Resources and External Commercial Officer Resources over the other External Resources (such as External Human Capital and External Commercial IP Resources) as predictors of a firm's PAET from PRIs is a significant contribution to the literature on commercialising research by PRI.*

Fourth, this research adapts the CDM model that was developed by the integration of knowledge production function and Cobb-Douglas production function to establish the mediating role of innovation output or outcome (in the form of product and process innovation) between innovation input and firm performance (Crépon et al., 1998). This study replaced the original measure of performance in the form of productivity by the new measure of projected and actual sales of products, as well as actual production volume of processes embodying the licensed technologies from the research institutes. This research establishes that innovation outcome is the mediating variable between PAET and commercial adoption performance, implying that there are two key relationships that are related and pivotal to ensure the successful execution from the stage of deciding on adopting an innovation to the stage of profiting from innovation. The first relationship describes the link between propensity to license external technologies and innovation outcome, while the second relationship depicts the connection between the innovation outcome and firm performance. The establishment of this mediating relationship has important implications for the research institutes, governments and the industry in understanding the resources and capabilities that are critical in strengthening the two key relationships.

Contribution 4: *Product Innovation Outcome mediates the relationship between PAET and commercial adoption Performance.*

Fifth, in the first relationship which describes the link between propensity to license external technologies and innovation outcome, this research shows that internal technological resources are significant moderating variables that interact positively with the PAET, rather than independent variables, to increase the level of innovation outcome. In other words, instead of using internal technological resources as a traditional

independent variable to test for its effect on innovation outcome (in a manner frequently found in the current literature), this study examined a different role for this variable and confirmed its significance as a moderating variable in this first relationship. On the other hand, the internal human capital is found to be significant antecedent to Innovation Outcome, consistent with the prior studies by Deeds et al. (1998) and Hemmert (2004).

Contribution 5: *Unlike previous research, this study established the relative importance of Internal Technological Resources over and above the other Internal Resources (Human Capital) in explaining the variation in Product Innovation Outcome. This study also found that Internal Human Capital has significant positive effect on the Product Innovation Outcome.*

Sixth, the same approach of testing the moderator role, as opposed to the traditional antecedent role, is adopted for the factor of external resources, of which the external commercial officer resources, external human capital, external commercial IP resources (effectiveness of IP protection) and external technological resource (technology readiness level) are established to have significant positive moderating effect on the first relationship as well. The significance of these external resources has important implications for the TTOs and PRIs in raising the quality and availability level of the TTO commercialisation officer, enhancing the quality of PRI researchers, increasing the readiness level of technologies developed by PRIs and strengthening the appropriability regime of the IP, thereby supporting the earlier works of O'Shea et al., (2005), as well as Powers and McDougall (2005).

Contribution 6: *Among firms that have high levels of PAET, those that report higher levels of Product Innovation Outcome have greater access to External Commercial Officer Resources and External Human Capital. Among firms that have high levels of PAET, those that report higher levels of Process Innovation Outcome have greater access to External Technological Resources and External Commercial IP Resources.*

Seventh, this research purports that NPD communication capability is a significant moderator, rather than an antecedent, in the first relationship between PAET and product

innovation outcome (Bstieler, 2006). This finding has important implications for both PRIs and the firms. To effectively transfer the licensed technology and knowledge from PRIs to the firms, it is important to have open, timely and accurate exchange of information between the two organisations. Such interaction fosters a climate of trust (Ring and van de Ven, 1994). On the other hand, NPD collaborative problem-solving is found to have significant positive effect directly on both Product and Process Innovation Outcomes, as consistent with the findings of Li et al. (2007).

Contribution 7: *Among firms that acquired external technologies, those that report higher levels of (Product) Innovation Outcome have superior NPD Collaboration Capability (Communication Capability). NPD Collaborative Problem-solving was found to have significant positive effect on both Product and Process Innovation Outcomes*

Eighth, in the second relationship between the innovation outcome and performance which spans from production to sales according to Porter's value chain (1985), the internal commercial IP resources are found in this study to have significant positive moderating effect. This means that the effectiveness of the firms' mechanisms in protecting their IP, their innovation activities and their outcomes by such means as secrecy or economies of scale during this stage is essential for sustaining their competitive advantage to exploit their innovation to achieve higher commercial adoption performance. This finding has important implications for firms that wish to strengthen the linkage between innovation outcome and performance to maximise profit from the innovation embodying the technologies licensed from PRIs. It has significant contribution to firms that wish to pursue open business model, as supported by the findings of van der Meer (2007) as well as Alexy, Criscuolo and Salter (2009), who examined the significance of IP appropriability issue as firms expose their technological knowledge for inter-firm transfer

Contribution 8: *Among firms that have high levels of innovation outcome with external technologies, those that report better commercial adoption performance have higher levels of internally available (commercial IP) resources.*

Finally, this study establishes the significance of absorptive capacity as a moderator rather than as an antecedent in the relationship between Performance and Innovation outcome. Among firms that have high levels of product innovation outcome with external technologies, those that report better commercial adoption performance have superior NPD absorptive capacity. The empirical result supports the absorptive capacity theory (Cohen and Levinthal, 1990) and prior research on the relationship between absorptive capacity and inter-firm NPD performance (Ettlie and Pavlou, 2006). This finding has significant implications for both public agencies promoting research and innovation in the industry, PRIs as well as firms that have licensed or planned to license PRIs. Apart from monetary incentive schemes, public agencies and firms should develop programmes to raise the skill level of the firms' technical staff to facilitate effective technology and knowledge transfer from PRIs to the receiving firms. PRIs, on the other hand, could also avail their researchers to build up human capital in the firms, such as GET-Up programmes[27] in Singapore. In addition, this study shows that the firms that report better commercial adoption Performance tend to have superior NPD Communication Capability (Bstieler, 2006)

Contribution 9: *Among firms that have high levels of Product Innovation Outcome with external technologies, those that report better commercial adoption Performance have superior NPD Absorptive Capacity. Firms that report better commercial adoption Performance have superior NPD Communication Capability.*

6.3 Implications for Theory

The extant literature on commercial adoption of research developed by PRIs to industry predominantly uses RBT (Wernerfelt, 1984; Barney, 1991), which states that in order to achieve sustained competitive advantage, a firm's resources must be 'valuable, rare, imperfectly imitable and non-substitutable' (Barney, 1991, p. 117). Prior studies of external technology acquisition developed their arguments informed by TCE (Williamson, 1985), to address the various types of contractual hazards associated with a transaction

[27] The GET-Up programme is one of the many programmes that the Singapore government has put in place to improve the technological capabilities of SMEs to enhance their competitiveness.

exchange. Absorptive capacity theory (Cohen and Levinthal, 1990) was often quoted in these studies to emphasise the firm's ability to innovate by identifying, assimilating and applying new knowledge for commercial adoption. Meanwhile, traditional research on knowledge, innovation and performance are built on NPD model. This study contributes to theory by combining the erstwhile disparate studies, and integrating the several theoretical frameworks. This section discusses the significant contributions of this study to its underlying theories of RBT (Wernerfelt, 1984; Barney, 1991), TCE (Williamson, 1985), and absorptive capacity (Cohen and Levinthal, 1990).

Based on the empirical results, this research has developed an integrated conceptual model building on the intersection of multiple theoretical lenses of the RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996), TCE (Williamson, 1985), PFI (Teece, 1986), absorptive capacity theory (Cohen and Levinthal, 1990) and Dynamic Capabilities Theory (Teece et al., 1997). This model demonstrates the moderating effects of internal resources (built on RBT, PFI and TCE), external resources (with reference to RBT and KBT) and NPD collaboration capability (based on absorptive capacity and dynamic capabilities theories) on the research, innovation and enterprise value chain. Figure 6-1 presents the integrated conceptual model from the stage of external technology acquisition (PAET) through technology integration to develop new or improved products or processes (innovation outcome) to production and sales (commercial adoption performance).

This study therefore contributes significantly to these theories that have been used individually in traditional research on inter-firm or university-firm technology transfers that are restricted to certain industries. By integrating these theories and applying them in the context of PRI-firm technology licensing in Singapore (ranked the most innovatively competitive country in the world by Information Technology and Innovation Foundation (Atkinson and Andes, 2011)), this study has significantly enhanced the explanatory value and predicting power of these theories in this context.

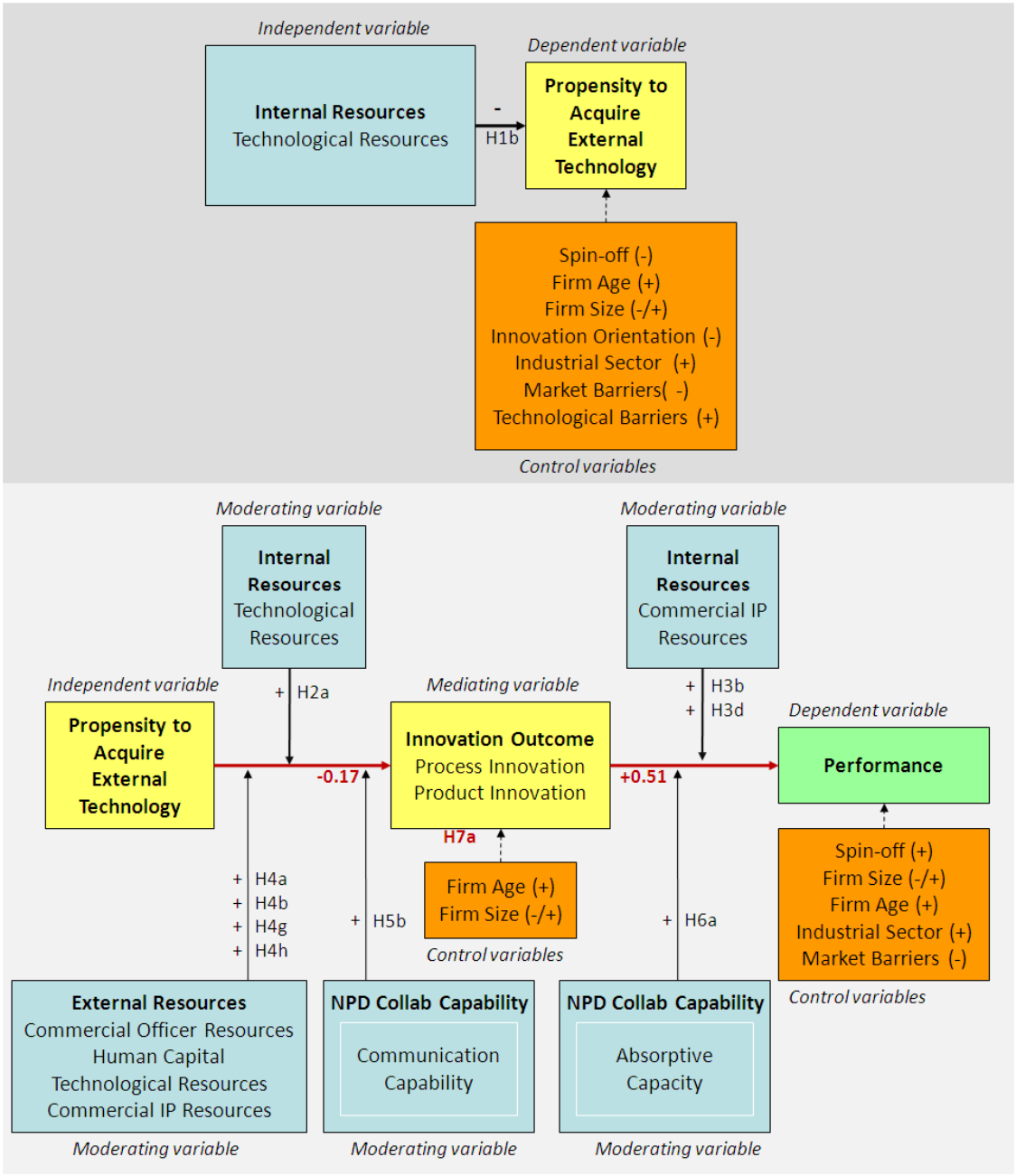

Figure 6-1: Conceptual Framework integrating the theoretical lenses of RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996), TCE (Williamson, 1985), PFI (Teece, 1986), absorptive capacity theory (Cohen and Levinthal, 1990) and Dynamic Capabilities Theory (Teece et al., 1997)

6.3.1 Contributions to TCE

TCE (Williamson, 1985) suggests that the more specific the nature of the assets that a firm needs, the greater is the corresponding increase in the risks of hold-up and opportunitism, thereby increasing contractual hazards and reducing the firm's PAET. This theory has been extensively used to explain the propensity for technology licensing arrangements between firms in the current literature on external technology acquisition, rather than that between the firms and public-funded research organisations. Unlike the firms in the industry which are likely to be profit-driven to maximise the rent that can be generated from the licensing agreements, public-funded research organisations have very different missions and objectives from these firms. As part of the NIS, public-funded research organisations are expected to play a significant role in promoting economic and social development for their nations through commercialising indigenous research and encouraging knowledge diffusion and spillovers into the industry.

While TCE adequately explains the opportunistic behaviour of profit-driven firms that decide to engage in technology licensing contracts, this study has found that there are two other dimensions that should be considered in the context of PRIs. First, the results of this study (Result No 1) show that the firms that have greater reliance on basic R&D tend to have a higher propensity to license technology from PRIs. Second, this study has established that the readiness level of the technology developed by PRIs tends to have a significant effect on the firm's propensity to license their technology. This study has made significant contributions to the TCE theory by adding two new dimensions of reliance on basic R&D and technology readiness level that are relatively more significant when the licensors are PRIs, which are more oriented to basic research than are the traditional licensors from the industry.

6.3.2 Contributions to RBT, KBT, PFI, Open Innovation and Dynamic Capabilities Theory

The RBT (Wernerfelt, 1984; Barney, 1991) argues that a firm's resources must be 'valuable, rare, imperfectly imitable and non-substitutable' to achieve sustained competitive advantage (Barney, 1991, p. 117). This study has established that a firm's

internal technological resources (Result No 2) are important for converting knowledge to new or improved products or services and from products and services to sales, as consistent with the PFI theory on the significance of CA and IP appropriability on a firm's competitive advantage (Teece, 1986) and the Dynamic Capabilities Theory to seize market and technological opportunities (Teece et al, 1997). This study also indicates that the availability of external commercial officer resources, external human capital, external technological resources and external commercial IP resources are important for a firm's innovative outcome (Result No 4), thereby providing empirical support for the open innovation model (Chesbrough, 2006a; Vanhaverbeke, 2012) in the emerging literature area of commercialising research by PRI. The results of this study contributed to these theories by demonstrating empirically that the availability of these internal and external resources alone is inadequate to guarantee superior performance. To successfully exploit the external knowledge that the firm has acquired from PRIs, their dynamic capabilities such as communication capability and absorptive capacity (Result No 5) are found to be critical in their NPD collaboration with PRIs.

