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University of Southampton

Faculty of Social Science

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Capability, Appropriability and Performance in the Context of Emerging University-Industry Collaborations

by

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Thesis for the degree of Doctor of Philosophy

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Abstract

Faculty of Social Sciences

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Doctor of Philosophy

Capability, Appropriability and Performance in the Context of Emerging University-Industry Collaborations

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Takron Opassuwan

This thesis aims to advance the knowledge of the impact of capabilities on performance in the context of emerging university-industry collaborations (UIC), and the roles of a firm's appropriability, as an antecedent of an engagement with universities, by addressing three key issues. First, the knowledge body on the relationship between capabilities and performance is fragmented due to ambiguous measures, diverse contexts, and the complex nature of the UIC. Second, empirical studies are biased towards the impact of a firm's technological capabilities on its performance; so, little is known about the effects of a firm's non-technological capabilities. Third, the findings regarding how a firm's appropriability influences its decision to cooperate with universities are contradictory, thus preventing their generalisation. The need to address these issues is further strengthened by the evidence from countries where the UIC is emerging and immature – i.e., a minimal effect of a firm's technological capabilities on its performance when engaged with universities, and a lack of research on the relationship between a firm's appropriability and its cooperation with universities. To address the gaps in the literature, three studies are conducted.

The first study explores ambiguities and complexities in the debate on the relationship between the capabilities of firms and universities on their performance in the UIC context by employing a systematic literature review. Based on 49 peer-reviewed articles, the findings reveal that UIC scholars focus on a broad spectrum of capabilities and performance measures. The firms' technological and non-technological capabilities as well as the universities' research and non-research capabilities are found as critical to enhancing their UIC performance. The impact of the capabilities is also contingent on several factors and contextual settings. The firm's absorptive capacity is a prerequisite to absorb and exploit the university's knowledge successfully. Several issues also emerge from the review such as the firm's R&D intensity as its technological capability, perplexing use of absorptive capacity, and lack of studies on the desorptive capacity. On the basis of synthesis insights, a framework that underpins the key components in the literature is established.

The second study empirically investigates the effects of the firms' innovation capabilities (ICs) on their innovation performance when engaged in various UIC channels. The findings reveal that the effects of ICs on innovation performance are contingent on the UIC channels employed by firms. Particularly, organisational IC is critical when engaged in collaborative research or in the use of the university's research facilities whereas marketing IC is beneficial when adopting consulting and contract research. This paper opens a black box thanks to the ambiguous findings from the literature on emerging UIC by shedding the light on the situation that given the firms' weak technological IC, they can benefit from non-

technological ICs in improving their innovation performance when engaged with the university partners.

The third study explores the relationship between a firm's appropriability and its openness in the UIC context. The analysis reveals that the firm's appropriability exhibits an inverted U-shaped relationship with an engagement with a university. Furthermore, being a product innovator strengthens an inverted U-shaped relationship between the firm's appropriability and its UIC breadth while being a process innovator weakens the relationship and exhibits a U-shaped curve to that relationship. Although excessive appropriability discourages the product innovator from cooperating with the universities through relational governance, the process innovator tends to shift its interest from relational governance to contractual governance.

This thesis finally offers contributions to theory, policy, and management, and suggests avenues for future research.

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Declaration of Authorship

Print name: Takron Opassuwan

Title of thesis: Capability, Appropriability and Performance in the Context of Emerging University-Industry Collaborations

I declare that this thesis and the work presented in it is my own and has been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission.

Signature: .....Date: .....

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Abbreviations

AC	Absorptive capacity
AIC	Akaike's Information Criterion
AJG	Academic Journal Guide
CIS	Community Innovation Survey
Coef.	Coefficient
DC	Desorptive capacity
GEE	Generalized Estimating Equation
IC	Innovation capability
IP	Intellectual property
IPR	Intellectual property right
MNC	Multinational cooperation
NSTDA	National Science and Technology Development Agency
OBM	Original brand manufacturing
OECD	Organisation for Economic Co-operation and Development
OEM	Original equipment manufacturing
OLS	Ordinary Least Square
PIR	Public research intuition
QIC	Independence Model Criterion
R&D	Research and development
SD	Standard deviation
SE	Standard error
TTO	Technology transfer office
VIF	Variance inflation factor
UIC	University-industry collaboration

Chapter 1 Introduction

1.1 Research motivation

University-industry collaboration (UIC) has been recognised as important means of knowledge transfer and technological spillovers in a national economy (Eun *et al.*, 2006; D'Este and Patel, 2007; Hemmert *et al.*, 2014). A firm can benefit from engaging in the UIC for its advancement of R&D in the light of acquiring and exploiting a university's valuable knowledge bases (Cassiman and Veugelers, 2006). In addition, the importance of a university as an R&D partner is further strengthened by its shift from a research-intensive institution - i.e. *the ivory tower*, to an entrepreneurial university, in response to the demands of a knowledge-based economy and entrepreneurial society, thus bridging the gaps between science and industry (Etzkowitz, 2003; Audretsch, 2014; Abreu *et al.*, 2016). Governments, therefore, strive to promote engagement between firms and universities by launching UIC policies and building supporting infrastructures (Bozeman, 2000; Cheng *et al.*, 2020). Over the decades, scholars have paid increasing attention to the UIC subject which has spanned various disciplines such as management studies, the economics of innovation, industrial organisation, the sociology of science, and science and technology policy (Perkmann and Walsh, 2007; Rajalo and Vadi, 2017; Galan-Muros and Davey, 2019).

Understanding the UIC is not straightforward since it is a sophisticated and complex phenomenon (Perkmann and Walsh, 2007) which involves several stakeholders and a broad range of factors (Galan-Muros and Davey, 2019). Scholars thus have conceptualised and developed the UIC frameworks that underpin the key elements in the UIC such as antecedents, collaboration mechanisms, facilitators, barriers, and consequences (e.g., Bonaccorsi and Piccaluga, 1994; De Fuentes and Dutrenit, 2012; Ankrah and Al-Tabbaa, 2015; Galan-Muros and Davey, 2019; Nsanzumuhire and Groot, 2020). These components have become a research trend in the UIC literature for over 50 years (Bastos *et al.*, 2021).

This thesis is inspired by ongoing debates on *what drives firms and universities to engage in the UIC?* and *what makes the UIC successful?* Specifically, this thesis seeks to understand the impact of the firms' capabilities on their performance, and how the firms' appropriability influences their decision to collaborate with the university partners. This thesis also focuses on the counties where the national innovation system is immature and the UIC is emerging.

1.1.1 Issues of capabilities and performance in the UIC literature

Literature has focused on a broad spectrum of UIC facilitating factors such as R&D capacity and resources, intellectual property policy, organisational management and culture, a firm's size, and a firm's absorptive capacity (Ankrah and Al-Tabbaa, 2015). Among those factors, scholars have paid increasing attention to the roles of the firms' and the universities' capabilities in the UIC as perceived as one of the key factors to overcome the barriers to successful UIC (Ankrah and Al-Tabbaa, 2015; Gerbin and Drnovsek, 2016; Nsanzumuhire and Groot, 2020). Specifically, firms need an ability to identify, transfer, integrate and apply universities' knowledge which is commonly known as *absorptive capacity* (Cohen and Levinthal, 1990). Despite the extensive literature on this subject, three main issues identified as the research gaps are addressed.

First, the knowledge body on the impact of capabilities on performance in the UIC tends to be fragmented and creates confusion for scholarly communities; this issue entails theoretical and empirical challenges for researchers and practitioners who aim to draw upon a comprehensive understanding, and to make progress of the research in the field. The fragmentation of knowledge can be first observed from a variety of capabilities addressed in the literature (e.g., R&D capability, technological capability, research capability, innovation capability, etc.) which the definitions and their measures are somewhat similar despite differing terms. The complexities also rest in the overlap between the use of a firm's absorptive capacity and its other capabilities (e.g., R&D capability, innovation capability, etc.). The means to capture the absorptive capacity is also diverse which ranges from a simple measure (e.g., R&D intensity) to complex ones. In addition, a consensus is yet to be reached on how to encapsulate the performance or the success of the UIC. The diversity and ambiguity of capability and performance measures lead to not only confusion in the field of study but also mixed findings. For instance, several studies agree to use a firm's R&D intensity to proxy for its technological capability, innovative capability, and absorptive capacity, but often find conflicting effects on a firm's performance (see, e.g., Santoro and Bierly, 2006; Arza and Vazquez, 2010; Eom and Lee, 2010).

Second, the majority of UIC literature is biased towards a firm's technological capabilities. It is asserted that firms need to develop not only technological capabilities but also non-technological capabilities since innovation is fundamentally a result of both types of capabilities (Ngo and O'Cass, 2013). There is also evidence regarding the important roles of a firm's non-technological capabilities in facilitating the UIC process. For instance, a firm's entrepreneurial capabilities are crucial for the development of radical innovation (Bierly et al., 2009; Kobarg et al., 2018) whereas a firm's project management capability is critical when dealing with complexity and uncertainty in the collaboration process (Buganza et al., 2014). Nevertheless, the literature on a firm's non-technological capabilities remains scarce.

Particularly, less progress has been made on how a firm's *management* and *marketing* capabilities influence its innovation performance when engaged with universities.

Third, while the UIC can be manifested through several mechanisms, scholars tend to focus on a limited range of UIC channels. Particularly, literature is biased towards specific channels such as collaborative research or whether a firm engages in the UIC. However, prior studies find that different types of capabilities are more relevant to some UIC channels than others. For instance, a firm's innovation capability is critical when engaged in *collaborative research* since it facilitates the exchange of tacit knowledge (Bierly *et al.*, 2009; Arza and Vazquez, 2012), emphasising that there is no one-size-fits-all strategy for improving a firm's performance in light of several kinds of capabilities being steered to different UIC channels.

In summary, the knowledge fragmentation regarding capabilities and performance of a firm and a university may hinder research progress in the UIC literature, both theoretically and empirically. Lack of studies on a firm's non-technological capabilities may also attenuate an understanding of how firms reap their benefits from the UIC. Given the aforementioned issues, researchers, firm managers and policymakers may ask the following questions: *What capabilities should be developed by a firm and a university to achieve UIC success? How should the capability and the performance of a firm and a university be effectively and appropriately measured? To what extent do a firm's technological and non-technological capabilities (or a university's research and non-research capabilities) play roles when engaged in different university-industry collaboration channels?* Yet, answers to these questions have not been comprehensively provided.

1.1.2 Tensions between openness and appropriability in the UIC context

Knowledge transfer between a university and a firm is often plagued with conflicts of interest. For instance, a university mainly aims to disclose the collaboration results, often in the form of publications, whereas a firm prefers to keep the knowledge secret (Lee, 2000; Brown and Duguid, 2017). Although scholars have suggested that knowledge appropriation in the UIC might not be a serious issue since universities are non-competing partners (Belderbos *et al.*, 2004; Veer *et al.*, 2016), a firm is likely to face the risk of a university's opportunistic behaviour since a university may share the knowledge in the collaboration with other market actors, or may become a direct competitor if creating a university spinoff (Bonaccorsi and Piccaluga, 1994). Firms may therefore be discouraged from engaging with universities if they have insufficient ability to protect and appropriate the knowledge which is shared in and derived from the collaboration (Bruneel *et al.*, 2010). The dilemma of protecting versus sharing knowledge in the R&D collaboration is commonly known as *the paradox of openness*; this can be alleviated through a firm's appropriability strategy

(Laursen and Salter, 2014). In the UIC context, this topic is also of scholarly interest, but two issues are currently observed.

First, although scholars have found that firms with sufficient *formal appropriability* - i.e. the use of legal methods such as patens to protect their intellectual properties (IPs), are more likely to engage with universities (Veugelers and Cassiman, 2005; Roud and Vlasova, 2020), this finding contrasts with those of some studies (e.g., López, 2008; Abramovsky *et al.*, 2009). According to the results from the non-UIC studies, the conflicting results in the UIC literature may not be surprising. Particularly, a firm's decision to collaborate with universities is not conditional on whether a firm employs any legal protections alone but also on *how strong a level of IP protection* is as well as what *IP protection strategies* are employed (see, e.g., Laursen and Salter, 2014; Yu *et al.*, 2020; Grimaldi *et al.*, 2021). Therefore, firms registering their IPs may not want to cooperate with any external partners if the *defensive IP strategy* is exercised. On the other hand, firms may decide to engage in R&D cooperation if the *collaborative IP strategy* is adopted. The same idea is also suggested by Henkel (2006) based on the concept of *selective revealing*. For instance, firms obtaining intellectual property rights may rely on their in-house R&D or selectively disclose their IPs to signal their innovation capabilities to attract potential R&D partners. Empirical studies on inter-organisational collaboration confirm this phenomenon by revealing an inverted U-shaped relationship between the firms' appropriability strength and their openness to R&D cooperation (Laursen and Salter, 2014; Yu *et al.*, 2020). Notwithstanding, since the UIC scholars predominantly assume a linear relationship, the expected curvilinear relationship between the firms' appropriability and their engagement with the universities is not detected by those linear models.

Second, UIC literature on firms' appropriability tends to focus on a narrow view of engagement in the UIC – i.e. whether a firm decides to collaborate with universities or not. The firms' appropriability seems to exhibit a close relationship with *governance modes* of the UIC and the intensity of the collaboration, explained by the *breadth of collaboration* - i.e. the number of UIC channels employed by a firm. For instance, contractual governance is often aimed at exploring and exploiting scientific and technological knowledge, thus requiring a stronger level of knowledge protection than relational governance which is aimed at trust-and-relationship building and thereby helping to mitigate the risk of opportunism (Garcia-Perez-de-Lema *et al.*, 2017). In addition, over engaging with universities in terms of the number of UIC channels may increase a level of knowledge disclosure which, in turn, aggravates the risk of universities' opportunistic behaviour (Bruneel *et al.*, 2010). Current literature predominantly focuses on whether a firm collaborates with a university whilst the exploration of the impact of a firm's appropriability on governance modes and UIC breadth is largely flying under the radar.

The relationship between a firm's appropriability and its openness in the UIC context is likely to be paradoxical; however, the methodological shortcoming in the UIC literature thanks to a bias towards a linear relationship may weaken an understanding of that relationship and prohibit an opportunity to reconcile the inconsistent findings. An understanding of this issue is further weakened if the importance of governance modes and UIC breadth are overlooked.

1.1.3 Emerging university-industry collaborations

In countries with an immature national system of innovation (e.g., developing countries), the UIC is being implemented as a means of technological upgrading and economic catch-up (Fischer *et al.*, 2019). Literature has addressed some common characteristics of emerging UIC. For example, the linkage between firms and universities is underdeveloped due to the inefficient UIC strategies and policies, thus leading to a low level of engagement from both firms and universities (Brimble and Doner, 2007). In addition, the interactions are limited to consulting and contract research, or informal collaboration channels (e.g., the recruitment of graduates by firms, student internships, industrial placements, and training) which firms prefer to establish direct contact with the individual researcher without necessarily passing through the university (Freitas *et al.*, 2013a). The efforts for the UIC are also mainly aimed at improving the quality of education and compensating inadequate university's research funding. Hence, the university's research outputs are sitting on the shelf rather than being patented or commercialised (Numprasertchai and Igel, 2005).

The government faces various barriers and challenges in promoting the UIC in a country where the UIC is emerging. For example, Nsanzumuhire *et al.* (2021) have recently identified four main barriers for a university to engage with industry: (i) lack of public research funding; (ii) low interest of companies in collaborating with universities; (iii) lack of network with firms, and (iv) academic departments not having structure and procedures to support the UIC. Particularly, insufficient research funding and supporting structure are mentioned as the major barriers to establishing the UIC (Nsanzumuhire and Groot, 2020). Consequently, a university's insufficient research capabilities prevent it from engaging in innovation projects with industry as well as discouraging firms from the UIC (Eun et al., 2006; Schiller and Brimble, 2009). Given a firm's and a university's inadequate experience in the UIC projects and their low level of managerial capabilities, promoting the UIC in the context of an immature environment is very time-consuming and challenging (de Moraes Silva et al., 2017).

However, despite a low level of engagement and various barriers to promoting the UIC, it does not mean that the UIC does not work in those countries where the system of innovation is immature. Instead, de Moraes Silva et al. (2017) argue that in a less developed

environment where firms are struggling to internalise their resources and capabilities in offering product novelty, universities can be even greater sources of innovation than in those developed economies. As emerging UIC is mostly found in developing countries, in recent years, UIC literature has accumulated on the case of developing countries and subjects such as entrepreneurial universities will be a major trend for future research (Bastos et al., 2021). Future research will revolve around the debate on how the UIC accelerates the well-being and economic development of developing countries, and the challenges of promoting the UIC in developing countries (Bastos et al., 2021).

Regarding the capability as the foci of this thesis, a major interest lies in the empirical evidence based on the UIC in the countries with emerging UIC which finds a minimal effect of firms' technological capabilities on their performance unlike the findings from the literature based on developed countries (see, e.g., Su et al., 2009; Chen et al., 2016). One possible reason is that firms in the context of emerging UIC may benefit better from their *non-technological capabilities* when engaged with universities, supported by the fact that those firms, despite having insufficient technological capabilities, are more active in pursuing non-technological innovations as a strategic way of enhancing their innovation performance (Pino et al., 2016; Perez et al., 2019). *Do firms in the context of emerging UIC benefit from their non-technological capabilities more than technological capabilities in improving their innovation performance when engaged with universities?* Yet, this question remains unanswered.