These findings are in support of the KBT theory, which regarded knowledge as a strategic valuable resource (Grant, 1996) and Dynamic Capabilities Theory (Teece et al., 1997), which posits that a firm needs to have dynamic capabilities to gain and sustain competitive advantage. According to Zahra et al. (2007), resources are factors of production that are at the disposal of the firm, while capabilities describe the capacity to exploit the resources. Although the authors further argue that capabilities are mediating variables between resources and outputs in the case of both university and corporate spin-offs, this study has established that we should not ignore the role of NPD collaboration capabilities as significant moderating variables in influencing the translation process from knowledge through innovation outcome to performance. This study therefore makes a significant contribution to the RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996), PFI (Teece, 1986), open innovation (Chesbrough, 2006a; Vanhaverbeke, 2012) and Dynamic Capabilities Theory (Teece et al., 1997).

6.3.3 Contributions to Absorptive Capacity Theory

The concept of absorptive capacity has been used by economists to define the ability of an economy to assimilate external resources and knowledge (Adler, 1965; Tu et al., 2006). Cohen and Levinthal (1990) have subsequently modified the definition to depict a firm's ability to innovate by identifying, assimilating and applying new knowledge for commercialisation. Earlier studies focused on the role of absorptive capacity in enhancing the firm's ability to benefit from technology licensing from other firms, such as those in the automotive industry (Ettlie and Pavlou, 2006) and electronics firms in Taiwan (Tsai and Wang, 2008). Little empirical research has been conducted on its effect on performance of firms that acquire technologies from public research centres, whose technologies have lower readiness level than those developed by the industrial scientists. This study contributes to the absorptive capacity theory by establishing that the absorptive capacity as dynamic capability is more significant than the other dynamic capabilities (such as communication capability and collaborative problem-solving capability) in positively moderating the later stage of translating product innovation outcome to sales performance rather than the earlier stage from conceptualisation to innovation outcome (Result No 6). On the other hand, communication capability is found to be more significant than the other dynamic capabilities (absorptive capacity and collaborative problem-solving) in the earlier stage from conceptualisation to product innovation outcome than the later stage of translating innovation outcome to sales performance (Result No 5). These findings have important implications for both public agencies and private firms, which will be elaborated in the next section.

6.4 Implications for Policy and Practice

This section discusses the implications of three key findings of this research for policy and practice with regard to enhancing technological resources, developing commercial resources, building NPD collaboration capabilities and nurturing absorptive capacity as NPD dynamic capability.

6.4.1 Enhance Technological Resources

Unlike industrial firms, PRIs are neither product designers nor product developers. This means that the technology that they offer for out-licensing has a relatively lower readiness level than that of the industry firms, which would imply higher development costs and longer time-to-market that are expected to be borne by the firms. The results of this study have established that (a) the external technological resource in terms of readiness level of the technology developed by PRIs and (b) internal technological resource in terms of reliance on basic R&D tend have a significant effect on the firm's propensity to license their technology. These could be critical factors contributing to the relatively low number of licensing volume from PRIs compared to that from the industrial research laboratories. According to the study by Intellectual Ventures in the US in 2008, although 60% of the patents were developed by academia, PRIs and individual inventors, they contributed to less than 1% of the licensing revenue (Hagiu, Yoffie and Wagonfeld, 2011). On the other hand, large enterprises which were the originators of 40% of the patents received more than 99% of the licensing revenue in the US. The distribution of licensing revenue between these groups that is disproportionate with that in patent origination presents a critical issue that public policy makers have to address if they are committed to encouraging more firms to license and commercialise technologies from PRIs to the industry.

The results of this study should help policy makers to understand that the technology readiness level plays a significant role in increasing the firm's propensity to acquire technology from PRIs. To enhance the technology readiness level so as to improve its attractiveness to the firms, governments could consider formulating programmes to fund further development of the technology to bridge the technology gap between the public research laboratory results and the required industry specifications. In fact, some state governments in the US, such as Ohio, Chicago and Minnesota, as well as the country governments of Singapore and Sweden have come up with different types of technology development funding programmes (also known as gap-funded programmes) to increase the firms' propensity to license technology so as to increase their commercial adoption

rate (UIC, 2012). As there is a time lag between the implementation of technology development programme and the commercial adoption of the technology by firms, the effectiveness of the programme remains to be seen.

Private firms, on the other hand, should allocate time and resources to work with the government agencies to participate in technology development programmes with PRIs to co-develop technologies that may still be in an early stage but have strong commercial potential. While profit-oriented firms may be focused on short-term profitability through exploitation of technologies of high readiness level, these firms also need to be cognizant that their future lies in their shrewd investment in exploration of new technologies that are low in their readiness level but high in their potential upside. It is therefore important for private firms to find sustainable ways of partnering with the relevant government agencies and collaborating with PRIs to improve the readiness level of their technologies. Leveraging the basic research capability of PRIs would enable firms that are resource-constrained to implement a technology roadmap that comprises not only exploitative projects, but also exploratory initiatives in order to sustain their competitive advantage.

6.4.2 Develop Human Capital, Commercial Resources and Build NPD Collaboration Capabilities

This study has established that the availability of internal and external resources alone is inadequate to guarantee superior performance. To successfully exploit the external knowledge that the firm has acquired from PRIs, their communication capability and absorptive capacity are found to be critical in their NPD collaboration with PRIs. Public agencies should therefore be aware of the importance of NPD capabilities, in addition to resource availability, and re-think the effectiveness of the current government support programmes in assisting firms to improve the success rate of converting knowledge to commercial performance. An example of an effective government programme is the Technology Innovation Programme launched in 2006 by the Singapore government agency, SPRING, that was set up to assist the development of Singapore SMEs. With an assistance fund of USD 172m to be granted to eligible SMEs over five years, the programme aimed to encourage SMEs to work with various technology partners, such as

PRIs and institutes of higher learning, their researchers (external human capital) and their technology commercialisation officers (external commercial officer resources), to upgrade their technological capabilities to absorb external technological knowledge so as to gain a competitive advantage (SPRING, 2012).

To encourage firms to commit resources to develop and protect IP (external commercial IP resources), the government could play a pivotal role in formulating policies such as building a positive grant system, developing patent profession protection and enhancing IP dispute resolution expertise (MinLaw, 2012). The relevant agencies could also implement programmes to provide training or advisory services to build IP management knowledge and expertise among SMEs (internal commercial IP resources). This is corroborated by the recommendation of Chang-Chieh Hang and Marvin Ng (2004, p. 5) in their paper on *IP and Innovation: Singapore's Experience* for innovating economies to ensure that universities include IP management in their basic curricula for engineering schools, so that their graduates would be 'IP literate and well-educated in IP management' as future R&D workers of MNCs and SMEs.

Private firms, on the other hand, should be cognizant of the factors that are critical for the commercial adoption success of external technologies that they license from PRIs. Having a good understanding of the dynamics among commercial resources, human capital, technological resources and NPD capabilities, firms will be in a better position to identify and acquire the necessary talent and resources, as well as develop the relevant NPD capabilities (such as communication capability) and organisational routines to work through the complexity of integrating external and internal knowledge to better exploit their product or process innovation output (Hang, 2007). The firms may also work with universities to customise professional development programmes for their staff in building up their knowledge and capabilities in NPD collaboration as well as overall R&D management. Chang-Chieh Hang, Marcelo Ang, Poh-Kam Wong and Annapoorima Subramanian's (2009, p. 453) publication of *Technology Management Educational Initiatives in Asia: A Case Study from the National University of Singapore* provides an excellent example of how universities could play a significant role in equipping R&D workers and their managers with fundamental knowledge and skills of technology

management to 'become innovation leaders' in the society and 'change agents' in their firms.

6.4.3 Nurture Absorptive Capacity as NPD Dynamic Capability

As different factors influence different stages of the value chain from external knowledge assimilation (PAET) through technology integration (innovation outcome) to production and sales (commercial adoption performance), it is essential that firms be aware of them and their relative importance. In the earlier stage of the value chain where a great deal of tacit knowledge that is embedded in the minds of inventors of PRIs needs to be transferred to the recipient firm, it is critical that open, accurate and timely communication takes place between the inventor and suitably trained staff to ensure effective knowledge assimilation and exploitation. In a similar vein, the significance of absorptive capacity in the stage from innovation outcome to actual firm performance implies that firms need to put in place the relevant training, processes, systems and tools to enhance their ability to identify, assimilate and apply new knowledge for commercial adoption.

Apart from private firms, the above findings have implications for public agencies, which could formulate more targeted schemes to help firms improve communication and absorptive capacity so as to ensure a more seamless knowledge transfer. For example, the Singapore government has the GET-Up programme that involves the secondment of researchers from PRIs at SMEs for a certain period of time to develop the human capital of these firms and improve their technological capabilities (SPRING Singapore, 2012). Similarly, the Belgian government has set up IMEC (Inter-University Micro Electronics Centre) to develop local industries through creating new ventures, research collaboration, training and development (Mina, Connell and Hughes, 2009). IMEC implements Industrial Affiliation Programmes (IIAP) that allows industrial partners to co-locate their staff to work alongside the IMEC researchers and utilise their facilities for prototyping, development and testing. This affiliation programme aims to engage the firms in sharing resources and new knowledge that are created through communication and collaborative research. Although some governments have such programmes in place, the turnover of

the researchers at both PRIs and the enterprises has invariably posed challenges in knowledge retention, thus affecting the effectiveness of these programmes (Mina et al., 2009).

6.5 Limitations

As with any research, this study is not without its limitations. As it uses a cross-sectional design, it does not capture the dynamic effects of the independent, moderating and mediating factors on the innovation outcome and commercial adoption performance of the firms. For example, the impact of NPD capabilities on organisational innovation at different points of the product life cycle is not within the scope of this study. For future studies, it would be worthwhile to consider longitudinal studies to examine and analyse the effects of these factors on the innovation outcome and commercial adoption performance of the firms that license technologies from PRIs (Gumusluoglu and Ilsev, 2009). A second limitation is that the study only looks at the PRIs in Singapore, hence it is difficult to generalise these results to other organisational (e.g., university research institutes or private research institutes) and geographical contexts (e.g., US, Australia, etc.). Nevertheless, the results of this study serve as useful and relevant references for other innovating economies in developing their national innovation systems. Finally, the *PAET* variable that was used in this research to measure a firm's propensity to acquire external technology has posed a third limitation. In this study, *PAET* was measured by respondents' prior technology licensing experience, as supported by the earlier works of Atuahene-Gima (1993). However, the use of binary measure for *PAET* rather than a more nuanced measure such as a ratio or a series of Likert-style questions weakens the validity of this variable. Although this research finding shows support for H1 that *Internal Technological Resources* have a significant negative influence on *PAET*, the *PAET* is likely to be influenced by a host of other factors not included in this study, such as the intent of the R&D, nature of knowledge transmitted and complementarity between internal and external research. These limitations are certainly areas to consider for future research.

6.6 Implications for Further Research

This section discusses the implications for further research based on the findings of this study.

This research has found that the technology readiness level and certain industrial sectors, such as biomedical, information and communication industries, have a significant effect on firms' PAET. Future research could examine the interaction between the technology readiness level and industry characteristics, such as life cycle, rate of technological change and industry barriers, to gain a deeper understanding of how they could impact the firm's decision to license the technologies from PRIs. An in-depth understanding of these underlying factors and their interaction effects would enable the innovation agencies and TTOs to develop more effective technology commercialisation programmes to encourage licensing and promote technology assimilation by the firms, with a view to sustaining their competitive advantage and promoting economic growth.

This study included firm size in terms of staff strength and fixed asset investment as control variables on the PAET, but the results were mixed and inconclusive. Future research could therefore investigate if, and how, firm size contributes to the variation in a firm's PAET. The results have implications on how TTOs and PRIs could vary their outreach approach according to the firm size, ranging from small and medium to large enterprises, to increase their technology adoption rate.

In this study, the innovative outcome comprising product and process innovation was found to be a significant mediating variable between propensity for external technology licensing and commercial adoption performance. As innovation outcome may also be analysed along the dimensions of radical innovation and incremental innovation (Crossan and Apaydin, 2010, p. 1161), future research could investigate the significance of these dimensions in their role in mediating or moderating the relationship between decision to acquire external technology and commercial adoption performance.

6.7 Concluding Remarks

In conclusion, the literature suggests that the role of PRIs is growing in importance in the NIS as external knowledge centres that firms could collaborate with to develop their R&D capabilities to sustain their competitive advantage. However, most empirical studies in these literature areas focus on universities, TTOs, new ventures, the external environments, including incubators, science parks, and venture capitalists (Rothaermel et al., 2007), as well as firms that acquire technology from foreign firms or large local firms (Liu and Buck, 2007). There has been little research done on the firms that license technologies from PRIs. This study has addressed this gap with its quantitative research on 250 licenses between PRIs of Singapore and firms from a wide range of industries. The results of this study show that the availability of a firm's internal resource (reliance on basic R&D) and external resources (technological readiness level and TTO commercialisation officer) could significantly influence its propensity to license technologies from PRIs in Singapore.

This study has also established that both internal and external commercial IP resources and technological resources of a firm, as well as its new product development communication capability, significantly moderate the relationship between its PAET and its innovation outcome. In addition, a firm's internal commercial IP resource and technological resource, along with its NPD absorptive capacity, were confirmed to positively influence the link between its innovation outcome and commercial adoption performance. Finally, the firm's innovation outcome was established as a mediator between its PAET and its performance. This research developed an integrated conceptual model building on the intersection of multiple theoretical lenses of RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996), PFI (Teece, 1986) and TCE (Williamson, 1985), as well as the perspectives of open innovation (Chesbrough, 2006a; Vanhaverbeke, 2012), absorptive capacity theory (Cohen and Levinthal, 1990) and Dynamic Capabilities Theory (Teece et al., 1997). Finally, the conceptual model developed in this research could set the foundation for future research on the interface between PRIs and industry.

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Appendix A: Innovation in Singapore

Overall Ranking		
Ranking	**Country**	**Score**
1	Singapore	2.45
2	South Korea	2.26
3	Switzerland	2.23
4	Iceland	2.17
5	Ireland	1.88
6	Hong Kong	1.88
7	Finland	1.87
8	United States	1.80
9	Japan	1.79
10	Sweden	1.64

Table A-1: Overall Ranking of 110 Countries in International Innovation Index by Boston Consulting Group (BCG)
Source: BCG, National Association of Manufacturers, and the Manufacturing Institute, Innovation Indexes. 2008 (Andrew et al., 2009, p. 10)

Singapore's Ranking of Doing Business 2012	
Rank	**Doing Business 2012**
Ease of Doing Business	1
Starting a Business	4
Dealing with Construction Permits	3
Registering Property	14
Getting Credit	8
Protecting Investors	2
Paying Taxes	4
Trading Across Borders	1
Enforcing Contracts	12
Closing a Business	2

Table A-2: Overall Ranking of 183 economies in Doing Business 2012 by The World Bank
Source: The World Bank, 2012, p. 125.