Given the differences between the UIC in different environments (i.e. developed and developing countries), it is necessary to revisit the main determinants of the UIC despite being identified over years (de Moraes Silva et al., 2017). Particularly for a firm's appropriability as another main focus of this thesis, the appropriability regime in most developing countries is weak and thus intellectual property rights are not efficiently protected by law (Ray and Ray, 2021). However, the IP protection in developing countries is somewhat paradoxical; for instance, a weak appropriability regime discourages firms from obtaining the IPRs but firms still need IPRs which allow them to efficiently control the outflow of knowledge and to protect their research results from infringement or imitation when engaged in the R&D cooperation (Bagheri and Casprini, 2013). Even in the UIC context where universities are perceived as a non-rival partner, firms with better appropriability conditions are likely to engage with universities (see, e.g., Dachs *et al.*, 2008; Aristei *et al.*, 2016; Roud and Vlasova, 2020). However, a concern arises from some reports based on developing countries regarding the opportunistic behaviours of the UIC partners (Guerrero et al., 2019;2021). Firms, therefore, cope with the opportunistic behaviours in the R&D cooperation by obtaining effective intellectual property protection mechanisms as known as

appropriability (e.g., Laursen and Salter, 2014; Yu et al., 2020). However, most studies on a firm's appropriability as a determinant of the UIC are biased towards the developed countries. The relationship between a firm's appropriability which reflects its IP strategies (e.g., protectionism or collaboration), and a firm's engagement with universities is not well understood when it comes to the context of countries where the UIC is emerging and immature.

1.2 Objective of the thesis

The central objective of this thesis is to make advancements on how a firm's and a university's capabilities affect their performance when engaged in the UIC, and how a firm's appropriability influences its decision to engage with a university.

The previous section shows that different types of the firm's capabilities can be more relevant to some UIC channels than others. The firm's decision on choosing governance modes of the UIC (e.g., contract-based or relational-based governance) or augmenting the UIC breadth is also contingent upon the firm's appropriability. Therefore, this thesis goes beyond the traditional research by embracing the influence of different *collaboration channels, governance modes,* and *breadth of collaboration*. This additional focus also responds to the criticism about the over-emphasis on the specific channels of the UIC and the lack of investigation of various UIC activities, and particularly, of the informal linkages between industry and university (Choonwoo *et al.*, 2001; Arvanitis and Woerter, 2009; De Fuentes and Dutrenit, 2012; Kafouros *et al.*, 2015). Based on the three-paper-based route, this thesis breaks down the research gaps and overall objective into three papers as follows.

The *first* paper aims to explore ambiguities and complexities in the debate on the relationship between firms' and universities' capabilities and their performance in the UIC context. This paper poses two research questions (RQ) as follows.

RQ 1.1: How do a firm's and a university's capabilities influence their performance when engaged in the UIC?

RQ 1.2: How can the measurement issues affect an understanding of the relationship between a firm's and a university's capabilities and their performance?

The *second* paper seeks to investigate the effects of the firm's technological and non-technological innovation capabilities on their innovation performance when engaged in different UIC channels. The main research question of this paper is;

RQ 2: *To what extent do a firm's technological and non-technological innovation capabilities affect its innovation performance when engaged in different university-industry collaboration channels?*

The *third* paper aims to investigate the effects of a firm's appropriability on the collaboration with universities expressed as (i) the propensity to adopt contractual and relational channels and (ii) the breadth of university-industry collaboration. This paper seeks to answer the following research questions.

RQ 3.1: To what extent does a firm's appropriability influence its decision to collaborate with universities through contractual and relational channels?

RQ 3.2: To what extent does a firm's appropriability influence the breadth of university-industry collaboration?

Regarding the context of this thesis, the *first* paper focuses on the UIC regardless of the countries but significant findings between countries will be addressed in the paper. For the *second* and *third* papers, the empirical results will be based on the UIC in Thailand which is selected as a case study of countries where the UIC is emerging and immature. Figure 1.1 thus presents the focus of this thesis while Table 1.1 summarises the research gaps, research objectives and research questions of this thesis.

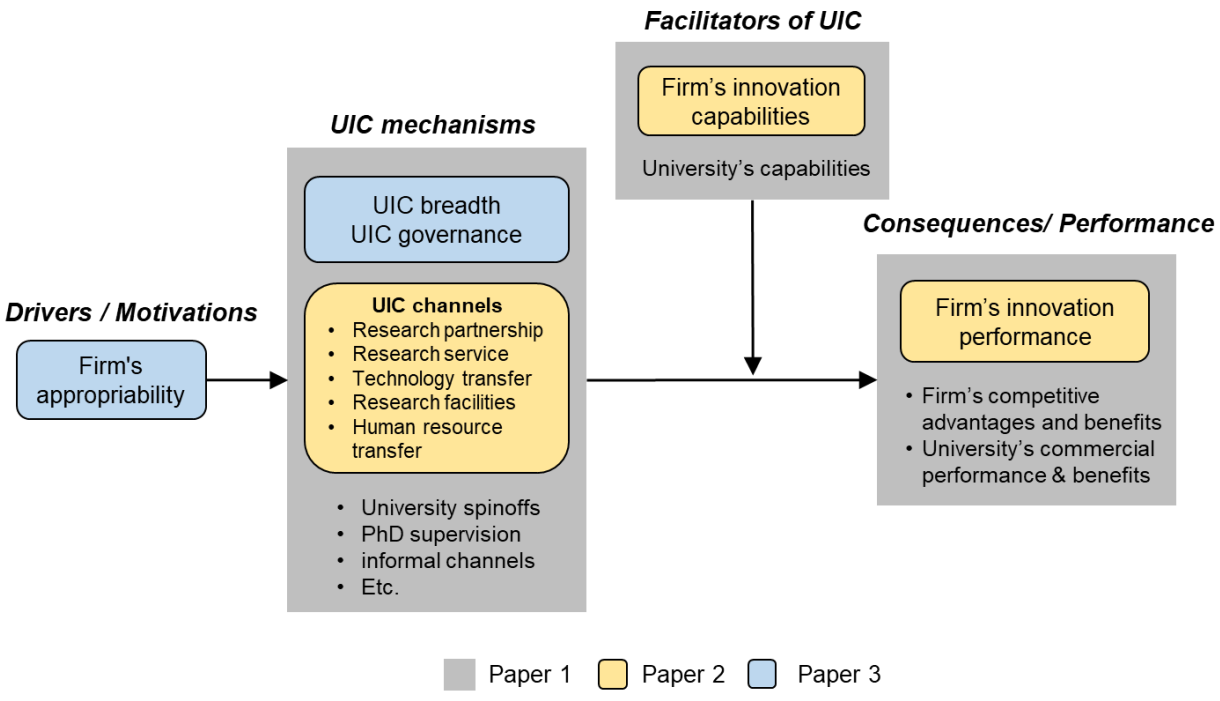

Figure 1.1 Focus of the thesis

Table 1.1 Summary of research gaps, objectives and questions

Paper	Title	Research gaps	Research objectives	Research questions (RQ)
1	*University-Industry Collaboration: A Systematic Literature Review on Capability and Performance*	Knowledge fragmentation, lacking a comprehensive review on capability and performance in the UIC context	To explore ambiguities and complexities in the debate on the relationship between a firm's and a university's capabilities and their performance in the UIC context	(RQ 1.1) How do a firm's and a university's capabilities influence their performance when engaged in the UIC? (RQ 1.2) How can the measurement issues affect an understanding of the relationship between a firm's and a university's capabilities and their performance?
2	*Technological and Non-Technological Innovation Capabilities and Innovation Performance of Firm Engaging with University*	Lacking studies on the effect of a firm's non-technological capabilities and limited focus on various UIC channels.	To investigate the effects of the firm's technological and non-technological innovation capabilities on their innovation performance when engaged in different UIC channels	(RQ 2) To what extent do a firm's technological and non-technological innovation capabilities affect its innovation performance when engaged in different university-industry collaboration channels?
3	*Appropriability and Firm's Engagement in University-Industry Collaboration*	Ambiguous effects of firm's formal appropriability on the firm's decision to collaborate with university due to the bias towards a linear relationship, lacking research focusing on governance modes and UIC breadth.	To investigate the effects of a firm's appropriability on the collaboration with universities expressed as (i) the propensity to adopt contractual and relational channels and (ii) the breadth of university-industry collaboration	(RQ 3.1) To what extent does a firm's appropriability influence its decision to collaborate with universities through contractual and relational channels? (RQ 3.2) To what extent does a firm's appropriability influence the breadth of university-industry collaboration?

1.3 Research methodology

1.3.1 Research philosophy

This thesis employs the research philosophy as a guide to defining overall research design (Creswell and Creswell, 2018). Despite being often overlooked, this step is critical since the research quality relies on how a researcher views the reality or the knowledge (Easterby-Smith *et al.*, 2012). Typically, there is a broad spectrum of philosophical stances such as *positivism*, *interpretivism*, and *pragmatism* (Saunders *et al.*, 2019).

Paper 1 adopts the *interpretivism* paradigm. Scholars normally deal with the knowledge fragmentation in the literature by employing a literature review. As shown in Table 1.2, a literature review can be undertaken through either the positivism stance or the interpretivism stance (Gordon, 2016). Paper 1 aims to clarify the confusion in the literature regarding the different types and measures of capabilities and performance. Also, it seeks an explanation of *what* and *how* capabilities affect the performance in the UIC. This paper thus adopts the lens of interpretivism. According to Myers (2008), interpretivism researchers view reality as socially constructed such as languages, consciousness, shared meanings, and instruments. Regarding Paper 1, the knowledge generation or the reality depends largely on the contexts, the society, and the community of the knowledge providers (i.e. the authors of the selected articles). The knowledge body of capabilities and performance in the UIC is perceived as subjective and heterogenous in which the conclusions are unlikely to lead to a law-like generalisation. Importantly, a reviewer cannot be independent of the knowledge provider (i.e. the selected articles) since he or she interprets the knowledge based on his or her own experience and opinion. In the eyes of interpretivism, Paper 1 adopts a qualitative approach by conducting a systematic literature review and applying thematic analysis (Rashman *et al.*, 2009; Gordon, 2016).

Papers 2 and 3 take on the pure *positivism* stance. Positivists view the world as having one reality of cause and effect. The positivists also draw inferences from observable phenomena and testing based on the scientific method in which the knowledge can be independently measured and observed (Saunders *et al.*, 2019). Given the objectives of Papers 2 and 3, the author perceives that the knowledge - i.e. an understanding of the impact of a firm's capabilities and appropriability, can be measured using highly structured data (e.g., the Community Innovation Survey) where the findings from a large sample size can provide the law-like generalisations as well as the replication. In addition, the author of this thesis is detached from the analysis by relying on the results from statistical analysis, thus mitigating the research bias. Against this backdrop, Papers 2 and 3 hence adopt a quantitative approach. The research in Papers 2 and 3 is conducted via the review of

relevant theories to develop hypotheses which are later tested by the application of statistical techniques.

Table 1.2 Research paradigms for a literature review (Gordon, 2016)

Research paradigm	Positivism	Constructivism (Interpretivism)
Ontological alignment	Realism	Relativism
Methodological alignment	Verification	Interaction
Review purpose	Description justification	Clarification
Outcomes	What work? Whether it works?	Why it works? How it works?
Implications	Define content or pedagogy widely used & confirm the effectiveness	Define underpinning theory and conceptual frameworks
Methods	Content analysis Meta-analysis	Thematic analysis Meta-ethnography

1.3.2 Research data

1.3.2.1 Data for qualitative research (Paper 1)

Regarding Paper 1, a systematic literature review is based on peer-reviewed journal articles published in English. The prevalent use of electronic journal databases has considerably improved the accessibility, dissemination, and impact of journal articles. In addition, journal articles can be considered as *validated knowledge* and are likely to have the highest impact on the field, thus enhancing the results' reliability (Saggese *et al.*, 2016). Although some working papers and proceedings are peer-reviewed, they are excluded thanks to the insufficient peer-review process (Wang and Chugh, 2014). This paper focuses only on articles listed in *Web of Science, Scopus, Science Direct and EBSCO* databases which are considered as the largest and widely accepted sources for bibliometric studies (Saggese *et al.*, 2016; Rybnicek and Königsgruber, 2019; Nsanzumuhire and Groot, 2020). The articles are searched without imposing any time restriction to increase the coverage of relevant articles.

1.3.2.2 Data for quantitative research (Papers 2 and 3)

For Papers 2 and 3, the analysis is mainly based on the Community Innovation Survey (CIS) of Thailand – namely, the *Thailand Business R&D and Innovation Survey*. As suggested by

Frenz and Ietto-Gillies (2009), the CIS provides rich data that cover multiple sectors, differences in firms' size, measures of firms' innovations, and a wide range of innovation factors. In addition, CIS allows researchers to make progress on the econometric analyses by offering a comparison across countries and industries, and compatibility to merge with other data, and longitudinal datasets (Mairesse and Mohnen, 2010).

The *Thailand Business R&D and Innovation Survey* has been conducted periodically since 1990 by the National Science and Technology Development Agency (NSTDA), The structure of this survey is based on the guidelines of the Oslo Manual (OECD) 1997. The data from the Thailand CIS used in this thesis cover a period of three years (2015, 2017 and 2018) which provides sufficient information relevant to innovation activities, and the UIC which are the main foci of this thesis. To conduct the survey, NSTDA first defines the size of the total firm population, which was 104,296, 92,669 and 95,430 in 2015, 2017 and 2018, respectively. The NSTDA sent the questionnaires to 12,918 firms in 2015, 13,597 in 2017, and 14,281 in 2018 by post, email or fax, and then received the responses from 4,797 firms in 2015 (37.13%), 5,512 firms in 2017 (40.53%), and 5,762 firms in 2018 (40.35%). The overall response rate ranges from approximately 37% - 40% which is deemed satisfactory. This study limits the data to innovative firms in the manufacturing sector since they actively conduct innovation activities and collaborate with universities.

1.3.3 Research setting: UIC in the context of Thailand

The context of empirical research (Papers 2 and 3) is that of a country where the national innovation system is measure and the UIC is emerging – i.e. weakly established. This thesis chooses Thailand as an appropriate case study.

Although the Thai government has initiated science, technology and innovation policies as well as stimulating Thai firms to engage in R&D and innovation activities with universities (Carvalho de Mello *et al.*, 2016; Intarakumnerd, 2017), the UIC practice in Thailand remains underdeveloped (Brimble and Doner, 2007). One of the issues is that the innovation policy heavily relies on the *knowledge-push* model - i.e. universities act as the main knowledge provider while firms are mainly the knowledge users (Arnold *et al.*, 2000).

Another issue is that Thai firms generally lack technological capabilities since they are the absorbers of knowledge from developed countries in which the knowledge is provided through technology diffusion (Liefner and Schiller, 2008). In addition, the research capabilities of Thai academic researchers are rather poor with little relevance to industry (Intarakumnerd *et al.*, 2002; Ratchukool and Igel, 2018). Most academic research outputs are sitting on the shelf, as known as *the ivory tower*, rather than being patented or commercialised (Numprasertchai and Igel, 2005), thus discouraging firms from engaging in

R&D collaboration (Schiller and Brimble, 2009). Policies in most Thai universities also demotivate researchers from engaging in the UIC due to the centralisation and fragmentation of Thai bureaucracy, overwhelming workload, complicated university policy, and undermined incentives (Brimble and Doner, 2007). The UIC in Thailand is thus mainly associated with short-term training, use of research consulting, and problem-solving (e.g., collaborative research project) (Intarakumnerd *et al.*, 2002; Pittayasophon and Intarakumnerd, 2016). Given that the joint research and the technology transfer are inefficient and thus less employed, provision of a university's service and consulting as well as informal modes (e.g., discussion, meetings, and conferences) are more popular than others (Brimble and Doner, 2007).

The Thai government has recognised the importance of increasing R&D capacity for enterprises and universities, thus targeting 2% of R&D investment per GDP by 2021 aimed at shifting into the knowledge-based economy (Shin and Limapornvanich, 2017). The Thailand Research Fund is also responsible for promoting the *Talent Mobility* programme as an incentive for matching funds to improve employee exchange between private and public sectors (Shin and Limapornvanich, 2017; Kongsoontornkijkul *et al.*, 2019). The policy includes enhancing joint programmes for commercialisation between universities and start-ups in addition to SMEs.

In summary, although the UIC in Thailand is underdeveloped, the Thai government is promoting the UIC for accelerating economic growth (see, e.g., Freitas *et al.*, 2013b; Guerrero and Urbano, 2021). Particularly, the Thai government is facing similar challenges in promoting the UIC to other countries[1] where the UIC is only emerging such as (i) an inefficient national innovation system and innovation policy, (ii) a low level of engagement with universities (or firms), (iii) indirect and informal U-I interactions, (iv) weak R&D and research capabilities of firms and universities and firms' low R&D investment, (v) the ivory tower of academia, (vi) a low share of total patents issued by universities, and (vii) mismatching between academic knowledge and industry demand (see, e.g., Brimble and Doner, 2007; Marin and Arza, 2009; Vaaland and Ishengoma, 2016; Nsanzumuhire and Groot, 2020). The contributions from the empirical results of this thesis will thus apply not only to the UIC in Thailand but also to the UIC in other countries where the UIC is emerging and immature but actively promoted.

[1] Example of countries that the UIC is emerging and immature: South Africa, Nigeria, Uganda, Egypt, China, Korea, *Thailand*, Taiwan, Malaysia, India, Brazil, Mexico, Costa Rica, Argentina, Columbia, Bolivia, Kazakhstan, Mozambique and South Korea (Nsanzumuhire and Groot, 2020).