Country	Overall Rank by ITIF 2011	Corporate Investment in R&D as % of GDP[1] 2010	Government Investment in R&D as % of GDP[1] 2010	Researchers per 1,000 labour force[1] 2010	Scientific Publications Score[2] 2009	Venture Capital Investment as % of GDP[3] 2011	New Firms as % of total corporations[4] 2009	FDI as % of GDP[5] 2010	GDP (PPP) per working adult age 25-64[6] 2010
Singapore	1	1.4%	0.8%	12.1	7.0	0.24%	7.4%	7.40%	$ 74,602
Finland	2	2.3%	0.8%	16.9	7.6	0.24%	3.4%	0.00%	$ 55,494
Sweden	3	2.2%	0.8%	10.9	8.5	0.21%	4.1%	5.40%	$ 60,898
USA	4	1.9%	0.8%	9.7	6.2	0.12%	4.3%	1.60%	$ 76,865
Korea	5	2.3%	0.8%	9.7	4.2	0.07%	1.7%	0.30%	$ 42,382
UK	6	0.9%	0.6%	9.2	7.2	0.20%	8.1%	2.30%	$ 57,843
Denmark	8	1.7%	0.7%	11.5	8.9	0.16%	4.6%	0.90%	$ 59,639
Netherlands	10	0.9%	0.6%	6.3	8.5	0.10%	3.1%	2.40%	$ 65,174
Australia	11	1.1%	0.6%	8.8	7.2	0.13%	6.4%	3.50%	$ 64,152
Japan	12	2.7%	0.6%	11.8	4.3	0.07%	1.3%	0.40%	$ 54,795
Belgium	13	1.1%	0.4%	8.9	7.5	0.10%	4.3%	6.40%	$ 59,312
France	14	1.0%	0.8%	8.9	5.8	0.13%	3.1%	2.30%	$ 57,157
Ireland	15	0.7%	0.4%	6.7	6.8	0.13%	4.7%	7.00%	$ 63,583
Germany	16	1.7%	0.7%	8.1	6.3	0.09%	1.2%	1.00%	$ 57,034

[1]Source: UNESCO, Institute of Statistics, 1999-2008 data

[2]Source: SCImago Journal & Country Rank, 1996-2009 data

[3]Source: OECD, 2000-2008 data

[4]Source: World Bank, 2005-2009 data

[5]Source: World Bank, 1999-2009 data

[6]Source: IMF, World Bank, 2000-2009 data

[7]Source: OECD, IMF, 2000-2009 data

Table A-3: Comparison of Singapore's Human Capital, Innovation Capacity, Entrepreneurship and Economic Performance (Atkinson and Andes, 2011)

Appendix B: Literature Review

B1 Endogenous Growth Theories

B1.1 Development of Endogenous Growth Theories

Paul Romer's (1986) seminal work on *Increasing Returns and Long-Run Growth* challenged exogenous growth models, which attributed economic growth to capital stock (Solow, 1956; Cass, 1965; Koopmans, 1965). These exogenous growth models advocated that the long-term economy growth rate is determined exogenously, predicting that the economy growth rate would converge towards a steady-state, subject to the growth rates of labour and technological progress. This gave rise to the convergence controversy (Maddison, 1982; Heston and Summers, 1991), where the critics questioned if the income per capita of different countries would eventually converge. The underlying assumptions of the exogenous growth models were that 'technological change is exogenous and that the same technological opportunities are available in all countries of the world' (Romer, 1994, p. 4). Romer (1986, 1990) argued that the existence of many poor countries in juxtaposition with the rich countries in the sample of Heston-Summer's study showed that these assumptions were flawed.

As an alternative model, Romer advanced the endogenous growth model, arguing that economic growth is fuelled by technological progress brought about by 'intentional investment decisions made by profit-maximising agents' and that the rate of technological progress was a function of human capital performing R&D and the knowledge stock available to the R&D workers (Romer, 1990, p. S71). There were other authors who also brought to bear on the endogenous growth models, integrating the 'product-life-cycle hypothesis with Schumpeter's (1943) description of product innovation' (Segerstrom, Anant and Dinopoulos, 1990, p. 1077), introducing the approach of 'quality ladder' for each product to sustain product innovation and long-term technological progress (Grossman and Helpman, 1991, p. 60), and applying Schumpeter's concept of 'creative destruction' to account for the issues of obsolescence

and discontinuous growth arising from technological progress (Aghion and Howitt, 1992, pp.1-2). These are the first-generation endogenous growth models which assert that the R&D intensity has a positive relationship with the total factor productivity (TFP), contributing to the long-run rate of technological progress (Segerstrom et al., 1990; Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992). Table B-1 provides a summary of the significant contributions to endogenous growth theories for the past three decades.

Author	**Significant contributions to endogenous growth theories**
Romer, 1990	Articulated that economic growth was fuelled by technological progress brought about by 'intentional investment decisions made by profit-maximising agents' and that the rate of technological progress was affected by the number of R&D workers and the knowledge stock available to these workers (p. S71).
Segerstrom, Anant and Dinopoulos, 1990	Integrated the 'product-life-cycle hypothesis with Schumpeter's (1942) description of product innovation' (p. 1077).
Grossman and Helpman, 1991	Introduced the approach of 'quality ladder' for each product to sustain product innovation and long-term technological progress (p. 60).
Aghion and Howitt, 1992	Applied Schumpeter's concept of 'creative destruction' to account for the issues of obsolescence and discontinuous growth arising from technological progress (pp. 1-2).
Jones, 1995a, 1995b	Found that a significant rise in R&D professionals in the US did not lead to a similar take-off in total factor production growth rate. Refuted first-generation endogenous growth models and spearheaded the second-generation endogenous growth models.
Segerstrom, 1998	Established that long-term economy growth rate was affected by quality of innovation, population growth rate and R&D complexity.
Young, 1998	Drew upon Gilfillan's (1935) principle of equivalent of innovation to illustrate that market expansion might not necessarily lead to economic growth as the market could expect increase in variety of technologies and thereby incur higher R&D expenditure. He found that the quality innovations had effect on long-run endogenous growth.
Dinopoulos and Thompson, 1998	Built on Young's (1998) findings to establish growth in quality innovations was not determined by market scale and growth in

Author	Significant contributions to endogenous growth theories
	population size.
Aghion and Howitt, 1998	Added capital to total factor production and supported effect on policy on long-run endogenous growth.
Peretto, 1998	Used the crowding-in effect to explain that population growth could encourage new entry and 'generates dispersion of R&D resources across firms and offsets the positive effect of the scale of the economy on the returns to R&D' (p. 283).
Peretto and Smulders, 2002	Argued that as economy expanded, the scale might diminish as more firms would choose to differentiate their new-to-market technologies from the other firms, leading to less technology spillovers.
Zachariadis, 2004	Found evidence for the 'Schumpeterian endogenous growth framework without scale effects' using US manufacturing sector of 1963-1988 period (p. 566). Zachariadis established that economic growth rate was positively related to technological progress, which in turn, was positively impacted by the patenting rate. Finally, he showed that the patenting rate was positively affected by R&D intensity.
Kneller and Stevens, 2006	Used the concept of absorptive capacity (Cohen and Levinthal, 1989) to explain the effect of human capital and R&D on the variance in productivity across countries in implementing new technology.
Ha and Howitt, 2007	Applied the two variants of second-generation endogenous growth theories: semi-endogenous and Schumpeter theories on the US data since the 1950s. Used co-integration analysis and found stronger support for the Schumpeter theory which explained the observation that 'sustained TFP growth requires a sustained fraction of GDP to be spent on R&D' (p. 733).
Madsen, 2008	Critiqued that Ha and Howitt (2007) and Zachariadis (2003) were focused on the US rather than explaining cross-country differences. Madsen (2008) used various proxy indicators for innovative activity and product variety to study 21 OECD countries and found that Schumpeter growth theory, rather than the semi-endogenous growth theory, was better at explaining the TFP growth and co-integration between innovative activity and product variety.
Madsen, Saxena and Ang, 2010	Applied the second-generation endogenous growth theory in a developing economy, India, and found that the Schumpeter growth theory was more consistent with the TFP growth and R&D

Author	Significant contributions to endogenous growth theories
	data for the 1950-2005 period.
Ang and Madsen, 2011	Examined the data of 'six Asian miracle economies' of 1953-2006 period: China, India, Japan, Korea, Singapore and Taiwan (p. 1360). The study presented strong support for the Schumpeter growth theory which predicted that research intensity would drive TFP growth.

Table B-1: Summary of significant contributions to the endogenous growth theories

The first-generation models implied that human capital engaged in R&D was positively related to new ideas generated. However, these models were refuted by Jones (1995a, 1995b) whose studies found that a significant rise in R&D professionals in the US did not lead to a similar increase in the rate of total factor production growth. Following these ground-breaking findings, second-generation endogenous growth theories emerged with two schools of thoughts: Schumpeterian growth theory (Young, 1998) and semi-endogenous growth models (Kortum, 1997; Ang and Madsen 2011).

The Schumpeterian growth theory was advocated by Young (1998), Dinopoulos and Thompson (1998), Aghion and Howitt (1998), Peretto (1998), and Peretto and Smulders (2002), who assumed that the increase in product range and complexity resulting from economic growth could negatively affect R&D productivity and therefore proposed to ramp up R&D intensity over time to compensate for the decline in productivity effectiveness so as to sustain constant TFP growth.

The semi-endogenous growth models by Kortum (1997), Jones (1995a) and Segerstrom (1998), on the other hand, believed that the returns to the R&D knowledge stock would diminish and thus recommended to step up R&D investment to maintain TFP growth.

As more data on TFP, innovative activity (patents and R&D) and product variety (GDP and employment) has become available in both developed and developing economies over the past decades, there seems to be stronger support for the Schumpeter growth theory in accounting for the long-run economic growth, technological progress, R&D and

their relationships in the US (Zachariadis, 2004; Ha and Howitt, 2007), the OECD countries (Madsen, 2008), developing economies (Madsen et al., 2010) and Asian economies (Ang and Madsen, 2011).

From the review of the literature on endogenous growth theories, it is apparent that R&D plays a pivotal role in technological progress and TFP growth.

B2 Cluster Theory

B2.1 Development of Cluster Theory

In *The Competitive Advantage of Nations,* Porter (1990) introduced the concept of industrial clusters and the national diamond framework. He demonstrated the importance of location on the productivity growth of the industry through the four elements of his diamond framework: (a) 'factor (input) conditions', (b) 'demand conditions', (c) 'related and supporting industries', and (d) 'context for firm strategy and rivalry' (Porter, 2000, p. 20). If a nation could develop each of these four elements by co-locating or clustering the firms of the same industry, Porter argued that the microeconomic foundations would be well laid and the nation well positioned to exploit the location sources of competitive advantage to achieve economic growth and international competitiveness. According to Porter, clusters are described as follows:

> Clusters are geographic concentrations of interconnected companies, specialised suppliers, service providers, firms in related industries, and associated institutions (e.g., universities, standards agencies, trade associations) in a particular field that compete but also cooperate. (Porter, 2000, p. 15)

The cluster theory (Porter, 2000, p. 15) asserts that local rivalry among firms operating in the same industrial clusters to compete as well as cooperate for demand (customers) and factors (input raw materials, human resources and infrastructural facilities, etc) is more effective than monopoly for spurring innovation and enhancing the competitiveness of a nation or region.

The concept of industrial clustering and its economics has gained interest among industrial economists and management scholars, fuelling research in areas including agglomeration and geographic economics (Martin and Sunley, 2003; Puga, 2010; Desrochers and Leppälä, 2011), externalities[28] (Henderson, Kuncoro and Turner, 1995; Beaudry and Schiffauerova, 2009), knowledge spillovers and regional innovation systems

[28] Beaudry and Schiffauerova (2009, p. 320) defined an externality as 'an effect emanating from one activity that has consequences for another activity, but is not directly reflected in market prices'.

(Malmberg and Maskell, 2002; Engel and del-Palacio, 2011), and competitiveness (Porter, 2000; Laureti and Viviani, 2011). The approach of clustering has appealed to policymakers in articulating the need for local intervention as part of their national or regional economic development strategies.

B2.2 Theoretical Foundations of Cluster Theory: Agglomeration Theory

In the Cluster literature, the initial publications debated the theoretical foundations of Porterian clusters and their empirical support (Gordon and McCann 2000; Malmberg and Maskell 2002; Martin and Sunley 2003). Some authors argued that Porter's industrial cluster concept was not new, but had its origins in the classical agglomeration theory (Marshall, 1890), which used the notion of economies of scale to explain the benefits of localisation of economies from the agglomeration of workforce with specialised skills, providers of specialised inputs and services, and knowledge spillovers (Glaeser, Kallal, Scheinkman and Shleifer, 1992; Bekele and Jackson, 2006).

Glaeser et al. (1992) integrated Marshall's (1890) agglomeration concept, Arrow's (1962) notion of learning by doing and Romer's (1986) endogenous growth theory into a Marshall-Arrow-Romer (MAR) model. The MAR model shared some similarity with Porter's cluster theory in that the spatial agglomeration of firms from the same industry could give rise to increased inter-firm interaction, knowledge spillovers and innovative activities. However, while the Porter cluster and its externality effect attributes innovation growth to inter-firm rivalry, the MAR and its externality prefers monopoly to competition as a means to protect innovation and maximise capture of value from the innovation (Beaudry and Schiffauerova, 2009).

Jacobs (1969) and his supporters, on the other hand, disagree with the postulations of MAR and Porter that spillovers and innovation come from specialisation within industry clusters or agglomeration (Desrochers and Leppälä, 2011). The Jacobian theorists argue that innovation comes from cross-industry diversity of skills and disciplines for the following reason:

> The greater the sheer number of and variety of division of labour, the greater the economy's inherent capacity for adding still more kinds of goods and services (Jacobs, 1969, p. 59).

B2.3 Recent Literature Strands of Cluster Theory

Since the publication of Glaeser et al. (1992) on the MAR-Porter-Jacobs debate, de Groot, Poot and Smit's (2009) literature survey found that more than 300 articles had been published citing their work. The debate has taken centre stage among the researchers with recent studies dwelling on the relative effectiveness of these three models in accounting for innovation and economic performance (Frenken and Boschma, 2007; Frenken et al., 2007; Beaudry and Schiffauerova, 2009; Neffke, Henning, Boschma, Lundquist and Olander, 2010; Lasagni, 2011).