1.3.4 Research methods

Paper 1 employs a systematic literature review to achieve the research objective: *to explore ambiguities and complexities in the debate on the relationship between firms' and universities' capabilities and their performance in the UIC context*. The systematic literature review is designed to engender a sense of collective endeavour, to assist in linking future research to the questions and concerns that have been posted by past research, and to improve the methods used to collect and synthesise previous empirical evidence (Pittaway *et al.*, 2004; Thorpe *et al.*, 2005). The systematic literature review also provides the validity of a review since it has a clear set of review steps that can be replicable (Denyer and Neely, 2004; Thorpe *et al.*, 2005). Compared to a quantitative approach such as meta-analysis, the systematic literature review is more appropriate since the articles retrieved are highly heterogeneous (Tranfield *et al.*, 2003). The review methods can be briefly illustrated in four steps.

- *Step 1*: The review protocol is developed by reviewing the review papers on the UIC. Given the research questions, the search keywords and the exclusion criteria are delineated.
- *Step 2*: The articles are searched with the use of keywords defined previously. The exclusion criteria are applied afterwards.
- *Step 3*: The quality of the articles is then evaluated by focusing on journals listed in the Academic Journal Guide 2021 and graded by the ABC classification.
- *Step 4*: The selected articles are descriptively and thematically analysed.

Paper 2 adopts a quantitative approach to achieve the research objective: *to investigate the effects of the firm's technological and non-technological innovation capabilities on their innovation performance when engaged in different UIC channels*. The research method of Paper 2 consists of five steps.

- *Step 1*: Literature on the impact of a firm's capabilities on a firm's performance in the UIC is reviewed to develop the theoretical motivation and hypotheses.
- *Step 2*: Variables such as a firm's technological and non-technological innovation capabilities, UIC channels, firm's innovation performance, and control variables are defined from questionnaire items in the Thai CIS.
- *Step 3*: Based on panel datasets, the Tobit regression with the random-effects model is adopted for the analysis.
- *Step 4*: For the robustness check, several alternative models are performed as well as the Heckman Correction to test the sample selection bias.
- *Step 5*: The results are discussed leading to several implications.

Paper 3 employs a quantitative method to achieve the research objective: *to investigate the effects of a firm's appropriability on the collaboration with universities expressed as (i) the propensity to adopt contractual and relational channels and (ii) the breadth of university-industry collaboration*. Similar to Paper 2, the research is undertaken through five steps.

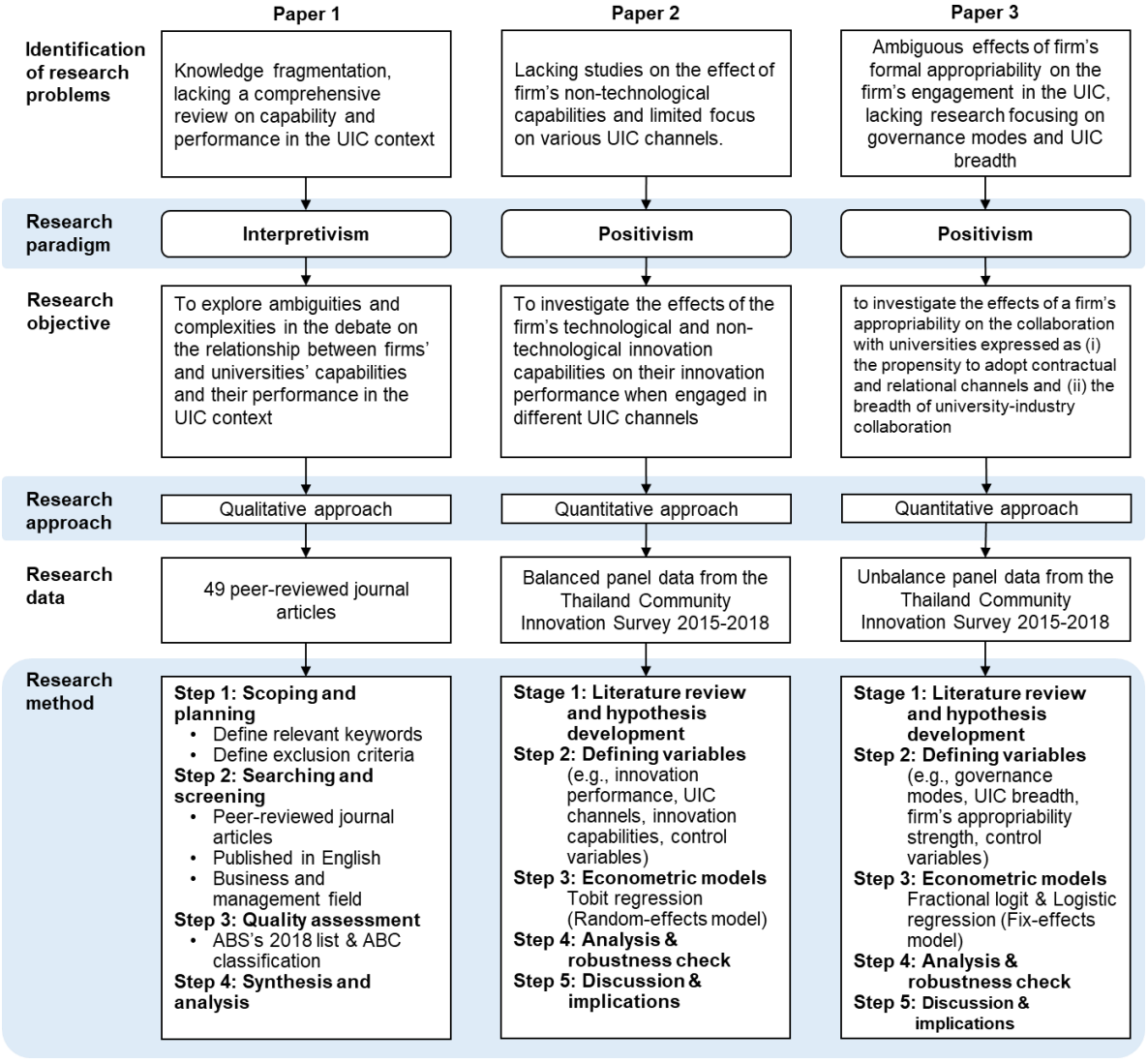

Figure 1.2 Summary of research methodology

- *Step 1*: Literature on a firm's appropriability in the UIC, UIC governance modes, and UIC breadth is reviewed to develop the theoretical background and hypotheses
- *Step 2*: Variables such as a firm's propensity to engage in contractual and relational channels, a firm's UIC breadth, a firm's appropriability strength, and control variables are defined based on the items in Thai CIS.

- *Step 3*: Given the panel data, fractional logit regression and logistic regression with the fix-effects model are performed to test the hypothesis.
- *Step 4*: The robustness check is performed through an analysis of alternative models.
- *Step 5*: The results are discussed leading to several implications.

Figure 1.2 presents the summary of the research method of each paper.

1.4 Key findings and contributions

This thesis offers several contributions to the literature. Paper 1 adds to prior review articles (see, e.g., Ankrah and Al-Tabbaa, 2015; Nsanzumuhire and Groot, 2020) by conducting a systematic literature review on the relationship between a firm's and a university's capabilities and their performance in the UIC context. The review is aimed at tackling the knowledge fragmentation and clearing up the confusion regarding measures of capabilities and performance which can pose a significant hindrance to the advancement of theoretical and empirical research. This paper first shows that the firms' capabilities, the firms' absorptive capacity (AC) and the universities' capabilities are critical for a successful UIC. Their impacts are also contingent on several factors such as UIC channels, uncertainties, market competition, knowledge explicitness, proximity and contextual settings. This paper then consolidates key components into an integrative framework that points out several intriguing issues for future exploration; for example, (i) a lack of studies on a firm's non-technological capabilities, (ii) the confusion on the use and measures of AC, (iii) ambiguous effects of a firm's R&D intensity on its performance, (iv) a lack of studies on a university's desorptive capacity, and (v) a lack of studies on the synergy between a firm's absorptive capacity and a university's desorptive capacity.

Paper 2 contributes to the theoretical arguments on the importance of technological and non-technological components of innovation in the UIC (Dill, 1990; Etzkowitz and Leydesdorff, 2000; Perkmann and Salter, 2012). Particularly, it advances the UIC knowledge of firms' non-technological capabilities which currently receives little scholarly interest. This paper reveals that firms can benefit from their non-technological innovation capabilities (ICs) in improving their innovation performance, and also confirms that different ICs are more critical for some UIC channels than others. Specifically, firms with organisational IC achieve better innovation performance when adopting collaborative research or using universities' facilities whereas marketing IC is critical when engaged in research service channels (e.g., consulting and contract).

Paper 3 unravels the conflicting findings in the appropriability-UIC literature as a result of the methodological bias towards a linear relationship (see, e.g., Veugelers and

Cassiman, 2005; López, 2008; Abramovsky *et al.*, 2009; Roud and Vlasova, 2020), by providing evidence of an inverted U-shaped relationship between a firms' appropriability and its engagement in the UIC. Particularly, a firm tends to collaborate with a university in both contractual and relational channels as well as in various UIC channels given an increase in a firm's appropriability strength. However, a firm tends to lower its interest in engaging with a university due to overemphasising appropriability. This finding sheds light on the fact that although the use of legal protection methods may increase a firm's confidence to engage in R&D collaboration (Teece, 2000), overly protecting knowledge (e.g., defensive IP strategy) may limit opportunities for a firm's innovation creation via partnering with universities (Von Hippel, 2006). This paper also contributes to the knowledge on the heterogeneity of firms by highlighting that being a product innovator strengthens an inverted U-shaped relationship between appropriability and UIC breadth while being a process innovator attenuates the relationship by displaying a convex shape to that relationship. While excessive appropriability discourages a product innovator from engaging in the UIC through relational governance, a process innovator tends to shift its interest from relational governance to contractual governance. This paper also offers an insight into the scant literature on the outward university-industry knowledge transfer by revealing that for a firm with a high level of appropriability strength, engaging with competitors and consultants may be more attractive than engaging with a university.

Holistically, this thesis contributes to academics in the field of UIC studies by clearing up the ambiguities regarding the measures and the effects of firms' capabilities and universities' capabilities on their UIC performance. The results from a systematic literature review attenuate that neither firms nor universities can succeed in the UIC without the presence of capabilities. The thesis also sheds light on the important roles of a firm's non-technological innovation capabilities in improving its innovation performance when engaged with universities. This thesis departs from the literature by presenting a non-linear relationship between a firm's appropriability and its engagement with universities, thus allowing a deeper understanding of this topic. This thesis also responds to the criticism of lacking diversity in terms of UIC activities (Choonwoo *et al.*, 2001; Arvanitis and Woerter, 2009; De Fuentes and Dutrenit, 2012; Kafouros *et al.*, 2015) by incorporating a broad spectrum of the UIC channels in all papers.

Importantly, this thesis contributes to the literature based on countries where the UIC is emerging and immature UIC, beyond Thailand or developing countries. Particularly, this thesis opens a black box due to the ambiguous impact of technological capabilities of firms in the countries with emerging UIC on their UIC performance (e.g., Su *et al.*, 2009; Eom and Lee, 2010; Xu *et al.*, 2011; Chen *et al.*, 2016) by shedding light on the fact that given a firm's weak technological ICs and its absent effects on performance, the firm can benefit

from its non-technological ICs in improving its innovation performance in the cooperation with university partners. In addition, this thesis is one of a few studies based on emerging UIC that investigates the roles of a firm's appropriability on its engagement with universities. This thesis confirms that given an immature UIC, firms may hesitate to collaborate with universities despite their roles as a non-rival partner (Belderbos *et al.*, 2004; Veer *et al.*, 2016). This thesis also shows that *the paradox of openness* is visible in the context of immature UIC in addition to literature elsewhere (e.g., Laursen and Salter, 2014). The findings point out that policymakers in the countries where the UIC is emerging, and immature should avoid a one-size-fits-all approach to a firm's appropriability and its engagement with universities. While the literature on emerging UIC and developing countries is generally scant, the insights from this thesis should be regarded as fruitful for both scholars and policymakers whose roles are promoting the UIC as a means to attain national technology upgrading, enter the knowledge-based economy, and escape the middle-income trap (Intarakumnerd, 2017; Shin and Limapornvanich, 2017; Intarakumnerd and Liu, 2019).

1.5 Outline of the thesis

The research body is divided into three chapters corresponding to three papers. Chapter 2 presents Paper 1, titled as *University-Industry Collaboration: A Systematic Literature Review on Capability and Performance*. Chapter 3 presents Paper 2: *Technological and Non-Technological Innovation Capabilities and Innovation Performance of Firm Engaging with University*. Chapter 4 presents Paper 3: *Appropriability and Firm's Engagement in University-Industry Collaboration.* Each of the three chapters includes several parts such as abstract, introduction, theoretical background, hypothesis development, method, findings, discussion, and conclusion. Finally, Chapter 5 revisits the research gaps and objectives of this thesis and summarises the research findings, contributions, implications, limitations, and future research avenues.

Chapter 2

University-Industry Collaboration: A Systematic Literature Review on Capability and Performance (*Paper 1*)

Abstract

While the relationship between a firm's and a university's capabilities and their performance has received increasing attention from scholars in the field of university-industry collaboration (UIC), there are theoretical and empirical obstacles due to ambiguities and complexities associated with the measures of capabilities and performance, and related findings. This paper aims to unravel the ambiguities in the debate on the impact of a firm's and a university's capabilities on their performance in the UIC context by employing a systematic literature review. To achieve the objective, 49 peer-reviewed articles are systematically reviewed and critically analysed. The results reveal that a firm's technological and non-technological capabilities as well as a university's research and non-research capabilities are critical to enhancing the UIC performance which the impact of capabilities is contingent on several factors and contextual settings. A firm's absorptive capacity is a prerequisite to absorb and exploit a university's knowledge successfully. Several issues emerge from the review such as ambiguous measures, use of absorptive capacity and its relationship to other capabilities, and lack of studies on a university's desorptive capacity. On the basis of synthesis insights, a framework that underpins the key components in the capability-performance relationship in the UIC context is established. This paper finally proposes the research agenda as distilled from the analysis and framework.

Keywords: Systematic literature review, Systematic review, University-Industry Collaboration, Capability, Performance

2.1 Introduction

Extensive literature has accumulated on the subject of university-industry collaboration (UIC) and acknowledged that UIC enables innovation creation (Etzkowitz and Leydesdorff, 2000; Rajalo and Vadi, 2017; Steinmo and Rasmussen, 2018). Nonetheless, an established linkage between a firm and a university alone does not always guarantee collaboration success (Choonwoo *et al.*, 2001; Eom and Lee, 2010; Apa *et al.*, 2020). Firms, therefore, need to have substantial capabilities as complementary components to identify and exploit knowledge from the collaboration (e.g., Walter *et al.*, 2006; van Hemert *et al.*, 2013; Steinmo and Rasmussen, 2018). Over the decades, the impact of the firms' and the universities' capabilities on their performance has been increasingly explored by UIC scholars (see, e.g., Santoro and Bierly, 2006; Arza and Vazquez, 2010; Kobarg *et al.*, 2018; Leischnig and Geigenmuller, 2020).

Despite a growing body of knowledge in the field, literature on the UIC seems to create confusion regarding the measures of firms' and universities' capabilities and performance. For instance, researchers have employed different proxies for such terms as innovation capability (see, e.g., Arza and Vazquez, 2010; Garcia-Perez-de-Lema *et al.*, 2017), and absorptive capacity (see, e.g., Kobarg *et al.*, 2018; Min *et al.*, 2019; Apa *et al.*, 2020). A similar issue is also observed for indicators such as innovation performance (see, e.g., Belderbos *et al.*, 2016; Qiu *et al.*, 2017; Tang *et al.*, 2020). Although this diversity is expected due to the methodological challenges (Bozeman, 2000; Camison, 2005; Arvanitis *et al.*, 2008), it may generate inconsistent findings, which is further aggravated by the heterogeneous and complex nature of the UIC (e.g., different perspectives, a variety of collaboration mechanisms, several influential factors, and diverse contexts) (Perkmann and Walsh, 2007; Galan-Muros and Davey, 2019). The ambiguities of measures and the fragmentation of findings thus lead to theoretical and empirical barriers for research as well as practical applications.

This paper aims to clear up the complexities and ambiguities in the debate on the relationship between capabilities on performance in the UIC context from both the firm's and the university's perspectives by performing a systematic literature review. Based on 49 articles published in peer-reviewed journals, the results reveal that most studies highlight that a firm's technological and non-technological capabilities and a university's research and non-research capabilities are critical to enhancing the UIC performance, and their impact is contingent on several factors and contextual settings. Scholars agree that absorptive capacity is a prerequisite for firms to absorb and exploit a university's knowledge successfully. This paper also establishes a framework which underpins the key components

and then proposes the research agenda as distilled from the analysis such as the ambiguous measures and use of a firm's absorptive capacity. There is also a relatively scant knowledge body on a university's desorptive capacity as well as the synergy between a firm's absorptive capacity and a university's desorptive capacity.

This review paper offers several contributions. *First*, it adds to prior reviews (see, e.g., Ankrah and Al-Tabbaa, 2015; Nsanzumuhire and Groot, 2020) by advancing the knowledge on the relationship between a firm's and a university's capabilities and their performance in the UIC context which, has increasingly gained not only attention but also confusion. *Second*, this paper goes beyond a simple review by developing an analytical framework that links the key components distilled from the literature. The framework allows a better understanding of how firms and universities can achieve their UIC performance, thus contributing to the policy and management settings. *Last*, this paper points out several under-researched areas for future work.

This paper is structured as follows. After the introduction, Section 2.2 provides a theoretical motivation of this study whilst Section 2.3 presents the review methods. Section 2.4 presents the descriptive overview of the literature. Section 2.5 discusses the main findings from the review towards an integrated framework and proposes a research agenda. The last section offers the concluding remarks, limitations, and potential direction for a future review.

2.2 Theoretical motivation

The importance of an organisation's capabilities has been addressed in the UIC literature from different theoretical views. For instance, grounded in the *resource-based view of firm theory* (Barney, 1991), the impact of inter-organisational collaboration depends on the firm's capabilities to translate internal resources, which are difficult to develop, imitate or substitute, into competitive advantages (Choonwoo *et al.*, 2001; Lockett and Wright, 2005). However, resources that often entail competitive advantages are a firm's knowledge base (Barney, 1991). Based on the knowledge-based theory of firms (Grant, 1996), a firm's valuable knowledge is the most strategically significant resource which can be internally developed or externally acquired. In the university-industry knowledge transfer, firms need an ability to identify, absorb, integrate and apply a university's knowledge (Santoro and Bierly, 2006; Bierly *et al.*, 2009). This firm's special capability is commonly known as *absorptive capacity* (Cohen and Levinthal, 1990). Most of the literature on the relationship between capabilities and performance in the UIC tends to centre around the roles of a firm's absorptive capacity, often captured through a firm's R&D or technological capabilities.

A linkage between a firm and a university does not always guarantee the success of innovation creation (Tsai, 2009; Eom and Lee, 2010), without the presence of sufficient capabilities (Choonwoo *et al.*, 2001; Apa *et al.*, 2020). Hence, scholars have increasingly explored the roles of firms and academics' capabilities on their UIC performance and confirmed their positive impact on successful UIC (Choonwoo *et al.*, 2001; Santoro and Bierly, 2006; Bierly *et al.*, 2009; Buganza *et al.*, 2014; Kobarg *et al.*, 2018; Leischnig and Geigenmuller, 2020). Nevertheless, despite a growing amount of interest, the knowledge body tends to be fragmented and creates confusion for the UIC scholars.

The fragmentation of the knowledge body can be first observed from various capabilities of firms that have been investigated in the literature such as R&D capability (Su *et al.*, 2009; Chen *et al.*, 2016), technological capability (Santoro and Bierly, 2006; Bierly *et al.*, 2009), innovation capability (Arza and Vazquez, 2010; Kobarg *et al.*, 2018), project management capability (Buganza *et al.*, 2014) and absorptive capacity (Dezi *et al.*, 2018; Min *et al.*, 2019). Similar to studies based on a university's perspective, different terms of capabilities such as research capability (Guerrero and Urbano, 2021), university specialisation (Petruzzelli and Murgia, 2020), knowledge capacity (Lin, 2017), technology diversity (von Raesfeld *et al.*, 2012), business development capability (Lockett and Wright, 2005) and alliance management capability (Leischnig and Geigenmuller, 2020) have been examined.

The fragmenting issue is more noticeable when focusing on capability measures which the literature seems confused about. For example, some capabilities are termed differently (e.g., R&D, technology, innovation, and absorptive capacity) but are often captured through common measures such as a firm's R&D intensity (see, e.g., Santoro and Bierly, 2006; Bierly *et al.*, 2009; Arza and Vazquez, 2010; Chen *et al.*, 2016). Conversely, despite a common definition, measures of a firm's technological capability are diverse such as R&D intensity (Santoro and Bierly, 2006; Bierly *et al.*, 2009), patents (Choonwoo *et al.*, 2001), and usefulness for a firm's growth (Belso-Martinez *et al.*, 2013). This confusion also emerges in the studies on a firm's absorptive capacity, variously explained from its R&D intensity (Arvanitis *et al.*, 2008; Tsai, 2009; Eom and Lee, 2010), technology relatedness (Petruzzelli, 2011), academic experience of start-up founder (Toole *et al.*, 2015), R&D investment (Dezi *et al.*, 2018), and internal R&D (Fudickar and Hottenrott, 2019).

The fragmented knowledge also partly comes from various kinds of performance as well as their measures. Although the outcomes of the UIC may be evaluated based on whether the collaboration goals are achieved (Min *et al.*, 2019), this may not always be feasible since the UIC outputs and commercial gain may not be observed and tend to be confounded with several factors (Arvanitis *et al.*, 2008). To date, there is no agreement to capture the success of UIC or performance, so methodological challenges persist

(Bozeman, 2000; Arvanitis *et al.*, 2008; Salimi *et al.*, 2016). Similar to the issues of capability measures, there is also a broad spectrum of performance measures that are different in nature (e.g., innovation versus non-innovation, input versus output, tangible versus non-tangible, directly derived from the UIC and otherwise). For instance, scholars have evaluated several kinds of performance; for example, innovation performance (Bstieler *et al.*, 2015; Belderbos *et al.*, 2016; Garcia-Perez-de-Lema *et al.*, 2017), research performance (Sengupta and Ray, 2017; Zhang and Wang, 2017), and commercial performance (Ambos *et al.*, 2008; von Raesfeld *et al.*, 2012).

The diversity of capability and performance measures leads to mixed findings in the literature. For instance, a firm's R&D capability expressed as its R&D intensity, often yields ambiguous results (see, e.g., Santoro and Bierly, 2006; Eom and Lee, 2010) and is often critiqued if it is a valid indicator of the firm's technological capability and absorptive capacity (Mowery *et al.*, 1996; Lane and Lubatkin, 1998; Coombs and Bierly, 2006). Besides, the UIC is a sophisticated and complex phenomenon (Perkmann and Walsh, 2007) that involves several stakeholders and a range of factors (Galan-Muros and Davey, 2019). Together with the effects of capabilities which are contingent on the contexts (Teece, 2007), the knowledge fragmentation is therefore accentuated by the heterogeneous nature of UIC such as perspectives (e.g., a firm or a university), UIC mechanisms, and levels of analysis (e.g., regional, organisation or individual level).

Knowledge fragmentation in the literature on capabilities and performance in the UIC may raise several questions for academics, practitioners and policymakers: *Are capabilities addressed in the literature similar or related to each other? What capabilities should be developed by a firm and a university to achieve their UIC success? How should a firm's and a university's capability and performance be effectively and appropriately measured? To what extent do a firm's technological and non-technological capabilities (or a university's research and non-research capabilities) play roles when engaged in different university-industry collaboration channels?* To deal with the fragmentation of the knowledge body, scholars typically make use of a literature review. Although prior reviews on the UIC have addressed a relationship between success factors and performance, the roles of capabilities, as well as their measures, are mentioned in a limited capacity, e.g., being suggested for academic institutions for facilitating knowledge transfer (Gerbin and Drnovsek, 2016) and as one of the determinants of UIC success (Ankrah and Al-Tabbaa, 2015). This paper postulates that a lack of a review on the capability-performance relationship may hinder research progress on this subject both theoretically and empirically.

This paper thus aims to clear up the confusion regarding the measures of a firm's and a university's capabilities and performance and to understand the diversity in the literature on the capability-performance relationship in the UIC context through a systematic literature

review. Particularly, this paper aims to answer two questions: *(1) How do a firm's and a university's capabilities influence their performance when engaged in the UIC? and (2) How can the measurement issues affect an understanding of the relationship between a firm's and a university's capabilities and their performance?* It is also noteworthy that this paper does not seek to standardise sets of capabilities and performance as well as their measures but rather aims to uncover the complexities and tidy them up for ease of discussion.

2.3 Method

This paper adopted a systematic literature review since it is a rigorous, comprehensive, structured, transparent and replicable approach to review a large volume of heterogeneous literature (Tranfield *et al.*, 2003; Higgins and Green, 2011). To conduct a review, this study developed a review protocol comprising four steps (Figure 2.1), following Thorpe *et al.* (2005).

2.3.1 Planning and scoping

This first step involved setting the research questions and then defining search keywords by reviewing the prior reviews in the UIC as a starting point for the preliminary search (e.g., Ankrah and Al-Tabbaa, 2015; Gerbin and Drnovsek, 2016; Nsanzumuhire and Groot, 2020; Bastos *et al.*, 2021). From this, this paper introduced nine keywords relevant to the UIC and collated them as Group 1. Since the targeted papers may be identified from other terms such as technology transfer, university outreach, and others, this paper proposed six more keywords and categorises them into Group 2. Following da Cunha Bezerra *et al.* (2020), keywords associated with capability were identified and included in Group 3. However, to avoid missing relevant papers, this study did not include keywords in Group 3 in the search strings since some relevant papers do not have these keywords in their title, abstract or article keywords. Hence, whilst 15 keywords from Groups 1 and 2 are used as the search strings, three keywords in Group 3 will be used in the full-text review process. All keywords in the form of search strings are presented in Table 2.1.

Next, the inclusion and exclusion criteria were developed. This paper targeted the peer-reviewed journal articles, published in English, since they are perceived as *validated knowledge* and likely to have the highest impact on the field, thus enhancing the results' reliability (Saggese *et al.*, 2016). In addition, the articles from the initial search can be voluminous due to generic search strings (Pittaway *et al.*, 2004). Hence, only articles in subjects relevant to business and management, social science and economics were included. The search was performed without imposing any time restriction to increase the coverage of relevant papers on the topic.

Table 2.1 List of keywords and search strings

Group 1	Group 2	Group 3
"university-industry" OR "university-firm" OR "university-business" OR "academia-industry" OR "business-university" OR "industry-university" OR "industry-academia" OR "industry-science" OR "science-industry"	**"***triple helix*" OR "academic engagement*" OR "third mission*" OR "university outreach*" OR "university technology transfer*"*	*"capabilit*" OR "competenc*" OR "capacit*"*

2.3.2 Searching and screening

For the searching process, four databases were chosen – Web of Science, ScienceDirect, Scopus, and EBSCO (Business source premier) – due to their wide coverage of scientific literature and a high number of top journals in a variety of business disciplines (Saggese *et al.*, 2016; Rybnicek and Königsgruber, 2019; Nsanzumuhire and Groot, 2020). The keywords strings in Groups 1 and 2 were used for searching within the title, abstract and keyword field. This step yielded 35,378 articles in total from all databases. After applying inclusion and exclusion criteria, next, the publications were limited to English peer-reviewed journals and relevant subjects and fields of studies, resulting in 8,708 articles. The software *Endnote* was then used to eliminate anonymously authored and duplicate articles, yielding 3,300 articles.

2.3.3 Quality assessment

Similar to prior reviews (e.g., Wang and Chugh, 2014; Fabiano *et al.*, 2020), this paper focused on articles published in journals listed in Academic Journal Guide 2021 (AJG's list)[2] – i.e. a list that indicates a level of quality for the journals and covers studies in Social Science and Business and Management research. Selecting journals in the AJG's list ensures the robustness and quality of the relevant articles, particularly if they are expected to be submitted to more respected, high-status journals. This process returned 1,550 articles which were exported from *Endnote* to a spreadsheet in *Microsoft Excel*. Next, following prior reviews (see, e.g., Pittaway *et al.*, 2004; Thorpe *et al.*, 2005; Mallett *et al.*, 2019), the remaining articles were classified into different grades (e.g., A, B and C) based on how relevant the articles were considered to the review focus. For the classification, the

[2] It was early the Association of Business Schools Guide (ABS's list) which prior review used older versions.

abstract and, if necessary, the whole paper was read. In this step, the keywords in Group 3 were searched within the article to assist the categorisation. This process produced 49 final articles for review. The information of selected papers (e.g., title, authors, years, journal, objectives, findings, theories, methods, country, sector, UIC channels, capability, and performance measures) was summarised in a spreadsheet created in *Microsoft Excel*.

2.3.4 Synthesis and analysis

This paper adopted the *Narrative Synthesis* as suggested by Briner and Denyer (2012), which allows the flexibility to thematically explore the relationship between and within studies and to tell the story of findings from a diverse body of literature. This approach is also suitable for this paper since the selected articles are heterogeneous in terms of research areas and methods (Zahoor and Al-Tabbaa, 2020).

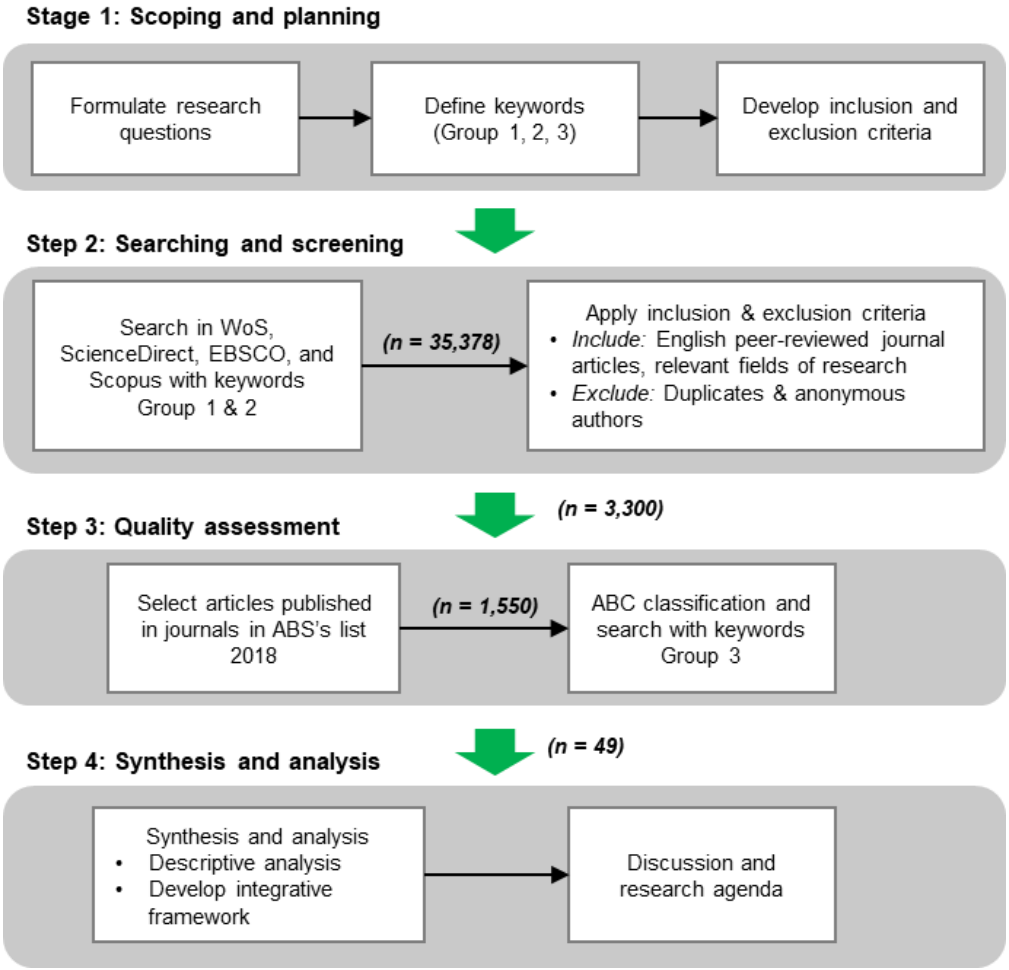

Figure 2.1 Systematic literature review protocol

2.4 Results

2.4.1 Status of the literature

2.4.1.1 Time of publications, journals, and subjects

The literature on capability and performance in the UIC has been realised since 2001 but the number of studies fluctuated over 20 years (Figure 2.2). Table 2.2 presents that the articles were published in 25 different journals in which the key articles were published in *Research Policy* (n = 8) and *Journal of Technology Transfer* (n = 7). The analysis revealed that the topic of capability in the UIC has gained attention in leading journals as 35 articles (71%) were published in 3- to 5- star journals according to the AGJ's list. A majority of articles were under the subject of *innovation* (n = 27) whilst the rest covered other subjects such as *Economics, Econometrics and Statistics* (n = 4), *Social Sciences* (n = 5), and *Operations and Technology Management* (n = 4), indicating that the interest in this topic has extended to non-innovation subjects.

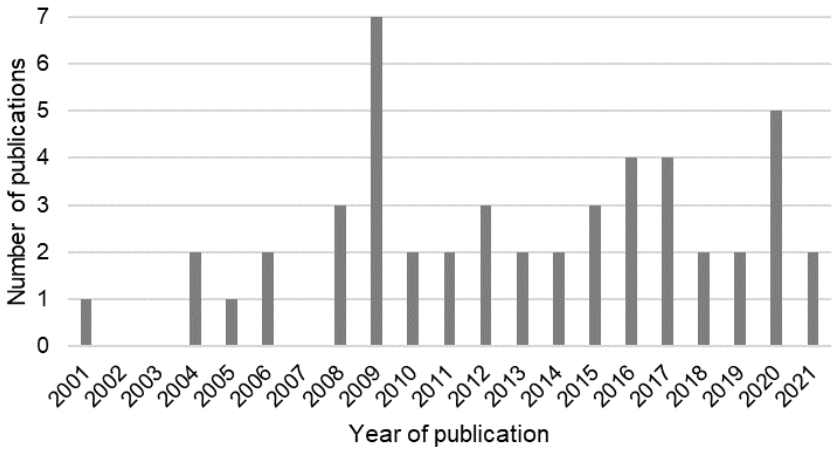

Figure 2.2 Number of publications in the 2001–2021 period

Table 2.2 Journals of selected publications

Journal	No. of papers
Research Policy	8
Journal of Technology Transfer	7
Economics of Innovation and New Technology	4
Technovation	3
IEEE Transactions on Engineering Management	2
Industry and Innovation	2
Journal of Management Studies	2
R and D Management	2
Science and Public Policy	2
Technological Forecasting and Social Change	2
Other journals	34

2.4.1.2 Contexts and methods

In terms of geographical area, the majority of the research was based on the data from developed countries (n = 31), mostly from Europe (n = 23) and North America (n = 8). Interestingly, the topic has also gained interest among researchers in developing countries (n = 14) where most empirical research was conducted in China (n = 6) followed by South Korea (n = 4) and Taiwan (n = 3). Most studies were conducted in a single country, thus lacking cross-country comparison. In terms of industry, the manufacturing sector was over-represented (n = 24) whereas the remaining focused on both manufacturing and service sectors (n = 6), indicating that the service sector appeared to receive less attention. Among studies on the manufacturing sector, scholars tended to target technology-intensive industries (n = 16) such as biotechnology, pharmaceuticals, ICT and electronics, and nanotechnology since this represented firms being active in innovation and the UIC.