Apart from the debate, the recent literature on cluster theory has some streams that focus on the factors affecting the relationship between cluster and firm performance (Gilbert et al., 2008; Laureti and Viviani, 2011; McCann and Folta, 2011; Heebels and Boschma, 2011), the plausible methodologies to define and measure the performance of clusters and their related concepts (Yu and Jackson, 2011; Titze, Brachert and Kubis, 2011), and extension of Porterian clusters to innovation clusters or innovation systems (Yu and Jackson, 2011; Engel and del-Palacio, 2011). In particular, one stream of the cluster literature tends to examine the evolution of a cluster and trace its life cycle. Some authors identify four distinct phases in a cluster life cycle from growth through maturity to transition (van Klink and De Langen, 2001; Menzel and Fornahl, 2010), while others support three stages from existence to either exhaustion or renaissance (Maskell and Kebir, 2006; Bergman, 2008).

There are different schools of thoughts on how clusters evolve. One school supports the coevolution of cluster life-cycle with that of the technology-industry (Dalum, Pedersen and Villumsen, 2005; Ter Wal and Boschmam 2011). However, the other group contends that the difference in computer industry growth pattern between Silicon Valley and Boston illustrates that the link between cluster and industry life cycles is either weak or

non-existent (Menzel and Fornhal, 2010). Table B-2 provides a summary of the recent literature on the cluster theory.

Author	Significant Contributions to Cluster Theory
van Klink and De Langen, 2001	Identified four distinct phases in a cluster life cycle from growth through maturity to transition.
Dalum, Pedersen and Villumsen, 2005	Argued that life cycles of high-technology clusters are tightly linked with the S-curves of the technologies.
Bergman, 2008	Supported that cluster life cycle exists in three stages from existence to either exhaustion or renaissance, as consistent with Maskell and Kebir (2006).
Gilbert, McDougall and Audretsch, 2008	Examined 127 new IT ventures which were publicly listed in 1996-2000. Applied absorptive capacity (Cohen and Levinthal, 1990) and found that new ventures situated in industry clusters had assimilated knowledge from the external environment and attained better performance. However, study showed that superior performance was not caused by 'technological knowledge spillovers', but possibly by other factors such as 'internal development capabilities' (p. 417), which warrants further research.
Beaudry and Schiffauerova, 2009	Reviewed 67 studies on the works of MAR, Porter and Jacobs using the concept of externalities. Found that Porter's theory of competitiveness was consistent with Jacobs' theory that assumed competition would promote growth. Also observed that Porter's theory of industry clusters agrees with MAR's theory that specialisation of skills within an industry could lead to intra-industry spillovers and growth.
Wong, Ho and Singh, 2009	Compared and contrasted the development of the new biomedical sciences cluster and the relatively mature offshore marine engineering cluster to examine the role of public policy in their development.
Menzel and Fornahl, 2010	Comparison of firm performance between clusters and non-clusters showed that the evolution of clusters is not related to the industry life cycle, supporting the findings of Audretsch and Feldman (1996).
Arikan and Schilling, 2011	Refined industrial clusters into 'four archetypes of industrial districts', defined by two dimensions of centralisation and coordination (p. 772). Analysed the relative costs and benefits of

Author	Significant Contributions to Cluster Theory
	each archetype and examined its comparative advantage at both district and firm level.
Desrochers and Leppälä, 2011	Based on qualitative survey of Canadian inventors, Desrochers and Leppälä drew upon social learning theory (Bandura, 1977) to delineate the processes of 'inter-industrial' a.k.a. 'Jacobs spillovers' as (a) incorporation of know-how to alternative product lines, (b) application of know-how to alternative context and (c) inter-disciplinary collaboration (p. 843).
Engel and del-Palacio, 2011	Using the data of Israel and Silicon Valley, extended the cluster theory by arguing that innovation could go beyond Porterian industry cluster to include clusters of innovation that could transcend industrial boundaries to spur innovation and enterprise.
Heebels and Boschma, 2011	Used hazard model to investigate the cluster effect on firm performance in the Amsterdam publishing industry. Based on dataset on firms established in 1880-2008 period, their study found that prior entrepreneurial experience, and not clustering, had a significant and positive effect on firm performance.
Laureti and Viviani, 2011	Performed Data Envelopment Analysis of Italian firms from two industry clusters in 2002 and 2005, and found a positive relationship between firm productivity and competitiveness, supporting Porter's theory.
McCann and Folta, 2011	Applied knowledge-based view (Grant, 1996) to examine the performance of biotechnology firms within a geographical cluster. Found that certain firm characteristics, such as age and knowledge stocks, could affect performance among the clustered firms.
Ter Wal and Boschmam 2011	Explained the coevolution of cluster with the life cycle of the technology and industry, with the firm and with the knowledge network.
Titze, Brachert and Kubis, 2011	Introduced the qualitative input-output (QIOA) methodology (Schnabl, 1994) to define regional innovation clusters and constructs for measurement and analysis interactions between industries, using adapted version of Porter's original definition of clusters by Roelandt and Den Hertog (1999, p. 9).
Yu and Jackson, 2011	Cautioned against the use of regional innovation cluster as an extension of Porterian regional industry cluster. They highlighted the lack of empirical evidence in support of regional innovation cluster, citing challenges of defining suitable constructs, methodologies of defining cluster boundaries and availability of

Author	Significant Contributions to Cluster Theory
	appropriate cluster data.

Table B-2: Summary of significant contributions to the Cluster Theory

From the literature, it is apparent that the concept of cluster theory has evolved to include not just industry cluster, but also innovation cluster. The approach of industrial and innovation clustering and its effect on firms' business performance as well as economic development has gained attention of among policymakers interested in building innovation-based economies. In Singapore, the policymakers have also adopted the approach of industrial and technology clustering as part of innovation-driven economic development (Wong, Ho and Singh, 2009; Porter, 2007). Publicly-funded research institutes support Singapore's national economic and innovation clusters by providing 'intellectual, human and industrial capital to its partners in the industry' (Economic Development Board, 2012; A*STAR, 2012). Given the important role of both industry and technology clusters in Singapore, this research considers them as control factors in examining the relations among firms' propensity to license technologies from Singapore publicly-funded research institutes, their innovation outcome and commercial adoption performance.

B3 Triple Helix and Coevolutionary Theory

B3.1 Introduction of the Triple Helix Concept

The growing emphasis that the state has been placing on academia and industry to increase R&D activities for endogenous development is evident in the growing R&D expenditure incurred. For the past 10 years, the OECD statistics in Figure B-1 show that the combined R&D expenditure by the EU-27 countries has achieved an average growth rate of 3.3 per annum in real dollars. While the rate of R&D growth by France, Germany and the UK averaged between 1.8% and 3.0%, the US and Japan R&D growth rate, averaging between 3.0% and 3.3%, were higher. The OECD comprising 30 countries as a whole registered a real average annual rate of 3.6% in R&D expenditure since 2000 (NSB, 2010).

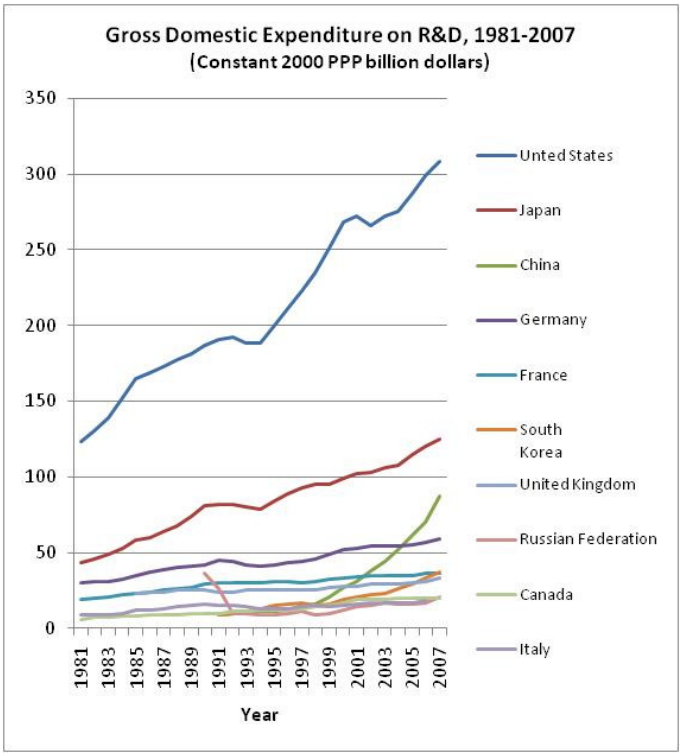

Figure B-1: GDP on R&D expenditures, 1981-2007 (Reproduced from National Science Board, 2010, p. 4-35 based on OECD data)

B3.1.1 Growing Importance of the Entrepreneurial University

According to the NSB Report (2010, p. 4-42), the governments of most nations have traditionally been the largest funding source for academic research. Nevertheless, the industry has been increasing in its funding support of academic research, as is evident in the growth of business support for public R&D from around 3% in the early 1980s to approximately 6% in 2006 among the OECD countries. This corroborates the increasing strength of relation between the academia and industry institutional spheres in developed economies (US and Sweden) and developing economies (Brazil) (Etzkowitz and Dzisah, 2008, p. 661).

The WIPO 2008 patent statistics show a corresponding increase in the immediate output of R&D, patents, with countries committing more R&D expenditures for developing their intellectual capital, as depicted in Figure B-2 and Figure B-3. From 1995 to 2006, the number of patent applications increased at an average rate of 5.3% per annum, with a significant rise in the share of non-resident patent filing from 30.7% in 1985 to 43.3% of total filings in 2007, as shown in Figure B-4 of Appendix B.

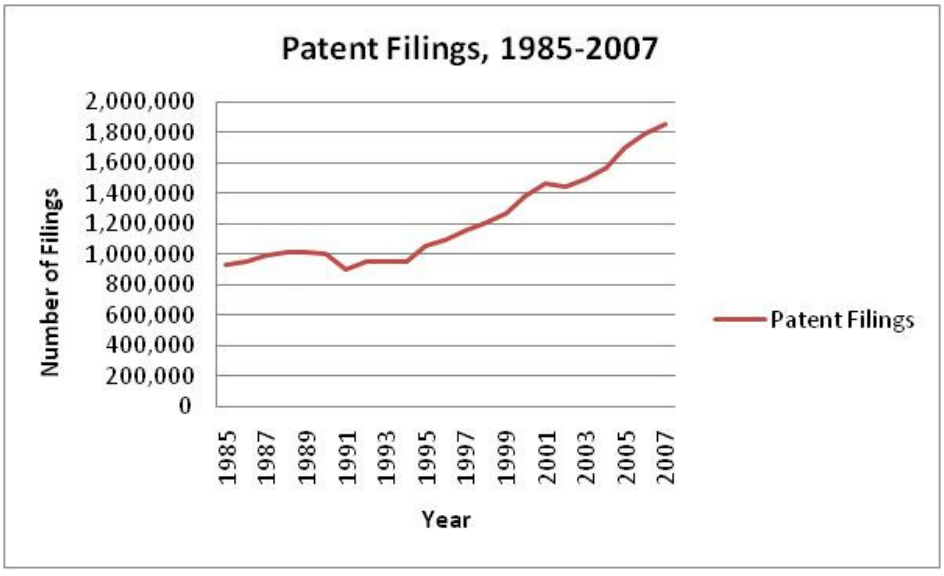

Figure B-2: Trend in Patent Filings, 1985-2007
Source: WIPO Statistics Database, June 2009

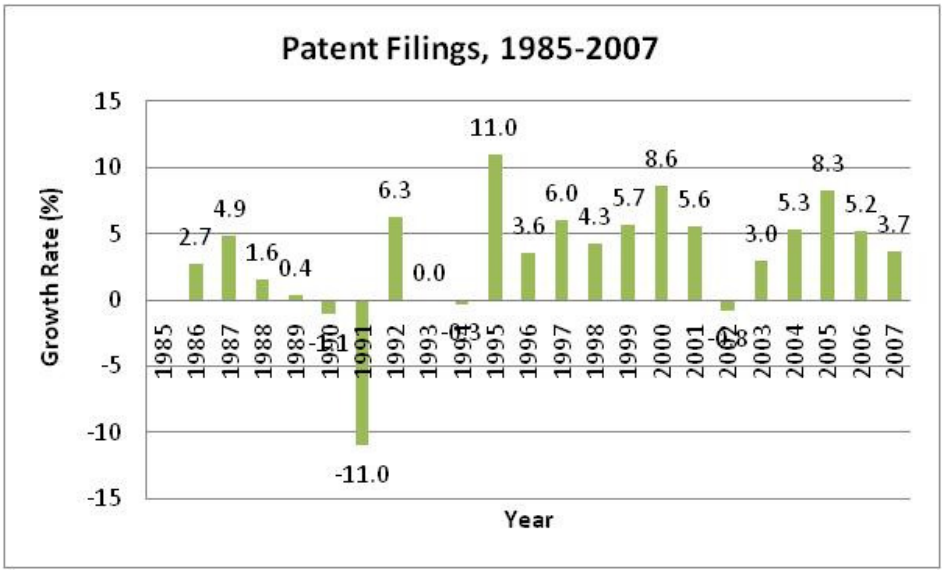

Figure B-3: Growth Rate Trend in Patent Filings, 1985-2007
Source: WIPO Statistics Database, June 2009

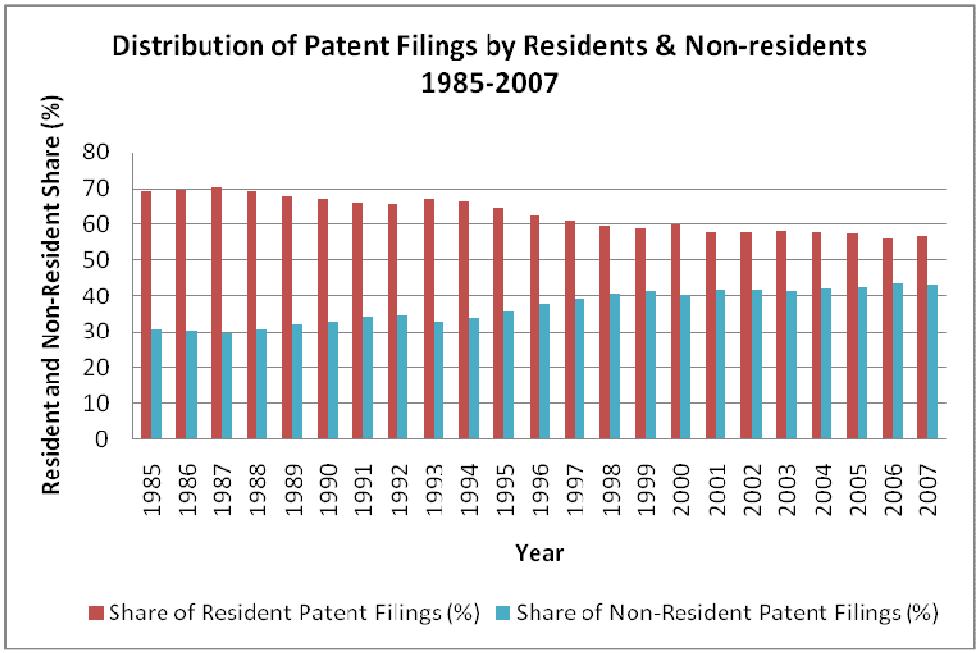

Figure B-4: Distribution of Patent Filings by Residents and Non-Residents, 1985-2007
Source: WIPO Statistics Database, June 2009

Etzkowitz and Leydesdorff (1996) heralded the Triple Helix concept to emphasise the increasingly prominent role of the university as 'equal partner' (Etzkowitz, 2011, p. 550) with the industry and government institutional spheres and fostering strong interaction among the spheres through 'circulation' (Etzkowitz and Zhou, 2007, p. 1) of intellectual capital among the spheres. The role of the university is more pivotal than ever in the innovation process as it contributes to the industry as a source of intellectual and human capital for economic development. One of the many regional policy implications of the Triple Helix model is the rise of 'hybrid organisations' such as technology transfer offices (TTOs), academic and public research institutes, incubators, science parks and venture capitalists that facilitate the interaction of the three institutional spheres in generating technological innovations from the laboratories, and commercialising them into products and services (Etzkowitz and Zhou, 2007, p. 10).