Regarding the research methods, the quantitative method was over-represented (n = 37) whereas qualitative (n = 4) and mixed approaches (n = 8) received less attention. Most studies were based on cross-sectional analysis (n = 38) although panel data were often recommended by quantitative studies. In terms of data collection, secondary data were mainly used (n = 27) whilst the remaining used primary data (n = 17) and a minority used both (n = 5). Regarding the means of data collection, most studies used surveys (n = 33) followed by databases (n = 14), interviews (n = 9) and other sources (e.g., patents, publications, websites, minutes, thesis). Most of the research performed the analysis at an organisational level– i.e. firm (n = 29) and university (n = 6). Research at an individual level was biased towards the university's side (e.g., researchers and students, n = 3). At the project level, studies were from both the firm's and the university's sides (n = 7). The remaining studies were at a patent level (n = 4).

2.4.1.3 Co-occurrence analysis on abstracts

Figure 2.3 presents a co-occurrence analysis of titles and abstracts by using *VOSviewer*. A total of 39 words have a minimum occurrence of five times. The size of the bubble represents the frequency of occurrence. Regardless of frequency, all words from abstracts were interrelated but could be grouped into three clusters. The green cluster consists of such words as "firm", "university", "collaboration", "knowledge", "innovation" and "capability" which represented the main theme: *knowledge and capability for innovation creation in the UIC context*. The red cluster comprises words such as "performance", "technology transfer", "partnership", "technology" and "success" indicating another research area: *performance and success of technology transfer*. The blue cluster includes "relationship", "absorptive capacity", "innovation performance" and "UIC", presenting the theme: *absorptive capacity*

and innovation performance in the UIC context. These three clusters insightfully informed scholars that capability, performance, and UIC were interrelated and, interestingly, absorptive capacity was a separate research stream, beyond ordinary capabilities.

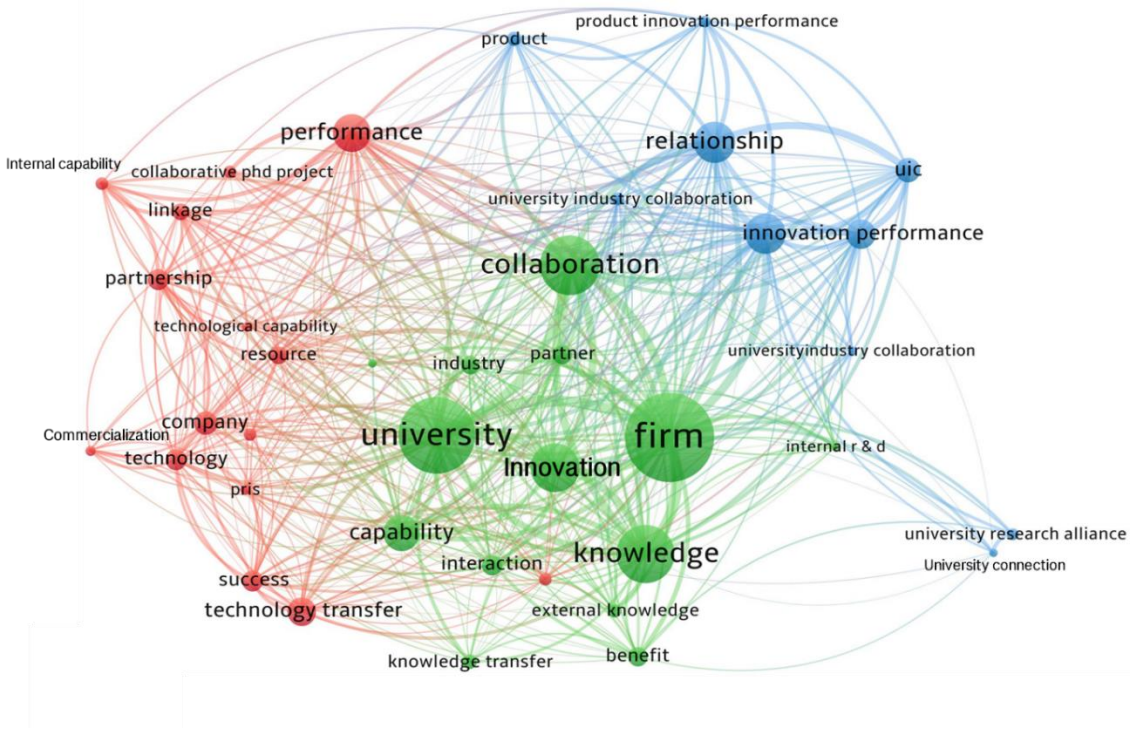

Figure 2.3 Mapping of keyword co-occurrences estimated by *VOSviewer*

2.4.2 Measures of capabilities

A close investigation of the UIC literature reveals that previous studies have investigated a wide spectrum of capabilities as well as diverse measures. To present an overview of capabilities in the UIC, all capabilities as well as their interpretation, given by the literature, are examined and classified. Table 2.3 and Table 2.4 present the summary of a firm's capability measures, and a university's capability measures, respectively.

For studies based on a firm's perspective, the first category is *technological capabilities* which refer to a collection of a firm's abilities to exploit *technological* knowledge and any relevant *technical* functions to create new technological knowledge and innovation. Based on this definition, such terms as innovation capability, technological capability, and R&D capability can be used interchangeably. The review reveals that most studies are biased towards quantifiable measures presenting the technology mastery such as R&D inputs (e.g., R&D expenditure, R&D employees, continuity of R&D activities and the existence of R&D department), technological path dependency (e.g., prior technical knowledge and experience), and R&D outputs (e.g., patents and number of new products). Only a few studies (see, e.g., Petruzzelli, 2011; von Raesfeld *et al.*, 2012) focus on an ability

to integrate or recombine existing and new technologies captured through the overlapping patent classes, either within a firm or between parties. Some studies depart from the mainstream by adopting subjective measures (e.g., Su *et al.*, 2009; Garcia-Perez-de-Lema *et al.*, 2017; Kobarg *et al.*, 2018).

Table 2.3 Measures of firms' capabilities

Category	Measures
A. Technological capabilities *(e.g., R&D capability, innovation capability)*	**a. R&D intensity**: ratio of R&D investment to total revenue, ratio of number of R&D employees to the total number of employees **b. R&D resource**: number of R&D employees, R&D expenditure **c. Innovation output**: number of new products and services, number of technologies, number of patents **d. Knowledge**: prior technical knowledge, level of firm supervisor's knowledge **e. Experience**: prior experience in R&D, production, and IT activities from technology transfer **f. Technology relatedness**: overlapping between firm's and university's technological field in a patent, access external expertise to strengthen firm's core area of business **g. Technology diversity**: overlapping of the patent classes in a project **h. Technology recombination focus**: breadth of patented technologies recombined in developing an innovation: based on technology class of patents cited by the patent issue **i. Benchmarking against competitors**: R&D capability, product improvement, commercialisation, unique product features **j. Usefulness**: Advantage relies on current technological capabilities **k. Technology management capability**: ability to identify and integrate relevant technologies **l.** Innovation capability in product and process **m.** New product development capability
B. Non-technological capabilities	**a.** Design capability (product design and marketing) *Entrepreneurship-related* **b. Risk-taking**: Number. of risky projects, expenditure on risky R&D projects, acceptance of the risky project, acceptance of uncertainty **c. Proactiveness**: number of first-mover pursing projects, expenditure on first-mover products, being the first mover, looking for competition **d. Innovation-orientation**: ability to recognise innovation and speed up commercialisation, ability to use the external resources and cooperate with external parties, marketing & R&D strategies, innovation incentives *Management-related* **e.** Prior organisational knowledge (incentive and reward system, job relation to other activities skills and technologies) **f.** Possessing management resources and capability (binary) **g.** Experience in technology innovation contracts/ programmes **h.** Project management capabilities – managing projects in terms of quality, cost, and time *Relationship-related* **i.** University tie (close relationship to university and frequency of communication)
C. Absorptive capacity (AC)	**a. R&D intensity**: external R&D expenditure on UIC over sales, investment expenditure per employee **b. R&D activities**: the existence of R&D department, continuity of internal R&D, frequency of R&D activities **c. Human capital**: employing R&D staff, personal training, the share of employees with tertiary-level education research-experienced academic founder **d. Knowledge intensity**: ratio of number of publications to R&D expenditure, co-authored publications with universities

Category	Measures
	e. External knowledge: outsource R&D activities, R&D cooperation with external partners
	Multi components
	f. Firm's capacity to carry out R&D, level of technological and scientific information, personal education, skills to gather and use relevant information from markets
	Process view of AC
	g. Explorative external AC (Pearson correlation between current research topics and new research topics) & Transformative external AC (Technology combination: Herfindahl–Hirschman Index)
	h. Ability to quickly recognise target market changes, quickly responds to competitor's changes, regularly monitors environment changes, actively adopts successful best practice, quickly changes strategies based on customer feedback

Although limited, scholars pay some attention to a firm's *non-technological capabilities* responding to the debate that to achieve collaboration outcomes and successful technology transfer, it requires, in addition to technological capabilities, capabilities relevant to entrepreneurship, management, marketing, and relationship (Choonwoo *et al.*, 2001; Buganza *et al.*, 2014; Tseng *et al.*, 2020). Since non-technological elements are inherently latent, researchers thus often rely on the aggregation of explanatory variables or subjective measures to capture non-technological capabilities.

The last category for studies is a firm's absorptive capacity (AC). Most studies capture AC through input-based measures of R&D such as R&D intensity, R&D human capital, and existence and R&D department and activities (Dezi *et al.*, 2018; Kobarg *et al.*, 2018; Min *et al.*, 2019; Apa *et al.*, 2020) similar to technological capabilities. However, some studies depart from a firm's R&D inputs to capture AC by focusing on an engagement in R&D cooperation (Arvanitis and Woerter, 2015), the academic characteristics of a firm's boundary spanner (Toole *et al.*, 2015), and a firm's scientific publications (Belderbos *et al.*, 2016). While a majority of articles are biased towards quantifiable measures and a static view of AC, some research follows prior studies (e.g., Lane *et al.*, 2001; Zahra and George, 2002; Lewin *et al.*, 2011) arguing that AC is a multidimensional and complex concept which consists of knowledge exploration and knowledge exploitation occurring in a sequential form, thus capturing AC from a process-based view (e.g., Brehm and Lundin, 2012; Min *et al.*, 2019; Melnychuk *et al.*, 2021), or a complex combination of multiple factors (Garcia-Perez-de-Lema *et al.*, 2017).

For studies based on a university's perspective, capabilities can be classified into research capabilities and non-research capabilities (Table 2.4). Research capability refers to the intensity of a university's scientific and technological knowledge as an input for collaborative projects. The review reveals that literature is biased towards a university's research capabilities mostly captured through academic publications. On the other hand, research quality is variously measured by the quality list of publications (Belderbos *et al.*,

2016), participation in R&D funding programmes (Tseng *et al.*, 2020), and other subjective measures (Salimi *et al.*, 2016). Since a university's roles have been expanded to be more entrepreneurial (Abreu *et al.*, 2016), UIC scholars have addressed the importance of a university's non-research capabilities relevant to UIC management and entrepreneurship. These capabilities can be captured from quantifiable measures such as the number of university staff, the engagement in entrepreneurial activities, and self-developed measures (Lockett and Wright, 2005).

Table 2.4 Measures of universities' capabilities

Category	Measures
A. Research capabilities (*AKA knowledge capacity, intellectual capital, scientific excellence, research quality*)	**a. University level**: high-quality universities (listed in R&D funding programme), three-year stock of publications, research capability (technological and knowledge capital), number of patents, research orientation: proportion of graduate students from the total number of students, level of university's knowledge **b. Faculty level**: score attributed to the university department based on the Research Assessment Exercise (RAE) 2001, number of publications per faculty **c. Individual level**: number of publications per academic, number of publications per number of publishing career years, the proportion of postgraduate researchers in the group, level of academic supervisor's knowledge
B. Non-research capabilities	**a.** UIC mechanisms (number of staff in charge with UIC affairs in the universities, number of staff whose responsibility is to establish the UIC) **b.** Entrepreneurship capabilities (involve in commercialisation, incubation, and alliance with strategic partners) **c.** Alliance management capabilities (proactiveness, transformation, inter-organisational coordination and learning) **d.** Business development capabilities (marketing, technical, and negotiating skills of university staff, availability of clear process for conducting IP correctly due diligence, clear process of spinout company, availability of university staff to manage commercialisation process)

2.4.3 Measures of performance

In this review, *performance* is broadly conceptualised as any results derived directly or indirectly from the UIC regardless of any terms such as benefits, outputs, outcomes, and technology transfer success. Emerging from the review, a firm's performance can be classified into three categories (Table 2.5). First, *innovation performance* refers to any forms of tangible output (e.g., new products, new processes, patents) derived from collaboration projects including the impact on innovativeness (e.g., forward citations, revenues of new products). Technology transfer success, usually captured through subjective measures and referred to as out-to-door outcomes, is also included in this category. The second category is associated with a *firm's business performance*. This performance is derived from but is not limited to, the results of innovation performance (Lofsten, 2019). This type of

performance can also be perceived and termed as a firm's *competitive advantage* and captured through productivity, growth, R&D investment, market share, and profitability, among others. The last category is a *firm's benefits* associated with intangible outcomes which are directly derived from the UIC (Daghfous, 2004b).

Table 2.5 Measures of firms' performance

Category	(1) Directly derived from UIC	(2) Indirectly derived from UIC
A. Innovation performance	**a. Innovation**: new products, new processes, improved products, improved processes, other outcomes (software, prototype, process description) **b. Intellectual property rights**: patents **c. Value of innovation**: forward patent citations, degree to which the collaboration projects create revenues **d. Technology transfer**: technology adoption/solution implementation, degree of technology transfer, meeting objectives of technology transfer and needs of innovation activities **e. Potential of technology**: number of drug candidates entering clinical trials	**a. Innovation**: introduction of new products or new processes, number of new products or new processes **b. Intellectual property rights**: patent applications, patent counts, other IPRs **c. Value of innovation:** forward patent citations, innovation intensity, sales of new products or improved products, export value of new products **d. Pace of innovation**: time lag between cited and citing patents or publications
B. Competitive advantage	**a. Productivity**: labour productivity, increase in throughput	**a. Productivity**: sales of new and improved products by the number of employees, labour productivity **b. Growth**: sales growth, productivity growth, employment growth **c. R&D**: R&D intensity (expenditure/sales) **d. Others**: market share, profitability, competitiveness, product quality, reputation, brand awareness
C. Firm's benefits	**a.** Acquisition of new scientific/technological knowledge **b.** Learning from technology transfer **c.** Better project management **d.** Building a learning alliance **e.** Productive and satisfactory relationship in technology transfer **f.** Innovation and production benefits	**a.** Technological upgrading

The review reveals that not all scholars measure a firm's performance directly from UIC outputs possibly because the commercial gain cannot be realised in the short run (Kobarg *et al.*, 2018) and the results of UIC may be confounded with other innovation activities (Arvanitis *et al.*, 2008). Therefore, this review classified performance measures into whether the results are directly or indirectly derived from the UIC. The review reveals that scholars often measure performance based on participants' opinions thanks to the difficulty in realising the commercial value of UIC results. However, this is exceptional for

those project-based studies in which the quantifiable measures (e.g., the number of citations and drug candidates) are available, providing more accurate measures with which to capture performance.

A university's performance is categorised into commercialisation and academic benefits (Table 2.6). In this study, commercialisation refers to the out-to-door results of UIC (e.g., technology adoption by a firm, prototypes), commercial from technology transfer (e.g., revenue from royalty, university spinoffs), and other academic outputs (e.g., publications and citations). Similar to a firm's performance, another category is academic benefits since university researchers also obtain such intellectual and economic benefits from engaging in the UIC. These benefits are normally not the primary objective of a university when engaged in the UIC.

Table 2.6 Measures of universities' performance

Category	Measures
A. Commercialisation	a. **Technology transfer**: adoption of technology by firms (include licensing out), licensing opportunities, revenue (or royalty) from university technology transfer b. **Research outputs**: prototypes and ready products, number of publications, number of patents, number of citations received c. **Spinoff-related**: university spinoffs, number of equity investments, pre-venture funding awards
B. Academic benefits	a. **Intellectual benefits**: get inspiration for future research, the share of knowledge, ideas for further collaboration projects, gain reputation, a job offer from university/ industry for PhD candidates b. **Economic benefits**: shared equipment, provision of research input, access to financial resource

2.4.4 Capability and performance relationship in the UIC literature

2.4.4.1 Firm's capabilities and performance

The previous section elucidates that there is a broad spectrum of a firm's capability and performance measures, and thus, this becomes one of the reasons why results from studies on a firm's capabilities and its performance are mixed and contradictory. This section aims to unpack the heterogeneous impact of a firm's capabilities on performance based on the diverse measures.

A firm's *R&D intensity* is found to have benefits in university-industry technology transfer (Santoro and Bierly, 2006) in that strong R&D intensity presents a high level of absorptive capacity (AC) leading to increased sales of new and labour productivity (Arvanitis *et al.*, 2008), and technological potential of drug candidates in biotechnology (Melnychuk *et al.*, 2021). Researchers also highlight that the positive impact of a firm's R&D intensity is

more prominent for an exchange of tacit knowledge since it requires an in-depth understanding of a specific topic to assimilate and apply knowledge (Santoro and Bierly, 2006; Bierly *et al.*, 2009). Hence, a firm with strong R&D intensity can benefit from engaging in joint research associated with an exchange of tacit knowledge (Arza and Vazquez, 2010).

On the contrary, several studies do not find the impact of a firm's R&D intensity on its performance (e.g., Medda *et al.*, 2006; Eom and Lee, 2010; Xu *et al.*, 2011; Chen *et al.*, 2016). Despite the lack of empirical investigation, scholars argue that this may be due to a lack of ability to translate and exploit a university's knowledge into innovation (Chen *et al.*, 2016), weak appropriability conditions (Medda *et al.*, 2006), and substitution effects (Kobarg *et al.*, 2018). Kobarg *et al.* (2018) find that a firm's strong R&D intensity hampers its incremental innovation performance while Tsai (2009) finds that a firm's R&D intensity entails an increase in its incremental innovation but not radical innovation. These two studies present the issue of how a firm's AC is operationalised. Specifically, Tsai (2009) captures a firm's AC from its R&D investment to total employees while Kobarg *et al.* (2018) traditionally use a firm's R&D expenditure per total sales. Researchers should thus be aware of the interpretation and quality of a firm's R&D intensity in capturing its technological capability or its AC despite common use. Coombs and Bierly (2006) claim that a firm's R&D spending is not a valid measure of its technological capabilities. It may also reflect the resource commitment that a firm invests in R&D to perform the non-innovation development purposes such as attracting partners, funding, and venture capital, not a product development (Hall and Bagchi-Sen, 2007). Even in the context of the UIC, a firm's R&D effort does not ensure its success of innovation (Eom and Lee, 2010).

A firm's *technological knowledge* is perceived as a prerequisite to obtaining benefits from collaboration projects with universities (Daghfous, 2004a; Daghfous, 2004b). Strong technological knowledge, expressed as publication intensity, is found to facilitate a firm to quickly search for more technological opportunities (Fabrizio, 2009) and enhances the gatekeepers' abilities to absorb knowledge from a university (Belderbos *et al.*, 2016). Recently, Melnychuk *et al.* (2021) have advanced the publication-related measures by examining the degree of change in a firm's research topic over time, to capture the progress of technological knowledge termed as '*exploration intensity*'. They find that pharmaceutical subsidiary firms with strong exploration intensity tend to have more drug candidates entering clinical trials. Nevertheless, excessive publication intensity may hinder a firm's innovativeness due to its redundancy and overlap with a university's knowledge (Soh and Subramanian, 2014).

Technological overlap between a firm and a university does not facilitate an exchange of *explicit* knowledge (Santoro and Bierly, 2006), or knowledge exploration (Bierly *et al.*, 2009). Knowledge exploration is often associated with the transfer of tacit knowledge

requiring a distant knowledge base to be combined and translated into novel knowledge. Alternative to technology relatedness between parties, a *firm's technology diversity*, defined as a firm's ability to recombine its technological knowledge, is also perceived as crucial in the UIC as it translates a university's knowledge into innovations (Soh and Subramanian, 2014; Melnychuk *et al.*, 2021). Nevertheless, the effect of technology diversity is likely to cause the *Goldilocks problem* (too much versus too little). Petruzzelli (2011) finds that under- or- over-emphasis on a firm's technology diversity may have an adverse effect on its innovation development. However, von Raesfeld *et al.* (2012) find contradicting results for nanotechnology firms and asserted that those firms may prefer to rely solely on either exploitation of existing knowledge or the pursuit of breakthrough knowledge creation for their innovation creation thanks to the nature of this industry.

Human capital is perceived as crucial for technology transfer success. Xu *et al.* (2011) find that R&D capacity (as a share of R&D employees) and strong ties with universities favours foreign firms in enhancing their innovation performance, but this is exceptional for domestic firms which can rely on a closer relationship with local universities without establishing their R&D capacity. In addition, for start-up firms, only founders who have been employed as academic scientists prior to establishing the firm can effectively absorb and exploit knowledge from collaborative R&D projects with university partners, thus resulting in employment growth (Toole *et al.*, 2015). Kobarg *et al.* (2018) find similar results in the relationship between a firm's R&D employees with higher education and its radical innovation performance. Whether it is in a form of capacity or academic quality embedded in individuals, scholars have found that human capital facilitates both industry and university partners to share common culture, knowledge and skills, thus allowing effective communication.

For those studies employing perceptual measures of a firm's *technology-related capabilities*, there is evidence that a firm benefits from these capabilities when engaged with university partners. For example, technological capabilities help a start-up firm to better absorb and exploit a university's knowledge, thus increasing sales growth (Choonwoo *et al.*, 2001). A firm is also required to have a minimum level of technological capabilities as a foundation to reap benefits associated with product innovation from the UIC (Belso-Martinez *et al.*, 2013). A firm needs technological management capabilities particularly in the early stages of development (Buganza *et al.*, 2014). Nevertheless, technological capabilities do not always enhance a firms' innovation performance derived from the UIC. For instance, Su *et al.* (2009) find that biotechnology firms do not benefit from innovation capabilities in improving their innovation performance which seems contradictory to the nature of the biotechnology industry which mainly benefits from innovation capabilities. Similarly, Kobarg *et al.* (2018) do not find the impact of a firm's new product development capability on its

radical innovation performance. While some explanations such as a low level of a firm's absorptive capacity, substitution effects by a university's capabilities, or the context of an emerging economy have been provided, none of them has been empirically investigated.

A firm's *absorptive capacity* (AC) is perceived as one of the most impactful factors for technology transfer success (Barbolla and Corredera, 2009). The effects of AC required for reaping benefits from the UIC are found to be contingent on which UIC channels are employed by firms (Brehm and Lundin, 2012; Dezi *et al.*, 2018; Fudickar and Hottenrott, 2019; Apa *et al.*, 2020). The positive effects of AC are also eminent for foreign firms (Brehm and Lundin, 2012) and intense market competition (Min *et al.*, 2019). These findings hint that understanding the relationship between a firm's AC and its performance when engaged in the UIC is not clear-cut; thus, there is a need to take the impact of influential factors into consideration. For instance, several scholars find that capabilities and AC encourage a firm to engage in different modes of collaboration (Arvanitis *et al.*, 2008; Arvanitis and Woerter, 2009;2015; Garcia-Perez-de-Lema *et al.*, 2017; Goel *et al.*, 2017) and develop entrepreneurial and innovation projects with universities (Guerrero and Urbano, 2021), thus resulting in increased their performance.

Regarding a firm's non-technological capabilities, *prior experience* in the UIC is found as beneficial for its innovation usefulness (Belso-Martinez *et al.*, 2013) and innovation outcomes (Petruzzelli, 2011). Nonetheless, Bierly *et al.* (2009) argue that prior UIC experience is only beneficial for a firm's exploitative innovation but may be insufficient for its explorative innovation in which organisational routines and managerial procedures need to evolve with the collaboration with universities. A firm's *entrepreneurial capabilities* are also crucial for the development of radical innovation (Bierly *et al.*, 2009; Kobarg *et al.*, 2018), particularly for a start-up's survival (Choonwoo *et al.*, 2001). Regarding *management-related capabilities*, a firm needs to develop project management capability to deal with complexity and uncertainty in the collaboration process, particularly at the research phase of development (Buganza *et al.*, 2014).

2.4.4.2 University's capabilities and performance

Similar to studies on a firm's capabilities, scholars have investigated the effects of a broad range of a university's capabilities on its performance derived from the UIC. At a national level, it is important for a government to integrate all types of academic capabilities (e.g., teaching, research and outreach activities) to attain national technological upgrading and economic catch-up (Liefner and Schiller, 2008). In addition, most studies find that a university's research capabilities are critical for achieving its commercial outcomes (Ambos *et al.*, 2008; Han and Kim, 2016), academic outputs (Sengupta and Ray, 2017), pre-venture funding awards for start-up firms (Wang and Shapira, 2012), and international spillovers

when knowledge is internationally acquired in firm-university technology transfer (Petruzzelli and Murgia, 2020). The findings underline an important role of *star scientists* - i.e. highly productive university researchers. A university's research capabilities are more important for some channels such as joint research than others since they lead to increased intellectual benefits (Arza and Vazquez, 2010). In addition, academic researchers with significant academic outputs (e.g., publications in top-ranking journals) benefit most from contract research in terms of commercial outcomes (Sengupta and Ray, 2017). However, this positive impact tends to be lower for large and top universities (e.g., the Russell Group) due to their mature ambidexterity in terms of performing research and outreach activities.

Neither under- nor over-engagement in the UIC leads to a firm's increased innovation performance (Kafouros *et al.*, 2015) and academic innovation (Lin, 2017). Nevertheless, this relationship can be alleviated by a university's research capabilities - i.e. a high level of a university's research capability weakens the downside of the effects of under- or over-engagement in the UIC on a firm's and a university's performance (Kafouros *et al.*, 2015; Lin, 2017). In addition, Tang *et al.* (2020) highlight that the impact of a university's research capabilities is conditional upon a firm's regional proximity. Specifically, cooperation with cross-regional and high-quality universities increases a firm's radical innovation, while collaboration with intra-regional and average low-quality favours the development of a firm's incremental innovation. Regarding co-PhD supervision, Salimi *et al.* (2016) find an adverse effect of academic supervisors' knowledge on technology commercialisation from PhD projects; they contend that university supervisors may be more interested in publications than in knowledge transfer.

A university's non-research capabilities are crucial for UIC performance. Lockett and Wright (2005) reveal that universities with strong business development capability are likely to attract more external equity investment for spin-off companies, resulting in an increased number of university spinoffs. Guerrero and Urbano (2021) find that a high level of a university's entrepreneurship capabilities encourages a firm to establish collaborative projects with academic researchers, thus improving a firm's performance. In addition to research and entrepreneurial capabilities, a university needs to develop sufficient *alliance management capability* to achieve successful technology transfer (Leischnig and Geigenmuller, 2020). Particularly, a university's *transformation capability* ensures openness and flexibility in response to changes in the UIC processes.

2.5 Discussion

2.5.1 Summary of results

Recent work confirms the important roles of a firm's technological capabilities in achieving the success of the UIC. Particularly, a firm needs to establish internal R&D, strengthen R&D intensity, and hire R&D employees to attain a sufficient degree of technical mastery and absorptive capacity (AC). Besides, a firm's technological knowledge and experience embedded in individuals such as employees with higher education and start-up founders with academic experience enhance a firm's AC, thus allowing it to better reap the UIC benefits. For such projects aimed at achieving radical innovation or exploratory knowledge application, a firm's prior technological knowledge and technology diversity are required only up to a certain threshold to avoid knowledge overlap and redundancy with a university.

Literature additionally shows that the effects of a firm's technological capabilities are contingent on factors such as UIC mechanisms, market competition, proximity, and collaboration objectives. A high level of a firm's technological capabilities and AC is a prerequisite in such situations as engaging in collaborative research, facing intense market competition, and involving with a distant knowledge base (e.g., cross-regional or international collaboration) where the knowledge is sticky and difficult to transfer. Given the uncertainties in the UIC implementation, a firm's non-technological capabilities (e.g., entrepreneurial orientation, project management capability, and strength of university ties) play important roles in managing the conflicts of interest, intellectual property issues, and changes in the collaboration. Both a firm and a university need to form an entrepreneurial mindset to make the project commercially feasible.

There is an agreement that a university's research capabilities, reflected as academic publication intensity, are crucial for attaining academic performance and commercial outcomes, thus suggesting that a firm should engage with productive researchers (i.e. *star scientists*), high-research-quality faculty, and top-ranking universities. A positive impact is more pronounced in some channels such as collaborative research than others. In addition, university researchers equipped with strong business development and marketing capabilities perform better in identifying knowledge transfer opportunities and commercialising their inventions. With management capabilities, academic researchers are more open and flexible to dealing with uncertainties and can manage issues such as intellectual property, among others.

On the basis of the synthetic insights, this paper proposes the framework (Figure 2.4) to advance an understanding of *what is known* in the literature while illuminating the areas where the evidence remains inconclusive or insufficient. The framework is also aimed at

identifying research opportunities derived from an absent body of knowledge. The framework starts from a firm's AC facilitating an evaluation of internal capabilities and identification of needed external knowledge as the means to knowledge acquisition. Once the academic partners are identified, an agreement is made in which the collaboration is manifested through selected mechanisms. The interaction can be unilateral– i.e. a university acts as the main knowledge provider, thus engaging in *knowledge transfer* (Mitton *et al.*, 2007). On the contrary, *knowledge exchange* is taken place under the bilateral relationship – i.e. both parties contribute to each other (e.g., collaborative research) (Perkmann *et al.*, 2013). The collaboration is facilitated by a firm's and a university's capabilities as well as being influenced by several factors leading to the UIC performance. A framework underpins the following sections to discuss the research agenda, emerging research areas, and research challenges in detail.

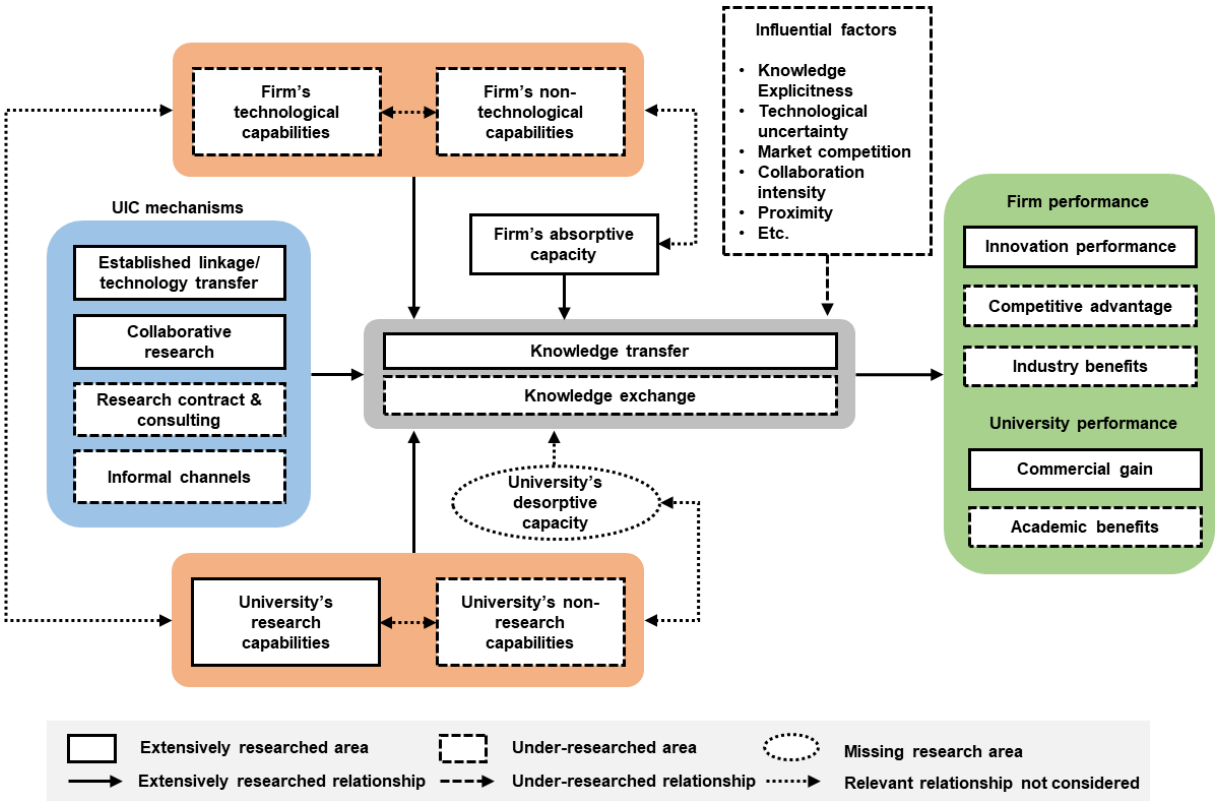

Figure 2.4 A framework of a capability-performance relationship

2.5.2 Research agenda

Based on a systematic literature review, synthesis, and a framework, a research agenda is proposed under several themes. Firms, in terms of *measures of capabilities and performance*, the review reveals that a firm's and a university's capabilities are diversely captured. This is unsurprising since capabilities are conceptually complex,

multidimensional, and difficult to measure (Deeds *et al.*, 2000; Camison, 2005). While creating a standardisation of measures can be challenging, this paper suggests that future researchers select measures that can best represent focused capabilities and fit with the research context. This paper summarises the advantages and drawbacks of common measures of capabilities (and also performance) as a guide for researchers, as presented in Appendix C. Specifically, researchers should not only rely on quantifiable measures because they are easily observable (Perkmann *et al.*, 2011). They should be aware of falling into the trap of using R&D input-based measures which are commonly used but cannot sufficiently link to performance (Koellinger, 2008). Particularly, researchers should be careful when using a firm's R&D intensity in capturing its technological capabilities given conflicting results in the literature and being claimed as an invalid measure of technological capabilities (Coombs and Bierly, 2006). In addition, using academic publication intensity is limited in terms of commercial value and innovation progress to fully capture a university's research capabilities. Future research may alternatively use patent counts or forward citations of publications.

Scholars tend to use perception-based measures to capture a firm's performance as a *direct result of the UIC*, possibly due to the difficulties in realising the financial outcomes. In contrast, for performance as *an indirect result of the UIC*, objective measures are preferred (e.g., sales of new products). Although both approaches are widely accepted, it is observed that the latter approach offers a lower degree of causation in the discussion and also causes diverse findings due to omitted variable biases. This paper thus suggests future studies use direct results of the UIC to gain an accurate assessment of the capability and performance relationship.