According to Etzkowitz and Leydesdorff (2000, p. 111), the Triple Helix 1 model[29] delineated the traditional configuration where the 'nation state encompasses academia and industry and directs the relations between them'. It is therefore apparent that the Triple Helix I depicted a model of strong state control occupying one end of the continuum of state influence. At the other end of the continuum, the Triple Helix 2 model[30] represented a rather laissez-faire configuration of government-industry-academia relations. While the Triple Helix I model was criticised as a failure for being too top-down and lacking innovative opportunities for industry and academia, the Triple Helix II model was regarded as a draconian measure to diminish the influence of the state found in Triple Helix I (Etzkowitz and Leydesdorff, 2000; Etzkowitz and Dzisah, 2008).

Recognising the limitations of both models, Etzkowitz and Leydesdorff (2000, p.111) built on the coevolutionary theory to highlight the need for the Triple Helix III, which 'is generating a knowledge infrastructure in terms of overlapping institutional spheres'. They

[29] Examples of countries adopting Triple Helix I model comprised the former Soviet Union and Eastern Europe where the state exerted strong directive influence under 'existing socialism' (Etzkowitz and Leydesdorff, 2000, p. 111). Many Latin American countries and some European countries like Norway were also deemed to be adopting this model although the states played a relatively weaker role than those of the former Soviet Union and Eastern Europe.

[30] In the Triple Helix II model, exemplified by Sweden and the US, the states, academia and industry were recognised as 'separate institutional spheres with strong borders dividing them and highly circumscribed relations among the spheres' (Etzkowitz and Leydesdorff, 2000, p. 111).

advocated that each sphere should take 'the role of the other and with hybrid organisations emerging at the interfaces' (Etzkowitz and Leydesdorff, 2000, p.111). They asserted that this was the model that most countries would strive to achieve in one way or another, with a view to fostering an innovative ecosystem made up of university spin-offs, university-government-industry partnerships to drive knowledge-based economic growth and collaboration among the public/academic research laboratories and the private sector. The Triple Helix III, contrasts with the traditional industry-government-university arrangements in that these relationships are not dictated by the state but motivated by other factors of the innovative ecosystem, including the availability of funding, public assistance programmes, IP policies (e.g., the Bayh-Dole Act in the USA) and the public venture capital fund (e.g., the Knowledge Competency Foundation in Sweden).

B3.2 Theoretical Foundation of Triple Helix: Coevolutionary and Endogenous Growth Theories

Etzkowitz and Leydesdorff (2000, p. 112) argued that 'national systems of innovations' (Lundvall, 1988; Nelson, 1993) were symptomatic of the ongoing state of flux and re-structuring occurring in the economy in its evolution from being a resource-based to knowledge-based society. Based on the coevolutionary theory, the authors asserted that the Triple Helix depicts continuous self-organisation into new institutional and cognitive structures within the existing three strands of the Triple Helix in response to mismatches in the transition and complexities of extant systems (Maturana, 1980; Luhmann, 1996). The concept of coevolution is not new. In the publication of *Prolegomena on Coevolution: A Framework for Research on Strategy and New Organisations*, Lewin and Volberda (1999) reviewed the literature on the coevolutionary theory and highlighted the key contributions to the theory. We performed a search on Google Scholar and found that, since the publication by Lewin and Volberda (1999), there were more than 630 publications in the fields of business and management citing the coevolutionary theory from 1999 to 2012, as shown in Figure B-5.

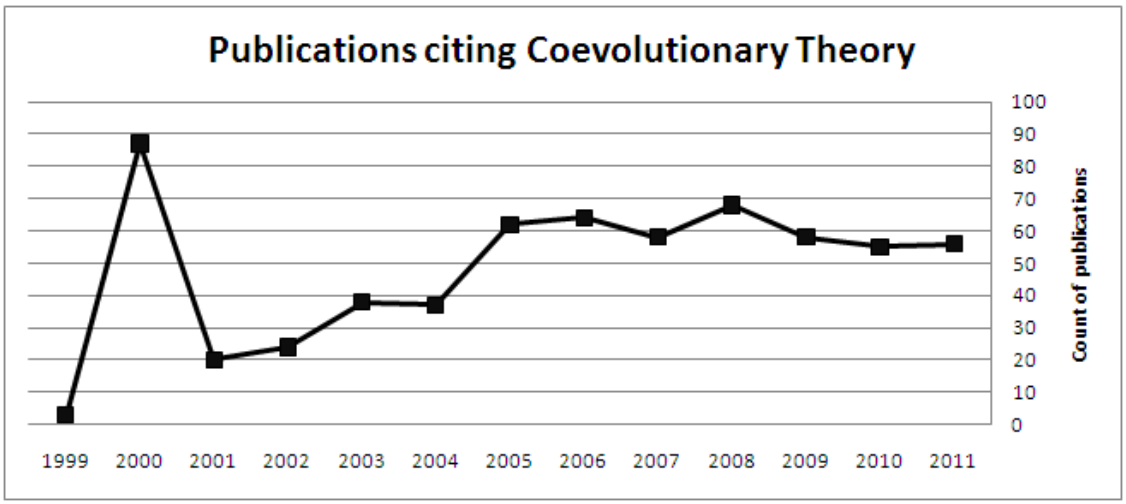

Figure B-5: Publications citing Coevolutionary Theory based on Prolegomena on Coevolution: A Framework for Research on Strategy and New Organisations by Lewin and Volberda (1999)
Source: Researcher's own source using Google Scholar search

The coevolutionary theory has gained intense interest in the strategy and organisation theory and introduced a new perspective on the long-standing debate between adaptation by the organisation (Child, 1972) and selection by the environment (Hannan and Freeman, 1977) as the key force spurring the transition of organisations, which are regarded as units of evolution. The notion of coevolution implied in Weber's (1978) work on bureaucratic organisation explains organisational change in response to transitions taking place in the industrial age. This principle of historical embeddedness in the coevolutionary theory is also illustrated in the work of Chandler (1962), who made similar arguments for the coevolution of organisation structure with the industry. The literature on coevolution examined several aspects of the coevolutionary theory (Lewin and Volberda, 1999, p. 526).

One aspect of coevolutionary theory pertains to the underlying principles and processes as involving 'variation, selection and retention' (Lewin and Volberda, 1999, p. 525; Aldrich, 1979), that is, the need for reciprocal learning for retention and improvement (Nelson and Winter, 1982; Levitt and March, 1988). Other aspects of the coevolutionary theory include 'multidirectional causalities', 'nonlinearity' and 'positive feedback' (Lewin and Volberda, 1999, p. 523), depicting the reciprocal and recursive nature of changes as organisations and their environment co-evolve as a result of their interactions

with one another (Baum, 1999; Kauffman, 1993; McKelvey, 1997). The coevolutionary theory also asserts that coevolution could take place at multiple levels, such as inter-firm microcoevolution and firm-industry macrocoevolution (McKelvey, 1997; Birkinshaw, 2000; Andersson, Forsgren and Holm, 2002). The microcoevolution level concentrates on competition for resources, competencies and capabilities within a firm, while the macrocoevolution level depicts the inter-firm competition within their niche (McKelvey, 1997; Levinthal and Myatt, 1994; Huygens, 1999).

Madhok and Liu (2006) integrated the macrocoevolution and microcoevolution aspects of the coevolutionary theory with the concepts of causal ambiguity (Reed and DeFillippi, 1990) and absorptive capacity (Cohen and Levinthal, 1990) to advocate that causal ambiguity and absorptive capacity could affect the transfer of knowledge and innovation across the subsidiaries of a MNC operating in a coevolutionary context. The causal ambiguity refers to the 'basic ambiguity concerning the nature of the causal connections between actions and results' (Lippman and Rumelt, 1982, p. 420), while absorptive capacity means 'a dynamic capability pertaining to knowledge creation and utilisation that enhances a firm's ability to gain and sustain competitive advantage' (Zahra and George, 2002, p. 185). Madhok and Liu (2006) regarded causal ambiguity as an inhibitor particularly in microcoevolution but absorptive capacity as a catalyst to inter-subsidiary knowledge transfer in both macrocoevolution and microcoevolution, and hence have a bearing on the MNC's competitive performance. Etzkowitz and Zhou (2007) also built on the coevolutionary and absorptive capacity theories to examine the coevolution of university technology licensing and knowledge transfer.

Other discussions of coevolutionary literature revolve around the different types of coevolutionary systems[31]: zero-sum competitive (Beinhocker, 1997), cooperative (Koza and Lewin, 1998), partially competitive and synergistic (Baum, 1999, p. 120; Galunic and Weeks, 2002). Madhok and Liu (2006, p. 17) extended the argument purporting that

[31] In a zero-sum competitive coevolutionary system, the rise in a firm's competitiveness leads to a decline in another firm's competitiveness. In a partially competitive coevolutionary system, there is sharing of some resources among competing firm. In a synergistic coevolutionary system, the rise in one firm's competitiveness could lead to a rise in other firms' competitiveness.

the ‘tacit, causally ambiguous, socially complex’ nature of the coevolutionary rents could render them ‘an important source of sustainable competitive advantage’.

Leydesdorff (2000) applied the principles of the coevolutionary theory to explain the foundation of the Triple Helix III model: historical embeddedness, multiple levels at which the coevolution takes place, retention-selection-variation process, non-linearity and positive feedback (Lewin and Volberda, 1999, p. 527). The Triple Helix III model depicts the social construction of meaning and reconstruction of historically embedded codification and communication in knowledge-based systems found in the three institutional spheres (Frenken, 2005; Leydesdorff and Zawdie, 2010). The relations among the university-government-industry institutions provide the mechanisms of knowledge retention. The selection mechanisms, on the other hand, may be presented in the form of vertical institutional configurations, or horizontal arrangements for ‘market transactions’ or ‘scientific communications’ (Leydesdorff and Zawdie, 2010, p. 797) across the institutions. As for the ‘sources of variation’, Leydesdorff (2000, p. 244) posits that the Triple Helix III model offers three: (i) ‘prolonged period of equilibrium’, (ii) ‘lock-in’ and (iii) ‘interaction factors’. The Triple Helix model enables analysis at multiple levels, including study of interactions among university, government and industry at institutional level (Gunasekara, 2006) or the relationship between university R&D knowledge and the industry from the perspective of communication (Langford, 1997). The non-linear interactions among the industry (economic), government (political) and university (technological) institutions with their ‘recursive’ and ‘positive feedback’ provide the dynamics for mutual learning and fostering innovation (Lewin and Volberda, 1999, p. 527).

Based on the principles of the coevolutionary theory, the Triple Helix model would therefore be useful to explain the apparent re-structuring taking place in the university-industry-government relations with due considerations given to sociological aspects including ‘institutional retention, re-combinatorial innovation and reflexive controls’ (Etzkowitz and Leydesdorff, 2000, p. 112).

Apart from using the coevolutionary theory as the foundational framework for the Triple Helix (Leydesdorff, 2000; Leydesdorff and Zawdie, 2010; Etzkowitz, 2000), Etzkowitz, together with Dzisah (2008), adopted the perspective of Schumpeter's endogenous growth theory[32] (Schumpeter, 1943, 1949). From the lens of Schumpeter's theory, the Triple Helix model recognised that economic development (built on 'exogenous development' based on foreign direct investment of technologies and resources for value creation that was attributable to lower-cost domestic resources, such as cheaper labour, land or raw materials) would not be sustainable in the long-term (Etzkowitz and Dzisah, 2008, p. 656). For a country to be able to sustain its economic development, it should be capable of 'endogenous development' through adding value to its domestic resources and utilising its own resources that are renewable and scalable (Etzkowitz and Dzisah, 2008, p. 656). Such resources should be the intellectual resources that are developed and harnessed by the academia institutional sphere, comprising the university and PRIs (Etzkowitz and Dzisah, 2008; Florence, 2007). The academia institutional sphere should therefore work very closely with the other two institutional spheres to develop an innovation-driven economy in a knowledge-based society. As public policy makers, sociologists, economists, political scientists of both developed and developing countries look for solutions for sustainable economic growth in the face of increasing mobility of capital and workforce, they have increasing expectations of the growing significance of science and technology on economic growth, given the emerging role that university and public research centres play.

B3.3 Implications of the Triple Helix

The Triple Helix is non-linear model that is useful for understanding the socio-economic aspects of the innovation system. However, some researchers such as Shinn (2002, p. 606) expressed concerns with the theoretical foundations of the model, citing the need for further clarity on the coevolutionary theory's expressions of 'lockin' and 'overlays' to deal with the extensive mathematical formulations supporting the theory. The author further highlighted the imperative for suitable units of analysis to ensure rigorous support

[32] Schumpeter's endogenous growth theory is discussed in Section 2.2.1.

of the theory with strong empirical evidence. This is consistent with the views of Leydesdorff and Zawdie (2010, p. 801), who conceded that the complexity of the Triple Helix model with the underlying recursive processes of the coevolutionary framework could mean a relatively 'high level of abstraction', and that 'empirical studies force us to be specific'. In the Triple Helix model, the 'analytic thrust' could be further elucidated, particularly in what constitutes the new entities that make up the hybrid organisations in the form of TTOs and incubators, why and how they emerge, as well as how they corroborate the model by linking 'institutional, economic and cognitive changes' taking place at both the macro regional or national level and the micro firm or PRI level (Shinn, 2002, p. 605 and p. 607). Smith and Bagchi-Sen (2010, p. 805), on the other hand, were concerned that the characteristics of the role of 'entrepreneurs' and 'individual actors' such as universities seemed to have been overlooked in the model. Such issues would entail further empirical research.