A closer look should be taken at the measures of a firm's AC. Traditionally, AC can be captured by a firm's R&D intensity, expressed as R&D expenditure, R&D continuity, and R&D employees (Cohen and Levinthal, 1990). Most UIC studies find a positive effect of AC regardless of how it is captured. However, when combined with results from the literature that uses similar measures to studies on AC to capture the effects of a firm's technological capabilities, the findings become inconclusive. This paper speculates that the issue may be rooted in the appropriateness of a firm's R&D intensity as a proxy for its AC. Despite being suggested for decades, a firm's R&D intensity is only '*absolute'* AC while, practically, AC is dependent on the organisation's norms, knowledge base and relationship in the collaboration (Lane and Lubatkin, 1998). The concept of a firm's AC has also been reconceptualised over time and thus become multidimensional and dynamic (Zahra and George, 2002; Lane *et al.*, 2006; Lichtenthaler and Lichtenthaler, 2009; Camison and Fores, 2010). Therefore, a firm's R&D intensity has limited capacity in operationalising its AC. As evidenced by the literature adopting a process view of AC, a firm's R&D intensity is only

associated with its internal ability to *transform* a university's knowledge, not all dimensions of AC (Brehm and Lundin, 2012; Melnychuk *et al.*, 2021). Like *the elephant in the room*, this paper observes that many recent studies still prefer to stick with a classic approach (see, e.g., Qiu *et al.*, 2017; Dezi *et al.*, 2018; Fudickar and Hottenrott, 2019; Apa *et al.*, 2020).This paper, hence, suggests that researchers depart from the traditional approach by adopting a dynamic view of AC given the limitations and ambiguous effects of R&D intensity.

The second theme of the research agenda is relevant to an exploration into different types of a firm's capabilities and performance. Future studies should focus on a firm's product-and-process innovation capabilities as these are found to have different effects on its performance and in networking with universities (Najafi-Tavani *et al.*, 2018). In addition, a university's teaching capability is often underestimated despite being regarded as one of the crucial academic capabilities for national technological upgrading (Liefner and Schiller, 2008). Researchers should investigate the roles of teaching capability as it can be critical for some UIC activities such as training. Importantly, current UIC literature is biased towards *a firm's technological capabilities and a university's non-research capabilities*. So, little is known about the roles of a firm's management and relational capability. Although the impact of a firm's innovation capabilities in the UIC is a well-explored topic, scholars should enrich the findings by breaking down a firm's innovation capabilities into *organisational and marketing innovation capabilities*. In addition, universities are often criticised as lacking entrepreneurial and marketing capabilities (Lockett and Wright, 2005; McAdam *et al.*, 2009; Wang and Shapira, 2012) despite being suggested acting as quasi firms (Leischnig and Geigenmuller, 2020). Therefore, future studies should investigate the antecedents of a university's non-research capabilities and how its capabilities affect performance when engaged with the industry. This issue should be explored in greater depth, particularly as a result of the increasing importance of entrepreneurial universities in today's world.

Several performance indicators are under-researched. While scholars have highlighted that the UIC can have a long-term impact on a firm's innovation development compared with other external partners (Briggs, 2015), little is known about the effects of capabilities on *spillovers* expressed as a firm's competitive advantages, industrial and academic benefits, and social impact. In addition, while the success of the UIC is often involved with tangible outcomes (e.g., technology adoption, new products, and patents), future research should embrace *soft* performance indicators such as partners' satisfaction and relationship productivity (Buganza *et al.*, 2014; Leischnig and Geigenmuller, 2020). In light of bilateral relationships, none of the research to date has investigated the mutual benefits or defined the success of the UIC from both a firm's and a university's perspectives.

The roles of UIC mechanisms are inadequately addressed in the literature. Regarding the means to collaboration, whilst one research stream focuses on collaborative research,

another is based on whether the linkage is established, without specifying UIC channels. The case for investigating the influence of various UIC channels rests on two arguments. First, a firm normally adopts a broad range of UIC channels in tandem (Arvanitis and Woerter, 2009; Hemmert *et al.*, 2014), limiting an ability to draw a generalisation if only focusing on collaborative research. Second, the effects of a firm's capabilities can vary among different UIC channels. For example, collaborative research is associated with a transfer of tacit knowledge which often requires a firm's strong technological capability and absorptive capacity compared with other informal channels (Arza and Vazquez, 2010; Toole *et al.*, 2015; Garcia-Perez-de-Lema *et al.*, 2017). As stressed by Arvanitis and Woerter, (2009, p. 1071), "*it is not sufficient to know what kind of capabilities… one has to find ways to transfer them or build them in the firm*". Therefore, incorporating multiple UIC channels will allow researchers to draw comparisons and enrich the findings.

The scholarly community also pays scant attention to informal UIC channels despite these being addressed as crucial for acquiring technological information, enhancing a firm's knowledge base, and providing a pathway to formal channels (Thursby and Kemp, 2002; Arvanitis and Woerter, 2009; Kafouros *et al.*, 2015). Given the ambiguous effects of a firm's technological capabilities on its UIC performance in developing countries (Su *et al.*, 2009; Chen *et al.*, 2016), researchers should replicate the analysis and further focus on informal collaboration channels as highlighted as more relevant to and preferred by firms in emerging economies (Choonwoo *et al.*, 2001; Arza and Vazquez, 2010).

Another promising research area is to focus on different stages of R&D. An early stage of development (e.g., the definition phase) requires a high level of a firm's technological and management capabilities to ensure the proof of concepts and information coordination before moving to an implementation phase (Daghfous, 2004b; McAdam *et al.*, 2009; Buganza *et al.*, 2014; Melnychuk *et al.*, 2021). In addition, an ability to integrate knowledge from the UIC into a complex system within an organisation is critical since 80% of technology transfer projects fail at this stage (Barbolla and Corredera, 2009). At the commercialisation phase, marketing and business development capabilities are more beneficial than technological capabilities (Jensen and Thursby, 2001). Hence, different capabilities, as well as their intensity, may be more relevant to some development stages of the UIC project than others. Given insufficient evidence, exploring this issue will contribute to an understanding of the UIC in a greater depth.

The last research agenda suggests that scholars focus on factors influencing the relationship between capability and performance. For instance, little is known about the moderating effects of UIC intermediaries (e.g., science park and technology transfer offices) and UIC-related policies, either at the regional level or university level. Plus, the emphasis on the effects of moderators in the capability-performance relationship is mainly found in

the literature focusing on a firm's capabilities and, thus, more research from a university's perspective is needed.

2.5.3 Outstanding research areas

This section identifies and discusses research areas that remain invisible but deserve more attention. First, the knowledge on the interaction effects of different capabilities on performance is nebulous despite being addressed (see, e.g., Choonwoo *et al.*, 2001; Lockett and Wright, 2005; Santoro and Bierly, 2006). The need for investigation of this issue is further underscored by the evidence in non-UIC research asserting the complementary effects between a firm's capabilities on its performance, often between technological and non-technological capabilities (Su *et al.*, 2013; Ferreira *et al.*, 2020). This paper thus encourages researchers to explore this issue in the UIC context.

The examination should also span the interaction between a firm's capabilities and a university's capabilities. Scholars often explain an insignificant or negative relationship between a firm's technological capability and its collaboration with universities on the substitution effects (e.g., Arza and Vazquez, 2010; Xu *et al.*, 2011; Soh and Subramanian, 2014; Kobarg *et al.*, 2018). It could be misleading if, given the substitution effects, a firm completely relies on collaboration with universities without investing in its in-house R&D (Tsai, 2009). Instead, this paper pleads that to claim the argument of substitution effects, future studies should examine the interaction between a firm's capabilities and a *university's capabilities* instead of a firm's capabilities and a university-industry *linkage* like most studies have relied on. The literature that incorporates both a firm's and a university's perspectives is relatively scant, except Arza and Vazquez (2010), partly due to the methodological challenge - i.e. collecting data from two informants.

Another promising research area is to explore the relationship between a firm's capabilities[3] and its absorptive capacity (AC). Although AC is a powerful concept to explain why a firm or a university can achieve UIC success, its applications and measurements are still puzzling; for instance, scholars often employ a firm's R&D intensity to proxy for both technological capabilities and AC. In addition, the roles of a firm's capabilities and AC overlap based on the interpretation given by the literature. *Are a firm's technological capabilities and its AC similar? To what extent are they related?* Technological capabilities and AC are indeed distinct concepts, in which the former is internally focused and

[3] Firms' capabilities refer to any capabilities studied in the literature besides absorptive capacity. The purpose of this separation is to elucidate that some capabilities play roles in the UIC similar to absorptive capacity, indicating that the concepts of capabilities and absorptive capacity may be interrelated.

associated with knowledge generation while the latter is more relevant to external knowledge exploitation (Lichtenthaler and Lichtenthaler, 2009). However, some scholars reason that both of them are somehow interrelated given that they complement each other to succeed in the university-industry technology transfer (Buganza *et al.*, 2014).

Absorptive capacity is an overarching and multidimensional concept which covers the whole process of knowledge transfer (e.g., identification and acquisition, assimilation, transformation and exploitation of external knowledge) (Cohen and Levinthal, 1990; Zahra and George, 2002). Thus, AC can be perceived as higher-order capabilities in which other capabilities should be substantial to each dimension of AC. Clearly illustrated by studies adopting the process-and-dynamic view, R&D intensity, technology diversity, innovativeness, and prior technical knowledge are constructs of each stage of AC (McAdam *et al.*, 2009; Brehm and Lundin, 2012; Melnychuk *et al.*, 2021). The constructs of AC also cover non-technological capabilities such as a firm's marketing knowledge and efforts in response to the market and competition changes (Lichtenthaler, 2016; Min *et al.*, 2019). Future studies are thus encouraged to empirically investigate the relationship between a firm's capabilities and its AC as well as the interaction effects on a firm's performance when engaged with universities. This will not only contribute greatly to the knowledge body but also clear up confusion regarding the interrelationship between capabilities and AC in the UIC literature.

The last topic that requires attention is a university's desorptive capacity (DC). DC refers to a capability of external knowledge exploitation in the outward knowledge transfer which is manifested through identifying external knowledge exploitation opportunities and subsequently transferring the knowledge to the recipient (Lichtenthaler and Lichtenthaler, 2009;2010). There are two reasons to convince why the university's DC should receive more attention. First, the shift to being an entrepreneurial university motivates a university to proactively seek opportunities to commercialise its research (Lockett et al. 2015; Siegel and Wright 2015). Therefore, a university needs to be equipped with a sufficient ability to identify compatible knowledge outside its boundary, and potential knowledge recipients. Second, knowledge transfer success is unlikely to be achievable if a university lacks DC even though a firm is equipped with high AC (Lichtenthaler and Lichtenthaler, 2010; Ziegler *et al.*, 2013).

Given the nascent knowledge on DC in the UIC literature, researchers should first investigate antecedents of DC. Such measures of DC proposed by prior literature (e.g., technological and marketing knowledge, IP management capability, entrepreneurial spirit, licensing experience, and human capital skills) can be used for the operationalisation of the DC and can be combined with other relevant measures to provide the standardisation of DC in the UIC context (Lichtenthaler and Lichtenthaler, 2010; Ziegler *et al.*, 2013; Hu *et al.*,

2015; Bianchi and Lejarraga, 2016). Also, little is known about how a university's DC affects a firm's and a university's UIC performance. Examining the effects of interdependencies between a firm's AC and a university's DC on their performance can also be another promising research area.

While *knowledge transfer* is extensively explored, *knowledge exchange* is only acknowledged in a limited capacity and is often found in qualitative studies. This is not surprising as the knowledge body of the UIC is largely based on unidirectional flows from a university to a firm where the 'mutualism' referred to as the bidirectional flows of knowledge, resources and capabilities is largely under-researched (Schaeffer *et al.*, 2021). The results from the review reveal the existence of a bilateral relationship in the UIC; for example, a firm and a university switch their roles at different stages of collaboration (Daghfous, 2004b; Barbolla and Corredera, 2009). Recently, Schaeffer *et al.* (2021) have argued that a university not only contributes knowledge to a firm but also benefits from the UIC in terms of accessibility to resources and capabilities. As the notion of university-industry mutualism has just emerged in the past few years, there are thus several research domains to explore.

In light of mutualisms, scholars may investigate what kinds of a firm's capabilities and a university's capabilities that are critical for the knowledge exchange as well as how they play roles in achieving collaboration success. Scholars may focus on the performance indicators when focusing on mutualisms. For instance, it is clear that most studies from a university's perspective are biased towards the unidirectional knowledge transfer since the UIC outputs are a result of the knowledge transfer (e.g., income from the collaboration or royalty revenues). Therefore, such performance indicators as benefits in terms of accessibility of resources and capabilities can be a focus for future studies. Interestingly, if knowledge and capability building is what a university seeks from cooperation with industry, a university's *absorptive capacity* should also be required. This issue is very nascent but worth investigating.

2.5.4 Contextual and methodological issues

In terms of geographical context, most findings are based on developed countries. The differences from developed countries are that a firm's technological capabilities and a university's research capabilities are generally weak and the UIC is under-developed (Liefner and Schiller, 2008; Nsanzumuhire and Groot, 2020). The need to focus on developing countries is further foregrounded by the contrary results that firms in developing countries do not benefit from technological capabilities when engaged in the UIC and the empirical investigation on this finding is lacking (e.g., Su *et al.*, 2009; Eom and Lee, 2010; Xu *et al.*, 2011; Chen *et al.*, 2016). Most studies focus on a single country and therefore the

comparison of the results across countries is not possible, thus calling for further investigation of the variations among countries.

Regarding the sector, studies are mainly based on manufacturing firms, particularly in high-technology industries (e.g., biotechnology, nanotechnology, and pharmaceuticals) thanks to the leading roles of universities in terms of innovation sources and knowledge providers (Gertler, 2010). Future research should diversify the industrial sectors to cover low-technology industries and service firms. Especially for the service sector, the evidence is very scarce. There is evidence that such service firms may benefit from the UIC through attending a university's training (Arvanitis and Woerter, 2009). In addition, scholars focus on the capabilities of a wide range of firms (e.g., SMEs, start-up firms, foreign firms, parent firms and subsidiary firms), the evidence from literature based on a university's perspective is still flying under the radar. Promising questions can be *What and how do a university's capabilities facilitate the UIC for different types of firms?* or *To what extent do the effects of a university's capabilities vary among different types of firms*?

In terms of methodological issues, literature is mainly based on a quantitative manner, thus creating challenges to causal interpretation, thus an in-depth interview is encouraged for future studies. An alternative approach to common techniques such as regression analysis is *Fuzzy-set Qualitative Comparative Analysis* (*fsQCA*) applied by Leischnig and Geigenmuller (2020). With the *fsQCA*, researchers will be able to further explain the findings as it bridges the quantitative-qualitative gap (Pappas and Woodside, 2021). Regarding the time horizon, most reviewed papers are cross-sectional by nature, thus lacking sufficient knowledge on the dynamics of capabilities and the UIC. Employing a longitudinal approach would allow for taking into account unobserved changes in the economy and capabilities which affect the UIC and performance (Qiu *et al.*, 2017). The comparison between the pre-and-post COVID-19 pandemic can also be an intriguing topic for future research.

Regarding the research philosophy, it is insufficiently mentioned by the literature although it can be implied that given the bias towards the quantitative approach, most studies adopt the *positivism* paradigm than others (e.g., interpretivism, pragmatism, realism). However, this can be regarded as common since the research philosophy is often perceived as less useful and unnecessary, drawing on *Midgely's plumbing analogy*[4]. Also, the use of philosophical terminology seems contradictory, thus creating confusion (Crotty, 1998). Nevertheless, in addition to the research methodology, the research philosophy provides the process of carrying out research (Žukauskas *et al.*, 2018). Thus, future research is encouraged to report the research philosophy employed.a variety of methods,

[4] Asking researchers to address the research philosophies is somewhat like explaining a thirsty person how a tap works instead of handing a glass of water (Midgley, 1992)

the research philosophy will ease the readers to understand how scholars come up with creative and innovative methods as well as the researchers' perception, beliefs, and awareness of theories and practices employed in the research (Easterby-Smith et al., 2012).

Last, regarding the unit of analysis, most research focuses on the organisational level. Particularly from an industry's perspective, less progress has been made in exploring the roles of a firm's managers and academic researchers in achieving UIC success. In addition, at a firm level, the results of the UIC are often confounded with other factors despite introducing several control variables (Melnychuk *et al.*, 2021). This issue is aggravated by the case of defining performance as an indirect result of the UIC (e.g., sales of all new products or market share). Therefore, focusing on the project level should overcome this issue.

2.6 Conclusions of the chapter

The subject of capabilities and performance has become increasingly important in the UIC literature. Nevertheless, despite the widespread recognition, the literature creates theoretical and hindrances for researchers due to confusion of measures and the mixed and contradicting findings. The fragmentation of the knowledge body can be misleading if researchers do not carefully investigate how previous studies capture capabilities and performance, as well as take the complex and sophisticated nature of UIC into consideration. The purpose of this systematic literature review is to understand the relationship between capabilities and performance and address the confusion in the UIC literature.

Through analysis of 49 peer-reviewed journal articles, the main findings are explained as follows. Scholars have examined various kinds of capabilities and performance, employed various measures to capture them. Most studies tend to adopt quantifiable measures to capture a firm's and a university's capabilities (e.g., R&D expenditure, patents, publications, etc.). The issue rests in the use of R&D intensity which creates confusion on the use of absorptive capacity. In addition, literature is highly biased towards a firm's technological capabilities and a university's research capabilities, thus underscoring the need for more research on a firm's non-technological and a university's non-research capabilities. The impact of capabilities is also contingent on several factors such as proximity, market competition, types of knowledge, UIC mechanisms, and contexts. This paper synthesises and consolidates the findings into an integrated framework that incorporates several under-researched domains for future studies.