The scholars who subscribe to the view of the New Economics of Science would argue that the primary role of the university should remain as education and research (Dasgupta and David, 1994). The scholars are sceptical that the close relationship between the university and the industry might focus the former on research for short-term commercial gain of the latter, but at the expense of long-term research that could have important social, in addition to economic, outcomes. As concentrating on industrial research only could have a deleterious effect on the capacity of the nations to build their scientific capabilities for the future, Eun, Keun and Wu (2006, p. 1329) recommended a 'contingent or context-specific' approach to academia-industry relation. They advocated that every nation should adapt its own NIS and choose an appropriate configuration of government-industry-academia relationships to maximise its socio-economic impact (Eun et al., 2006; Eom and Lee, 2011).

As the 'context-driven' characteristic of the Triple Helix framework becomes apparent (Eun et al., 2006, p. 1329), we witness increasing interest by researchers and public policy makers in both developed countries (US by Kim et al., 2012; Sweden by Frykfors and Jönsson, 2010; UK by Smith and Bagchi-Sen, 2010) and developing nations (China

and Korea by Kim, Huang, Jin, Bodoff, Moon and Choe, 2011; Taiwan by Shapiro, 2011) that they are keen to investigate the relevance of the Triple Helix, the coevolutionary and Schumpeter's endogenous growth theories with regard to the various aspects of their innovation systems. They further propose the appropriate configuration of government-industry-academia relation for their societies as they co-evolve through the variation-selection-retention process to transition from being resource-based to knowledge-based, and from pursuing exogenous to endogenous economic development (Leydesdorff, 2010; Etzkowitz and Dzisah, 2008). Indeed, the current need for availability of empirical data and rigorous quantitative research methodology with consideration of the macro-level (regional or national elements) and its linkage with the micro-level (firm factors) provides much room and clear directions for further research and analysis (Leydesdorff and Zawdie, 2010).

This research builds on the principles and theoretical foundations of the Triple Helix model based on the coevolutionary and Schumpeter's endogenous growth theories to examine the growing significance of how the public sector (government institution)-funded PRIs (academia institution) and TTOs (hybrid organisation) positively influence the (a) propensity of the innovating firms (industry) to license PRIs' indigenous technologies and (b) the firms' business performance (which contributes to economic performance) (Suvinen, Konttinen and Nieminen, 2010). The results of this research contribute to the body of knowledge of the Triple Helix not only by refining the analytic thrust of the Triple Helix framework (Shinn, 2002; Leydesdorff and Zawdie, 2010), but also by investigating how the relationships impact the firms' commercialisation performance (Eom and Lee, 2011).

B4 Knowledge Production

For the past 67 years since the end of World War II, we have witnessed the introduction of different models of knowledge production and innovation, as economists, politicians, technologists and business schools have debated intensely over the roles of research, invention, innovation and their relationships with economic growth. This section reviews the key models postulated by scholars and practitioners of recent decades: Linear Model, Chain-linked Model and New Production of Knowledge Model. This discussion concludes with the limitations and implications of these models and directions for future research.

B4.1 The Linear Model

The Linear Model of Innovation has been regarded as one of the earliest theoretical models developed to study science and technology and its significance to economic development (Godin, 2006). The Model posits that the innovation process undergoes four sequential phases: (a) 'basic research', (b) 'applied research', (c) 'development' and (d) 'production and diffusion' (Godin, 2006, p. 4). Although the exact source of this model has never been formally documented, some researchers have attributed the introduction of the model to Vannevar Bush's work on *Science: The Endless Frontier* in 1945 (Rosenbloom and Spencer, 1996; Freeman, 1996). Some critics have found the four-stage Linear Model of innovation to be over-simplistic in assuming that socio-economic benefits could be reaped with basic research spilling over to industrial research and strong federal support, despite empirical evidence in the US indicating that basic research could positively influence economic growth and productivity (Mansfield, 1980; Griliches, 1986).

B4.2 Chain-Linked Model

Kline and Rosenberg (1986) criticised that the Linear Model of innovation viewing innovation as an orderly process has failed to take into account that innovation is highly complex, disorderly and iterative with a great deal of uncertainties arising from changes

in many dimensions. They argued that innovation should be regarded as an outcome of two major types of forces at play that 'interact with one another in subtle and unpredictable ways': the forces of market demand and the forces of technology supply (Kline and Rosenberg, 1986, p. 275). The technology supply forces allude to the performance trajectories of science and technologies at the forefront and their potential applications for new or improved products and services. The market forces refer to changing market demographics, affluence levels, preferences and expectations that represent opportunities for technology commercialisation. As a case in point, Tushman and Moore (1982) demonstrated that out of the 1800 innovations reported by Marquis (1982) that were successfully commercialised, as high as 75% was motivated by 'perceived market needs', while the remaining 25% was inspired by 'perceived technical opportunity' (Kline and Rosenberg, 1986, p. 276).

Recognising the significant role of trials and feedback on innovation and the complex interaction between technology supply and market demand that the Linear Model neglected, Kline and Rosenberg developed an alternative model, Chain-linked Model (1986). The Chain-linked Model (Kline, 1985; Kline and Rosenberg, 1986) is the most-cited non-linear model of innovation emphasising the socio-technological aspects of innovation and that knowledge should not be limited to a particular discipline, but be accumulated and distilled from multiple disciplines to arrive at a solution at system level that is holistic and robust (Fischer, 2001; Lundvall, 2007). The notion of inter-disciplinary knowledge production is also consistent with the works of Gibbons et al. (1994) who advocated the need for multi-disciplinary team to work together for short periods to solve real-world problems. Laursen and Foss (2003) suggested that appropriate job design and workplace factors for research scientists and engineers could enhance knowledge sharing and build-up. Although it comprises five phases commencing with the (a) market-finding phase, and proceeding to (b) design, (c) testing and (d) production, before ending with the (e) marketing and distributing phase, it is different from the Linear Model in that there are five pathways instead of one to innovation, as innovation may occur at any of the phases. These pathways capture the chain of innovation, feedback,

linkage to science through design, development and production, NPD and research support.

According to Marques and Monteiro-Barata (2006), the Chain-linked Model is deemed as one of the fourth-generation models of innovation described by Rothwell (1994, p. 12) comprising the essential features of 'integration' and 'parallel development' among a firm's internal functions and with its external users and suppliers. Although the Chain-linked Model was a significant improvement over the previous generations of the Linear Model, it was criticised for lacking in system integration and networking (Rothwell, 1992). Critics contended that the Chain-linked Model only became a compelling success factor for firms wanting to remain profitable in the faltering economies of the 1990s marked by higher quality expectations, shorter product life cycles and market de-regulation (e.g., telecommunication) and industry convergence (e.g., computer and mobile equipment industries). Other criticism included its bias towards incremental rather than radical innovation (Klevorick, Levin, Nelson and Winter, 1995; Cohen, Nelson and Walsh, 2002; Van Gils, Vissers and De Wit, 2009), as well as its lack of organisational learning dimension (Caraca et al., 2010).

B4.3 Mode-2 Knowledge Production Model

Apart from the Chain-linked Model, the Mode-2 Knowledge Production model introduced by Michael Gibbons, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott, and Martin Trow in the publication *The New Production of Knowledge* (1994) has gained much attention in the literature on knowledge production. The authors noted that the mode of knowledge production was changing rapidly from the current set of discipline-based research practices, which they referred to as Mode-1, to a new form of context-driven and multi-disciplinary research practice, described as Mode-2.

B4.3.1 Mode-1 Knowledge Production

The Mode-1 Knowledge Production denotes the current accepted modes of intellectual work and behavioural patterns in universities and research institutes, stipulating what constitutes good research problems, how good research should be conducted, who is

qualified to conduct or contribute to good research and what is considered a good research outcome. The current research practices of universities and research institutes are structured by *areas of technical specialisation or disciplines*. Similarly, the academic faculty members are organised in *hierarchical forms* by their *areas of expertise.* Their research *problems are defined according to the interests of academics* who are given considerable *autonomy* in proposing research topics of their disciplines, and solutions worked out by research teams possessing relatively *homogeneous technical knowledge,* and *reviewed by peers of similar expertise.*

B4.3.2 Mode-2 Knowledge Production

As the system of knowledge production becomes distributed driven by the above trends of government policies, computer and communications technologies and market competition, Gibbons (2000) asserted that this phenomenon would shift the mode of Knowledge Production from the current Mode-1 to Mode-2. Mode-2 is distinguished from Mode-1 by *trans-disciplinary structures*, *flatter organisation forms* by projects with a greater sense of social responsibility, research problems defined according to *practical applications*, research teams of *heterogeneous* technical knowledge and review teams with more *diverse* interests and a *wider range* of considerations. A summary of the comparison between Mode-1 and Mode-2 Knowledge Production may be found in Table B-3.

Mode-1	Mode-2
Investigator-led research	Context-driven research
Disciplinary	Trans-disciplinary
Knowledge homogeneity	Knowledge heterogeneity
Research Autonomy	Social Accountability/ Reflexivity
Traditional Quality Control of Research Process and Outcome (Peer Review)	New Form of Quality Control

Table B-3: Comparison between Mode-1 and Mode-2 Knowledge Production (Hessels and van Lente, 2008, p. 741)

Although the New Production of Knowledge Model has been discussed positively by researchers and practitioners of diverse disciplines, it has also attracted opposition from

other scholars. Hessels and van Lente (2008) found that the *New Production of Knowledge* by Gibbons et al. (1994) had been cited more than 1000 times in academic journals by January 2007. While 80% of the citations generally accepted the publication by Gibbons et al., the remaining 20% were critical of the model, with some challenging its claims. These criticisms revolved around the need for empirical support, the weakness of the theoretical concepts and the resemblance to political ideology (Godin, 1998; Weingart, 1997; Etzkowitz and Leydesdorff, 2000; Hessels and van Lente, 2008).

B4.4 Implications of the Knowledge Production Models

In this section, we have seen the various models of innovation and knowledge production and how the Chain-linked Model and the New Production of Knowledge Model are regarded as significant improvement over their predecessor, the Linear Model (Kline and Rosenberg, 1986; Gibbons et al., 1994). However, these non-linear models are not without their critics. On the one hand, the Chain-linked Model needs to consider structuring for radical innovation (Crossan and Apaydin, 2010), organisational learning dimension (Caraca et al., 2010) and inter-organisational collaboration (Marques and Monteiro-Barata, 2006), including looking beyond organisational boundaries to access complementary assets (Teece, 1986) and open innovation (Chesbrough, 2006a). On the other hand, the New Production of Knowledge Model has been advised to perform rigorous empirical analysis underpinned with strong theoretical concepts and research methodology such as the Triple Helix model (Shinn, 2002; Hessels and van Lente, 2008). This research attempts to include in its conceptual framework some of the dimensions that have been highlighted above as lacking in the current knowledge production models: organisational learning, inter-organisational collaboration specifically in the form of external technology acquisition (van Gils et al., 2009), access to complementary assets and open innovation. In particular, the concepts of RBT (Wernerfelt, 1984; Barney, 1991), KBT (Grant, 1996) and CBT (Hamel and Prahalad, 1994) are discussed in Section 2.3 on University-Industry Collaboration to examine the above dimensions. Section 2.4 on External Technology Acquisition reviews the literature on the absorptive capacity theory (Cohen and Levinthal, 1990), the complementary assets and IP appropriability (Teece, 1986) from TCE (Coase, 1937). Section 2.5 on Innovation and Performance at Firm

Level traces the development of the open innovation concept (Chesbrough, 2006a; Vanhaverbeke, 2012) in greater detail.

Figure B-6 illustrates the growth in disclosures and patent filing activities in US universities, hospitals and research from 2000 to 2010. Figure B-7 depicts the rising trend in the gross license income that they have received for the same period (AUTM, 2010). These figures are discussed in Section 2.3.1.

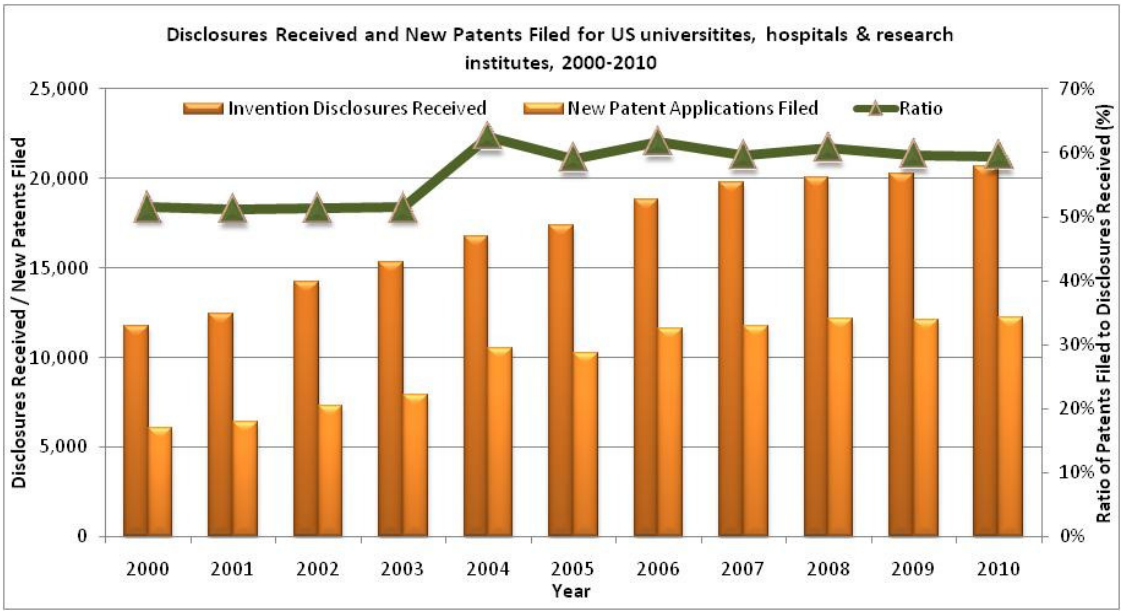

Figure B-6: Disclosures Received and New Patents Filed for US universities, hospitals and research institutes, 2000-2010 (AUTM, 2010)

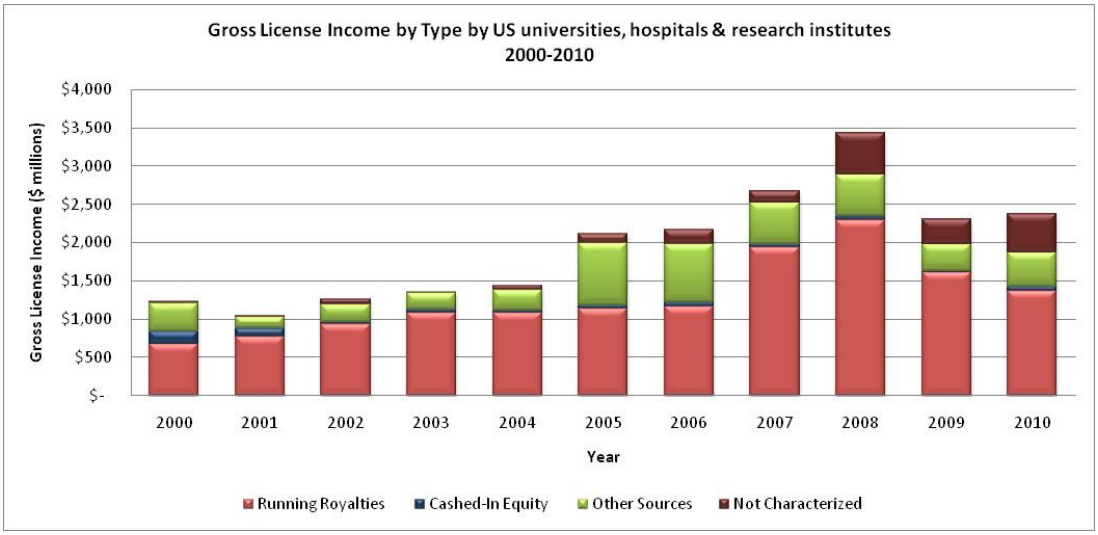

Figure B-7: Gross License Income by Type by US universities, hospitals and research institutes, 2000-2010 (AUTM, 2010)

Figure B-8 illustrates the growth in patent filings by the top 20 countries of origin between 2003 and 2007. The implication of this figure is discussed in Section 2.3.2.

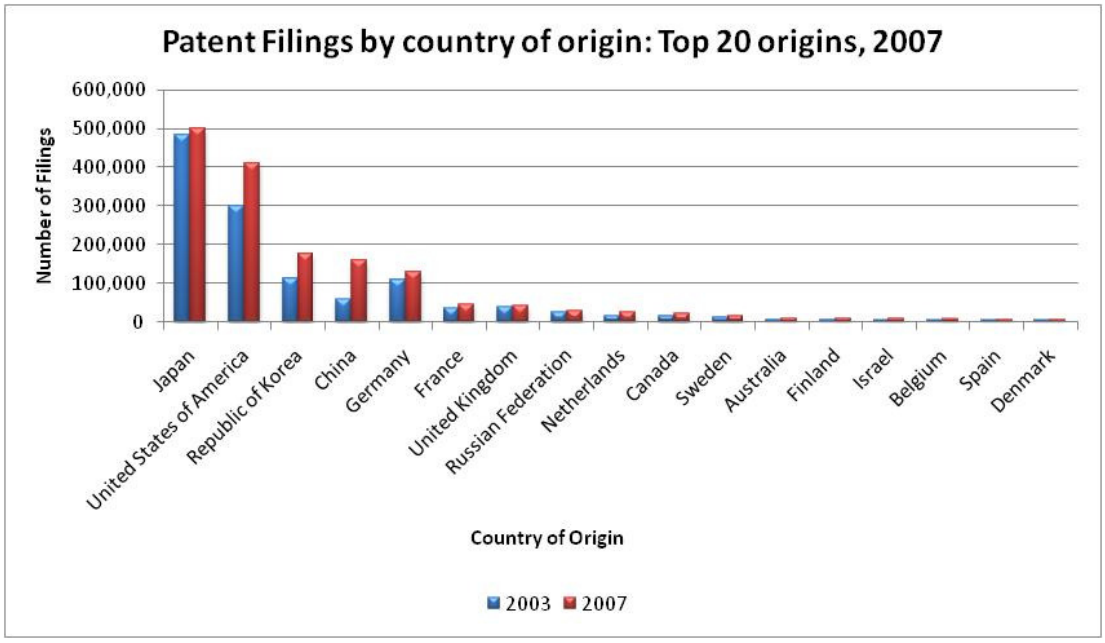

Figure B-8: Patent Filings by country of origin: Top 20 origins, 2007
Source: WIPO Statistics Database, June 2009

Figure B-9 shows that the trend of foreign ownership of domestic inventions for a range of countries, as discussed in Section 2.5.

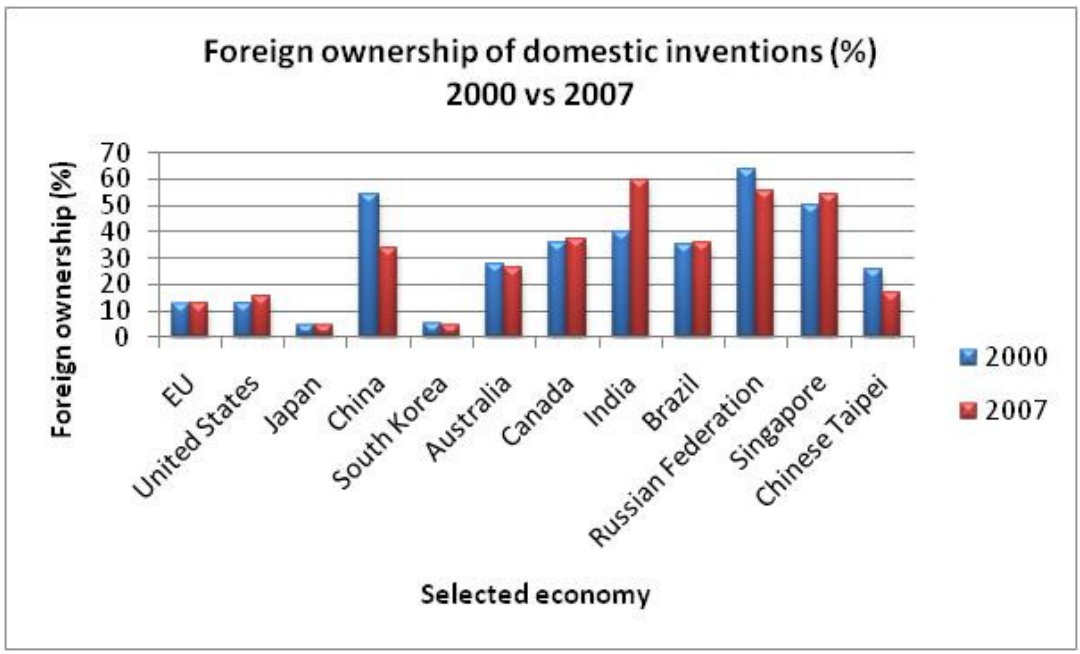

Figure B-9: Foreign ownership of domestic inventions (%) 2000 versus 2007
Source: *Innovation Union Competitiveness Report* (European Commission, 2011, p. 303)

Figure B-10 compares the domestic ownership of foreign inventions between 2000 and 2007 across various regions, while Figure B-11 contrasts the innovation barriers between SMEs and large firms, as discussed in Section 2.5.

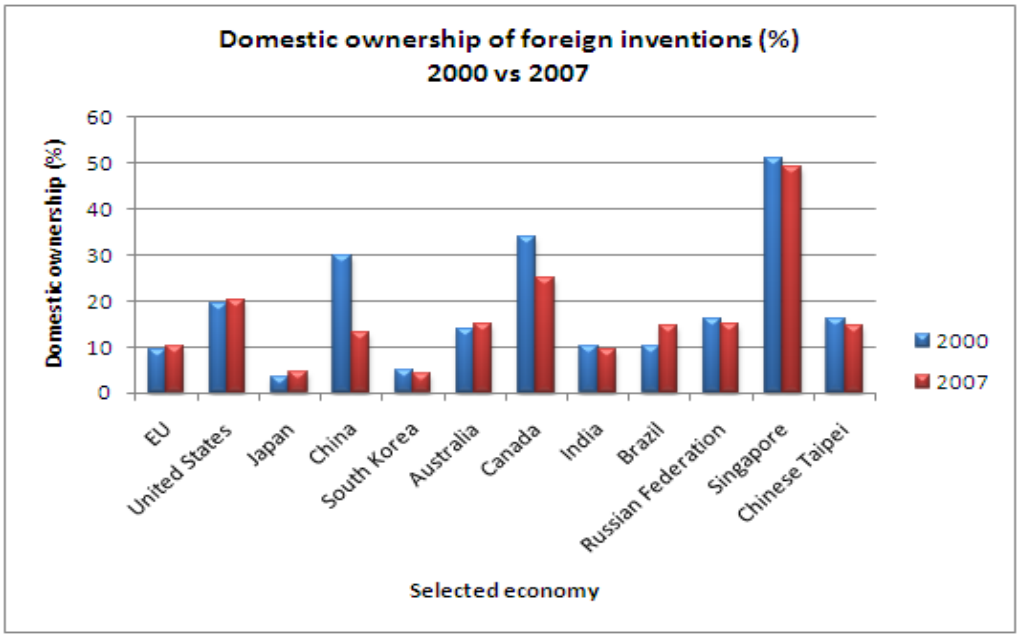

Figure B-10: Domestic ownership of foreign inventions (%) 2000 versus 2007
Source: *Innovation Union Competitiveness Report* (European Commission, 2011, p. 304)

Innovation barriers	SME	Large Enterprises
Challenges in seeking appropriate staffing	1	3
Lack of appropriate staffing within the firm	2	11
Uncertainty in innovative products in market	3	18
Likelihood of innovation imitation	4	16
Lack of capability in R&D management	5	23
Lack of technological intelligence	6	9
Lack of fund arising from high risk in technology	7	26
Lack of fund arising from high commercialisation costs	8	2
Lack of market intelligence	9	7
High turnover in R&D staff	10	5
Challenges in engaging external technology and business services	14	10
Lack of empowerment and autonomy for R&D managers	16	8
Imperfect market structure	18	1
Cash flow challenge from customer payment delay	23	6
Redundancy of additional innovation	25	4

Figure B-11: Comparison of Innovation Barriers between SMEs and large enterprises (Source: Lee et al., 2010)

Appendix C: Questionnaires for Evaluation Licensees

GENERAL INFORMATION

1. Year organisation is established: _____

2. a) Total employment in 2009 (full-time equivalent) _____

   b) Fixed Asset Investment (FAI) as of 2009:
   i) Below S$1 million [ ] ii) S$1 - S$3.9 million [ ] iii) S$4 - S$7.9 million [ ]
   iv) S$8 - S$11.9 million [ ] v) S$12 – S$15 million [ ]

3. Please indicate your organisation's primary technological area:
   a) Infocomm Technology [ ] b) Engineering and manufacturing [ ]
   c) Materials, Chemical and Energy [ ] d) Biomedical sciences and life sciences [ ]

4. Please indicate your organisation's primary industrial focus:
   a) Electronics [ ] b) Chemicals [ ] c) Info communications []
   d) Engineering [ ] e) Biomedical products & services [ ] f) General Manufacturing []

5. Has your organisation ever licensed technology from any other organisation before?
   a) Yes [ ] b) No [ ]

EVALUATION LICENSEES

The following questions relate to your experiences in evaluation licensing

6. Would/Did your organisation license technologies from PRI after evaluation?
   a) Yes [ ] b) No [ ]
   If 'No', Please select (by ticking) the reasons for deciding not to license technologies from PRI (you may select more than one reason):

a)	My organisation lacks the manpower to commercialise the licensed technology	
b)	My organisation lacks the funding to commercialise the licensed technology	
c)	My organisation lacks the complementary technology needed to commercialise the licensed technology	
d)	There is a mismatch between the licensed technology and the innovation needed for my organisation	
e)	The PRI researcher is not available to transfer the licensed technology to my staff	
f)	The PRI's technology readiness level is not adequate for the purpose of our R&D	
g)	The technology commercialisation officer is not available to respond to our requests	
h)	The results of the evaluation are below expectations.	
i)	Others: (please specify)_____	

7. To what extent do the following factors negatively impact your organisation's ability to commercialise the evaluated technology? (1 – 'Low Impact to 5 – 'High Impact')

a)	Stringent regulatory requirements	1 2 3 4 5
b)	Lack of customers' interest in our new products	1 2 3 4 5
c)	Intense market competition	1 2 3 4 5
d)	Customer's fear of Technology Obsolescence	1 2 3 4 5
e)	Competing technologies and standards	1 2 3 4 5

8. On a scale of 1 to 5, how satisfied are you with the following attribute of the licensed technology evaluated for the purpose of your organisation's R&D? (1- 'Very Dissatisfied', 5 – 'Very Satisfied')

a)	The technology readiness level	NA 1 2 3 4 5

9. Please select the extent to which you agree with the following statements of the technology commercialisation officer/s (1 – 'Strongly Disagree', 5 – 'Strongly Agree')

a)	The officer provides adequate advice and guidance on the licensing process	1 2 3 4 5
b)	The officer is always available to respond and attend to my queries and requests	1 2 3 4 5

10. Please select the extent to which you agree with the following statements of the researcher/s of the public Research Institutes (PRI)(1 – 'Strongly Disagree', 5 – 'Strongly Agree')

a)	The PRI researchers are knowledgeable and competent to transfer the licensed technologies to our organisation.	1 2 3 4 5
b)	The PRI researchers are available to transfer the licensed technologies to our organisation	1 2 3 4 5

The following questions help us understand more about your organisation to serve you better.

11. Please select the extent to which you agree with the following statements about your organisation resources in transferring technology from PRI (1 – 'Strongly Disagree', 5 – 'Strongly Agree')

a)	Our own R&D staff are knowledgeable and competent to assimilate and exploit internally the knowledge from PRI	1 2 3 4 5
b)	Our own R&D staff are available to assimilate and exploit knowledge from PRI	1 2 3 4 5
c)	Our organisation requires the technologies that are developed by the PRI.	1 2 3 4 5
d)	For our organisation's innovation, knowledge from the PRI is more important to us than knowledge from our suppliers and customers.	1 2 3 4 5
e)	The following are effective mechanisms in protecting my organisation's competitive advantage: i. secrecy ii. economies of scale	 1 2 3 4 5 1 2 3 4 5
f)	Our organisation is willing to commit resources to IP protection to gain competitive advantage.	1 2 3 4 5

12. How would you rate the following capability of your organisation in relation to your competition (1 – 'Much Weaker Than Competition', 5 – 'Much Stronger Than Competition')

a)	The quality of our market research	1 2 3 4 5
b)	The range of our products	1 2 3 4 5
c)	The cost of our production	1 2 3 4 5
d)	The effectiveness of our marketing strategy	1 2 3 4 5
e)	The quality of our customer service	1 2 3 4 5
f)	The extensiveness of our distribution network	1 2 3 4 5

Appendix D: Questionnaires for Commercial Licensees

GENERAL INFORMATION

1. Year organisation is established: _____

2. a) Total employment in 2009 (full-time equivalent) _____

   b) Fixed Asset Investment (FAI) as of 2009:
   i) Below S$1 million [ ] ii) S$1 - S$3.9 million [ ] iii) S$4 - S$7.9 million [ ]
   iv) S$8 - S$11.9 million [ ] v) S$12 – S$15 million [ ]

3. Please indicate your organisation's primary technological area:
   a) Infocomm Technology [ ] b) Engineering and manufacturing [ ]
   c) Materials, Chemical and Energy [ ] d) Biomedical sciences and life sciences [ ]

4. Please indicate your organisation's primary industrial focus:
   a) Electronics [ ] b) Chemicals [ ] c) Info communications []
   d) Engineering [ ] e) Biomedical products & services [ ] f) General Manufacturing []

5. Has your organisation ever licensed technology from any other organisation before?
   a) Yes [ ] b) No [ ]

COMMERCIAL LICENSEES

The following questions relate to your experiences in commercial licensing

6. What is the commercialisation status of your new products or services that embody the technology licensed from the technology commercialisation organisation? Please circle the appropriate option below:
   a) No plans to commercialise
   b) Commercialised
   c) Expect to commercialise in 1 year
   d) Expect to commercialise in 2 years
   e) Expect to commercialise more than 2 years from now

   If you have selected (a), please answer question 7.
   If you have selected (b), please answer questions 8.1 to 8.3
   If you have selected (c)-(e), please answer questions 8.3.

7. Please select (by ticking) the reasons for not commercialising the licensed technology (you may select more than one reason):

a)	My organisation lacks the manpower to commercialise the licensed technology	
b)	My organisation lacks the funding to commercialise the licensed technology	
c)	My organisation lacks the complementary technology needed to commercialise the licensed technology	
d)	There is a mismatch between the licensed technology and the innovation needed for my organisation	
e)	The PRI researcher is not available to transfer the licensed technology to my staff	
f)	The PRI's technology readiness level is not adequate for the purpose of our R&D	
g)	The technology commercialisation officer is not available to respond to our requests	
h)	Others: (please specify) _____	

8.1 Please indicate your actual sales of new/improved products embodying the licensed technology in the latest fiscal year (in approximate % of total annual sales)
a) 0 b) Less than 5% [ ] c) 5%-10% [ ] d) 11%-15% [ ] e) 16%-20% [ ] f) 21% & above [ ]

8.2 Please indicate your actual production volume using new/ improved processes from the licensed technology in the latest fiscal year (in approximate % of annual production volume):
a) 0 b) Less than 5% [ ] c) 5%-10% [ ] d) 11%-15% [ ] e) 16%-20% [ ] f) 21% & above [ ]

8.3 What is your projected annual growth rate of sales revenue of the product(s) embodying the licensed technology in the next 3 years (in approximate %)?
a) Less than 5% [ ] b) 5%-10% [ ] c) 11%-15% [ ] d) 16%-20% [ ] e) 21% & above [ ]

9. The following are criteria used to assess the commercial outcome of the licensed technology. To what extent do you agree with the following statements? (1- 'Strongly Disagree', 5 – 'Strongly Agree')

a)	The licensed technology opens new market(s)	NA 1 2 3 4 5
b)	The licensed technology increases market share	NA 1 2 3 4 5
c)	The licensed technology improves quality of good or services	NA 1 2 3 4 5
d)	The licensed technology increases the range of goods or services	NA 1 2 3 4 5
e)	The licensed technology reduces unit labour costs	NA 1 2 3 4 5
f)	The licensed technology reduces materials per unit	NA 1 2 3 4 5
g)	The licensed technology reduces lead time	NA 1 2 3 4 5
h)	The licensed technology improves capacity	NA 1 2 3 4 5

10. To what extent do the following factors negatively impact your organisation's ability to commercialise the licensed technology? (1 – 'Low impact to 5 – 'High impact)

a)	Stringent regulatory requirements	1 2 3 4 5
b)	Lack of customers' interest in our new products	1 2 3 4 5
c)	Intense market competition	1 2 3 4 5
d)	Customer's fear of Technology Obsolescence	1 2 3 4 5
e)	Competing technologies and standards	1 2 3 4 5

11. On a scale of 1 to 5, how satisfied are you with the following attribute of the licensed technology for your organisation's R&D? (1- 'Very Dissatisfied', 5 – 'Very Satisfied')

a)	The technology readiness level	NA 1 2 3 4 5

12) Please select the extent to which you agree with the following statements of the technology commercialisation officer/s (1 – 'Strongly Disagree', 5 – 'Strongly Agree')

a)	The officer provides adequate advice and guidance on the licensing process	1 2 3 4 5
b)	The officer is always available to respond and attend to my queries and requests	1 2 3 4 5

13) Please select the extent to which you agree with the following statements of the researcher/s of the public Research Institutes (PRI)(1 – 'Strongly Disagree', 5 – 'Strongly Agree')

a)	The PRI researchers are knowledgeable and competent to transfer the licensed technologies to our organisation.	1 2 3 4 5
b)	The PRI researchers are available to transfer the licensed technologies to our organisation	1 2 3 4 5

14) Please select the extent to which you agree with the following statements about your organisation's internal processes for transferring technology from PRI (1 – 'Strongly Disagree', 5 – 'Strongly Agree')

a)	We have internal processes to identify, assimilate and exploit external knowledge from the PRI	NA 1 2 3 4 5
b)	We have internal processes to successfully exploit the new integrated knowledge from PRI into new products or processes	NA 1 2 3 4 5
c)	We ensure that the communication of our work between us and the PRI researchers is timely, accurate and adequate	NA 1 2 3 4 5
d)	We have internal processes to ensure adequate allocation of resources (e.g., information, time, reports) to work with the PRI researcher	NA 1 2 3 4 5
e)	We ensure there is good understanding between the PRI researcher and our R&D staff of each other's roles & responsibilities	NA 1 2 3 4 5
f)	Both the PRI researcher and our R&D staff work closely to ensure that there is smooth transfer of knowledge	NA 1 2 3 4 5
g)	When there were conflicts during the NPD process, • we resolved them by ensuring accurate and complete information between us and the PRI researchers • we resolved them by focusing on our common goals rather than differences	 NA 1 2 3 4 5 NA 1 2 3 4 5

The following questions help us understand more about your organisation to serve you better.

15) Please select the extent to which you agree with the following statements about your organisation resources in licensing technology (1 – 'Strongly Disagree', 5 – 'Strongly Agree')

a)	Our own R&D staff are knowledgeable and competent to assimilate and exploit internally the knowledge from PRI	1 2 3 4 5
b)	Our own R&D staff are available to assimilate and exploit knowledge from PRI	1 2 3 4 5
c)	Our organisation requires the technologies that are developed by the PRI.	1 2 3 4 5
d)	For our organisation's innovation, knowledge from PRI is more important to us than knowledge from our suppliers and customers.	1 2 3 4 5
e)	The following are effective mechanisms in protecting my organisation's competitive advantage: i. secrecy ii. economies of scale	 1 2 3 4 5 1 2 3 4 5
f)	Our organisation is willing to commit resources to IP protection to gain competitive advantage.	1 2 3 4 5

16) How would you rate the following capability of your organisation in relation to your competition (1 – 'Much Weaker Than Competition', 5 – 'Much Stronger Than Competition')

a)	The quality of our market research	1 2 3 4 5
b)	The range of our products	1 2 3 4 5
c)	The cost of our production	1 2 3 4 5
d)	The effectiveness of our marketing strategy	1 2 3 4 5
e)	The quality of our customer service	1 2 3 4 5
f)	The extensiveness of your distribution network	1 2 3 4 5

Appendix E: Recruitment Material for Participants

<Date>

<Name of Participant>
<Address of Participant>

Dear <Name of Participant>,

STUDY OF TECHNOLOGY TRANSFER SERVICES

Greetings to you!

From 2006 to 2010, the Singapore Government has committed $13.5 billion dollars to strengthen the nexus between R&D and businesses as a key strategic thrust of our National R&D Agenda. We have also witnessed an increased interest at the international level on the impact such technology transfer programmes have on the innovation and performance of companies that license and commercialise technologies developed by public research institutes. We are a strategic partner in this agenda to transfer public research expertise to firms through a dedicated licensing framework.

As part of its goal to enhance the quality and impact of its services, we are pleased to commission a study on the link between public research and the economic performance of Singapore. In particular, we are keen to identify the factors that have a significant impact on improving the process of technology commercialisation.

In your capacity as licensees or potential licensees, we would like to invite you to participate in our study. The study is scheduled to commence in July and complete by September 2010. Needless to say, this study is not possible without your contribution and feedback. We appreciate your nomination of a liaison person to participate in our study by completing a survey questionnaire that takes no more than 20 minutes.

We look forward to your support of the study. Please be assured that your responses will be treated with strict confidence. Only aggregated data will be reported or published. No identities will be disclosed without your prior consent. Thank you.

Yours sincerely,

<Name of Representive>

Appendix F: Information Sheet for Participants

UNIVERSITY OF SOUTH AUSTRALIA
International Graduate School of Business

INFORMATION SHEET

Research Project: Commercialisation of Technological Innovation from Public Research Institutes

Researcher's name & contact details: Sarah Cheah, PhD Candidate, MBA
Email: chely065@unisa.edu.au

- You are invited to participate in the above research study. Your participation will be on a voluntary basis.

- The purpose of the study is to investigate the factors that have significant impact on improving the process of technology licensing and commercialisation.

- During the research, the Participant is requested to complete a questionnaire. At any stage, the Participant may withdraw from the research project without affecting his/her status now in the future. The questionnaire should take approximately 20 to 30 minutes to complete.

- The findings of the research will enable us to have a better understanding of the factors affecting firm's decision and ability to commercialise technologies developed by public research institutes. These will enable us to play an even more effective role in facilitating transfer and proliferation of publicly-funded R&D, by avoiding pitfalls and replicating successes.

- The data will be stored on CDROM for 5 years in a locked filing cabinet at our office, as per University policy. The data will be individually non-identifiable.

- No individual is identifiable in the analysis of data. No information which could lead to identification of any individual will be released.

- The University of South Australia's Human Research Ethics Committee has reviewed this study. Should you wish to discuss the project with someone not directly involved, in particular in relation to matters concerning policies, information about the conduct of the study, or your rights as a participant, please contact

  Ms Vicki Allen, Executive Officer
  Human Research Ethics Committee
  University of South Australia
  GPO BOX 2471
  Adelaide SA 5000
  Email: Vicki.Allen@unisa.edu.au
  Tel: +61 8 8302 3118

- Upon the completion of the study, we will send you a copy of the summary of the research findings.

Appendix G: Analysis of Data

Variables	Dependent Variable = Performance (Product Innovation) N=106							
	Model 1		Model 2		Model 3		Model 13	
	b	SE	b	SE	b	SE	b	SE
(Constant)	4.44	1.05	5.05	1.25	5.57	1.22	4.69	1.29
Firm Size log employment	0.28†	0.14	0.54**	0.17	0.62**	0.18	0.58**	0.18
Firm Size log FAI	-0.56**	0.18	-0.69**	0.21	-0.80**	0.21	-0.68**	0.22
Age squared	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Market Barrier	-0.08	0.12	-0.02	0.11	0.04	0.11	0.04	0.11
Technology Barrier	0.13	0.12	0.10	0.12	0.11	0.11	0.06	0.11
Infocomm Industry	0.83**	0.25	0.71**	0.25	0.82**	0.25	1.05**	0.27
Other Industries (Engineering, Manufacturing, Chemicals, Electronics)	0.50**	0.22	0.24	0.23	0.15	0.23	0.38	0.25
Prod Innov Outcome	0.50**	0.09	0.54**	0.09	0.58**	0.10	0.62**	0.11
Internal Commercial CA Res			-0.34**	0.12	-0.44**	0.12	-0.41**	0.12
Internal Commercial IP Res			0.01	0.09	-0.01	0.09	0.02	0.10
NPD Absorp Cap			0.08	0.09	0.03	0.09	-0.06	0.11
NPD Comm Cap			0.37**	0.15	0.53**	0.16	0.60**	0.16
NPD Collab Prob-solv			-0.51**	0.15	-0.63**	0.16	-0.53**	0.17
Prod Innov Outcome x Int Comm CA Res					-0.09	0.10	0.01	0.12
Prod Innov Outcome x Int Comm IP Res					0.22*	0.09	0.19†	0.11
Prod Innov Outcome x NPD Absorp Cap							0.29†	0.16
Prod Innov Outcome x NPD Comm Cap							-0.27	0.28
Prod Innov Outcome x NPD Collab Prob-solv							-0.22	0.32
R-Square Change	0.38		0.12		0.05		0.02	
Probability	0.00		0.00		0.01		0.19	

Table G-1: Regression Results on Performance (Product Innovation) (Models 1 to 3, and full Model 13 after controlling for *Spin-off* effect)
Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$

Variables	Dependent Variable = Performance (Process Innovation) N=73							
	Model 1		Model 2		Model 3		Model 13	
	b	SE	b	SE	b	SE	b	SE
(Constant)	4.26	1.41	4.50	2.09	4.95	2.00	5.17	2.18
Spin off	Not Applicable							
Firm Size log employment	0.23	0.17	0.37	0.26	0.33	0.26	0.26	0.28
Firm Size log FAI	-0.43†	0.25	-0.53	0.38	-0.56	0.36	-0.57	0.40
Age squared	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Market Barrier	-0.04	0.18	0.08	0.19	0.06	0.19	-0.01	0.23
Technology Barrier	0.04	0.17	-0.06	0.18	-0.05	0.18	-0.05	0.19
Biomedical Industry	-0.51	0.38	-0.47	0.43	-0.67	0.44	-0.62	0.46
Other Industries (Engineering, Manufacturing, Chemicals, Electronics)	-0.10	0.25	-0.04	0.29	-0.12	0.30	-0.04	0.32
Proc Innov Outcome	-0.01	0.11	0.17	0.13	0.05	0.13	0.17	0.16
Internal Commercial CA Res			-0.22	0.20	0.07	0.24	0.02	0.25
Internal Commercial IP Res			0.15	0.16	-0.08	0.18	-0.01	0.19
NPD Absorp Cap			-0.03	0.14	0.01	0.13	0.01	0.15
NPD Comm Cap			0.34	0.24	0.26	0.26	0.24	0.30
NPD Collab Prob-solv			-0.52†	0.28	-0.52†	0.30	-0.48	0.34
Proc Innov Outcome x Int Comm CA Res					-0.27†	0.16	-0.19	0.19
Proc Innov Outcome x Int Comm IP Res					0.33*	0.13	0.27†	0.14†
Proc Innov Outcome x NPD Absorp Cap							0.02	0.20
Proc Innov Outcome x NPD Comm Cap							-0.21	0.32
Proc Innov Outcome x NPD Collab Prob-solv							-0.09	0.26
R-Square Change	0.11		0.09		0.09		0.02	
Probability	0.48		0.24		0.03		0.61	

Table G-2: Regression Results on Performance (Process Innovation) (Models 1 to 3, and full Model 13 after controlling for Spin-off effect)
Notes: b values are unstandardised regression coefficients. SE values are standard errors. † $p < 0.10$; * $p < 0.05$; ** $p < 0.01$