This paper offers several theoretical contributions. *First*, it adds to prior discussions (see, e.g., Ankrah and Al-Tabbaa, 2015; Nsanzumuhire and Groot, 2020) by offering a comprehensive review on the relationship between a firm's and a university's capabilities and their performance in the UIC context. This paper responds to the question of what capabilities of a firm and a university facilitate the UIC process to achieve performance. This paper also uncovers the complexities and ambiguities regarding capabilities and performance which rest in the measurements and the use of such concepts as absorptive capacity. *Second*, this paper reviews literature from the holistic stance which allows for developing an analytical framework that links the key components addressed in the literature. *Third*, this paper provides potential avenues for future research. Research domains such as the impact of a firm's non-technological capabilities and a university's capabilities, the roles of a university's desorptive capacity, and a synergy between a firm's absorptive capacity and a university's desorptive capacity are worth exploring.

The results also offer several policy implications. *First*, policymakers should adopt multiple and more sophisticated indicators for an assessment of a firm's capabilities and a university's research capabilities in addition to the common measures such as a firm's R&D intensity and academic publication intensity. Policymakers should establish a robust evaluation system based on a variety of capabilities and performance measures when making a decision relevant to the UIC funding. *Second*, the government should attach importance to promoting the UIC and level up a firm's and a university's capabilities, absorptive capacity, and desorptive capacity by providing incentives (e.g., grants, R&D tax credits) and supporting infrastructures (e.g., training and laboratory). *Third*, the policy should incentivise universities to provide a wide range of collaboration mechanisms and encourage firms to employ channels based on their needs and capabilities.

Despite its many contributions, this paper is not without limitations. *First*, since this paper focuses only on the articles published in the journals in the AJG's list, a future review should consider other journal quality lists such as the German Academic Association for Business Research (VHB), and ABDC Journal Quality List to increase the coverage of relevant papers. *Second*, this paper limits the roles of capabilities to an antecedent of UIC performance, so scholars should broaden the scope of the review to capabilities as a determinant of the UIC engagement (see, e.g., de Moraes Silva *et al.*, 2017; De Silva and Rossi, 2018; Orazbayeva *et al.*, 2019). *Third*, this review focuses on two actors whereas the UIC involves various stakeholders. Researchers are thus recommended to include, for example, technology transfer offices as their capabilities are highlighted as crucial for supporting the UIC implementation (Lockett *et al.*, 2005; Markman *et al.*, 2005; Soares and Torkomian, 2021). *Last*, future reviews may adopt other quantitative approaches such as meta-analysis or bibliographic analysis.

Chapter 3

Technological and Non-Technological Innovation Capabilities and Innovation Performance of Firm Engaging with University (*Paper 2*)

Abstract

Although the impact of a firm's capabilities on its performance in the university-industry collaboration (UIC) has been extensively explored, literature is biased towards technological capabilities and disregards the importance of various collaboration mechanisms by focusing on a specific form of UIC. This study investigates the effects of various innovation capabilities (ICs) of a firm on its innovation performance when engaged in different UIC channels. Based on the Tobit regression analysis of Thai innovative firms in the Thailand Community Innovation Survey in 2015 and 2017, the results reveal that while the impact of a firm's technological ICs on its innovation performance is absent, a firm can benefit from its non-technological ICs for cooperation with university partners. Particularly, organisational IC is critical for achieving better innovation performance through collaborative research or the use of the university's research facilities, whereas marketing IC is more likely to improve innovation performance from consulting and contract research arrangements with a university. Nonetheless, excessive marketing IC tends to hamper a firm's performance when engaged in collaborative research and human resource transfer (e.g., placements, mobilities, meetings, conferences and informal contacts). The findings stress that there is no one-size-fits-all strategy for improving a firm's performance given the matter that some ICs are critical for some UIC channels than others. Importantly, based on these findings, this paper provides several implications for practitioners and policymakers.

Keywords: university-industry collaboration, innovation capability, innovation performance, technological capability, non-technological capability

3.1 Introduction

Despite a growing literature on the effects of a firm's technology-related capabilities termed as innovation capability (Arza and Vazquez, 2010; Najafi-Tavani *et al.*, 2018), innovation competency (Kobarg *et al.*, 2018), technological capability (Bierly *et al.*, 2009), and R&D capability (Chen *et al.*, 2016) on its performance in the context of university-industry collaboration (UIC), previous studies show rather mixed results. For instance, whereas most research highlights a positive effect of technological capabilities, some studies find no effect (e.g., Su *et al.*, 2009; Chen *et al.*, 2016; Kobarg *et al.*, 2018). Focusing on a firm's technological capabilities may be insufficient to understand how innovation is created in R&D cooperation since innovation is a product of not only technological but also non-technological capabilities (OECD2005; Ngo and O'Cass, 2013). While the relationship between a firm's non-technological capabilities and its performance has been extensively explored by non-UIC literature (Foroudi *et al.*, 2016; Lewandowska *et al.*, 2016; Hwang *et al.*, 2019; Davcik *et al.*, 2020), little is known about these issues in the UIC context.

The case for investigating the effects of a firm's non-technological capabilities on its performance in the UIC context is further strengthened by prior literature's findings on different types of a firm's capabilities being more critical for some UIC channels compared with others (Arza and Vazquez, 2010; Brehm and Lundin, 2012), hinting that a firm's performance may not equally benefit from the same kind of capability when adopting different UIC channels. Nonetheless, research on a firm's capabilities and its performance in the UIC tends to focus on a specific channel such as collaborative research (e.g., Zhang and Wang, 2017; Kobarg *et al.*, 2018; Cheah *et al.*, 2019; Guerrero and Urbano, 2021) or simply an established linkage (e.g., Su *et al.*, 2009; Tsai, 2009; Soh and Subramanian, 2014; Chen *et al.*, 2016). Thus, an understanding of the impact of a firm's capabilities on its performance in various UIC channels remains a black box.

This paper investigates the effects of a firm's technological and non-technological *innovation capabilities* (ICs) on its innovation performance when engaged in different UIC channels. Based on the analysis of 830 innovative and manufacturing firms from the Community Innovation Survey (CIS) of Thailand collected in 2015 and 2017, this study finds only the significant effects of a firm's non-technological ICs which may either ameliorate or attenuate innovation performance, depending on what UIC channel is pursued. For instance, organisational IC is important when achieving better innovation performance through collaborative research or the use of a university's facilities, whereas marketing IC is more likely to improve innovation performance when using a university's service (e.g., consulting and contract research). On the contrary, marketing IC is likely to enervate

innovation performance when engaged in collaborative research and human resource transfer (e.g., mobility, student internship, personal contact, and meeting).

The findings underscore a *no one-size-fits-all* strategy in achieving the same level of innovation performance by revealing that all kinds of ICs are not equally important for an improvement of innovation performance when being steered to different channels. This paper also unravels the puzzles associated with an insignificant impact of a firm's technological capabilities in the UIC literature by highlighting the roles of a firm's non-technological capabilities in enhancing its innovation performance even with the absence of significant effect of a firm's technological capabilities. This paper thus suggests that firm managers should be aware of the interrelationship between innovation capabilities, innovation performance and different UIC channels when entering an agreement with university partners.

For the outline of this paper, Section 3.2 presents the theoretical background concerning a firm's capabilities in the UIC context and the relevance of UIC channels leading to the development of hypotheses in Section 3.3. Section 3.4 proceeds to the overview of the Thailand CIS, the classification of UIC channels and capabilities, and the econometric models of analysis. Sections 3.5 and 3.6 present the results and elaborate on the findings. The final section discusses research implications and research limitations and proposes future research directions.

3.2 Theoretical background

3.2.1 Beyond technology-related capabilities

Grounded in the resource-based view of firm theory, variations in a firm's resources and capacities are critical when being translated into competitive capabilities, resulting in superior performance (Barney, 1991). However, relying on internally developed capabilities may be insufficient for a firm to sustain its competitive advantage and, thus, a firm collaborates with external partners to complement its internal research (Powell *et al.*, 1996). While university-industry collaboration (UIC) is perceived as a driver to the economic development of countries or regions (Belderbos *et al.*, 2015; Zhang *et al.*, 2016; Rajalo and Vadi, 2017), it does not guarantee the success of innovation creation (Eom and Lee, 2010), without a firm's ability to acquire and absorb external knowledge (Cohen and Levinthal, 1989; Cohen and Levinthal, 1990; Veugelers and Cassiman, 2005; Apa *et al.*, 2020).

The relevant literature in the UIC tends to centre on a firm's technology-based capabilities, defined as *a firm's ability to develop and use its substantial technological resources and capabilities for new product development and manufacturing improvement*

(Song *et al.*, 2007; Zhou and Wu, 2010). For instance, having investigated the effects of internal capabilities on performance in start-up companies that collaborate with universities, Choonwoo *et al.* (2001) found that only start-ups with technological capabilities can take advantage of university linkages, resulting in an increase in sales. Santoro and Bierly (2006) and Bierly *et al.* (2009) also highlighted that a firm's technological capabilities facilitate the transfer of tacit knowledge. Similar findings are found by many other studies, which used different terms relevant to technological capabilities such as innovation capabilities (Arza and Vazquez, 2010; Kobarg *et al.*, 2018; Najafi-Tavani *et al.*, 2018), and absorptive capacity (Toole *et al.*, 2015; Apa *et al.*, 2020).

Despite growing interest in the impact of a firm's capabilities on its performance in the UIC context, the findings vary. While most studies find positive effects of a firm's technological capabilities on its performance, some studies do not find sufficient evidence of that (see, e.g., Medda *et al.*, 2004; Bierly *et al.*, 2009; Su *et al.*, 2009; Eom and Lee, 2010; Xu *et al.*, 2011; Chen *et al.*, 2016; Kobarg *et al.*, 2018), thus reasoning on the weak collaboration linkages (Su *et al.*, 2009), a firm's inadequate absorptive capacity to translate a university's knowledge into commercial value (Chen *et al.*, 2016), and substitution effects – i.e. a firm's technological capabilities are substituted by academic partners' capabilities or a firm's strong product development competence crowding out the incentives to benefit from the UIC (Kobarg *et al.*, 2018). Yet, none of the scholars has provided compelling evidence to support their suggestion.

One can plead that a firm's technological capabilities may partially explain the success of technology transfer and its innovation performance when engaged in the UIC unless addressing the importance of non-technological capabilities. For instance, scholars thus have increasingly paid attention to *relational capabilities* (De Silva and Rossi, 2018) and *alliance management capability* (Leischnig and Geigenmuller, 2020). Nevertheless, non-technological capabilities which are necessary for R&D cooperation are not limited to collaboration management capabilities, but also include organisational and marketing capability (Mothe and Uyen Nguyen Thi, 2010; Foroudi *et al.*, 2016; Pino *et al.*, 2016; Geldes *et al.*, 2017; Hwang *et al.*, 2019).

Research on non-technological capabilities in the UIC context is not rising as a new paradigm. It has been long notable by Dill (1990) stressing the importance of a simultaneous coupling of marketing, manufacturing, and R&D elements for an effective UIC. A need to go beyond purely research and technological capabilities is mostly addressed by research from a university's perspective (e.g., Lockett and Wright, 2005; Ambos *et al.*, 2008; Escobar *et al.*, 2017). In particular, a university should act as *'firm-like'* entities (Leischnig and Geigenmuller, 2020). Facing challenges of ambidexterity (research-intensive universities and academic entrepreneurship), a university often relies on the technology transfer office

(TTO) to compensate for its shortcomings (Siegel *et al.*, 2003; Lockett and Wright, 2005; Soares and Torkomian, 2021). Nevertheless, the TTO only acts as an external boundary spanner where its role is mainly to encourage academic researchers to engage in invention disclosures and licensing agreements, but not to get involved in knowledge co-creation (Markman *et al.*, 2005). Instead, knowledge co-creation rather emerges from the combination of a firm's market knowledge and a university's scientific knowledge (Etzkowitz and Leydesdorff, 2000; Perkmann and Salter, 2012). While non-technological capabilities (e.g., management and marketing) are highlighted as crucial for facilitating the R&D partnerships and improving performance by non-UIC studies (Hecker and Ganter, 2016; Anzola-Roman *et al.*, 2018; da Costa *et al.*, 2018), this issue has largely been under the radar in the UIC literature.

As stressed by Veugelers and Cassiman (2005), future studies should go beyond the firm's R&D capacity as well as seek better proxies for a firm's innovative capabilities. This is particularly important for the UIC in developing countries where a firm's technological capabilities may be less important for the cooperation with universities (Su *et al.*, 2009; Chen *et al.*, 2016) and where non-technological innovation can be a major focus (Perez *et al.*, 2019).

3.2.2 The relevance of a firm's capabilities and UIC channels

Scholars have shown that the UIC can manifest through a broad spectrum of channels such as collaborative research, contract, consulting, mobility, licensing, and personal contacts (Perkmann and Walsh, 2007; Perkmann *et al.*, 2013). Although prior research strives to provide abundant evidence on how a firm's capabilities affect its innovation performance when engaged with universities, the relationship between a firm's capabilities and the UIC is somewhat more complex than what is being addressed in the literature. One issue is relevant to a narrow focus on UIC mechanisms while another arises from the heterogenous governance of the UIC.

Literature on firms' capabilities in the UIC is biased towards a specific channel such as collaborative research. This traditional view of UIC research is increasingly criticised for ignoring other forms of collaboration (Arvanitis and Woerter, 2009; Petruzzelli, 2011; Kafouros *et al.*, 2015). Mostly, informal channels are often overlooked as being not product- or solution-oriented (Feller *et al.*, 2002). This bias is problematic since scholars revealed that a research contract and other informal channels are often employed and perceived as more important than collaborative research by firms in developing countries (Choonwoo *et al.*, 2001; Eom and Lee, 2010; Arza and Vazquez, 2012). In addition, informal mechanisms are important for firms to obtain information regarding available technologies from academic research (Thursby, 2000), and as a condition for adopting formal channels (Arvanitis and

Woerter, 2009). Since a firm normally employs multiple channels simultaneously (Gesing *et al.*, 2015; Garcia-Perez-de-Lema *et al.*, 2017), contradicting views on UIC channels may lead to a misunderstanding of the impact of a firm's capabilities on its performance in various UIC channels and finally to a black box.

Regarding the *second* issue, UIC channels are inherently different in terms of the degree of knowledge codification (Arza, 2010; Alexander and Martin, 2013), collaboration goals related to the degree of innovation (D'Este *et al.*, 2019), and a degree of ability to appropriate knowledge (Freitas *et al.*, 2013a). Hence, due to this heterogeneity, a firm may not equally benefit from the same capabilities in improving its performance when engaged in different UIC channels. This paper thus reasons that collaboration governance (e.g., UIC channels) should not be considered in isolation from capabilities (Makadok, 2003).

There is evidence that different levels of a firm's technological capability may be better suited when dealing with different types of knowledge as well as a degree of innovation outcomes. For instance, a firm benefits from a high level of technological capability to absorb and exploit a university's knowledge when dealing with tacit knowledge (Santoro and Bierly, 2006) or pursuing radical innovation (Kobarg *et al.*, 2018). A firm's strong technological capability is also crucial for absorbing and implementing a university's knowledge particularly in joint research which is associated with an exchange of tacit knowledge, bi-directional communication, and valuable inventions (Arza and Vazquez, 2010; Garcia-Perez-de-Lema *et al.*, 2017; D'Este *et al.*, 2019). Recently, Apa *et al.* (2020) have confirmed that a firm can benefit from formal UIC channels only when its absorptive capacity is present. On the contrary, for such channels as research contract and technology transfer (i.e. use of a university's license) in which the transferred knowledge is almost transactional, a firm's advanced technological capabilities may be unnecessary (Todtling *et al.*, 2009; D'Este *et al.*, 2019).

Recently, the case for investigating the effects of different UIC channels is further accentuated by the evidence showing that a certain type of a firm's capabilities may be more important in a specific channel than in others. Scholars pointed out that UIC channels may differ in the extent to which the relevant intellectual property can be protected (Abreu and Grinevich, 2013; Fassio *et al.*, 2019). According to the heterogeneity of UIC channels, only a certain capability may suit a specific channel. For instance, the contract-based governance (e.g., collaborative research, research contract and consulting) is often involved with knowledge appropriation issues, and thus requires an ability to negotiate with university partners on the collaboration objectives and to share the collaboration results, rather than relation-based governance (Plewa *et al.*, 2005; Freitas *et al.*, 2013a; Sharma, 2020).

Previous research revealed that a firm's capabilities and UIC channels are highly intertwined and thus should not be considered in isolation. As stated by Arvanitis and Woerter, (2009, p. 1071), *"…it is not sufficient to know which kind of resources or capabilities are lacking. In addition, one has to find ways to transfer them or build them in the firm*". This study postulates that a narrow focus on UIC channels may not only fail to capture the multifaceted ways through which a firm employs different capabilities to achieve its innovation performance when engaged with universities, but also may impair the generalisability of the findings across different UIC channels.

3.3 Development of hypotheses

Despite diverse terms related to capabilities, this study adopts the term *innovation capability* (IC) since its definition is more overarching than other terms used in the literature (e.g., R&D capability or technological capability). In line with prior research, this paper delineates IC as a firm's ability to produce distinct types of innovation such as product, process, organisational and marketing innovation (Damanpour, 1991; Damanpour *et al.*, 2009; Ngo and O'Cass, 2013), and thus classifies ICs into technological innovation capabilities and non-technological innovation capabilities. Based on the theoretical background, this work aims to answer the research question: *To what extent do a firm's technological and non-technological innovation capabilities affect its innovation performance when engaged in different university-industry collaboration channels?* To answer this question, this paper conceptualises the impact of a firm's innovation capabilities on its innovation performance in the UIC context and formulates the relevant hypotheses presented as follows.

3.3.1 Effects of a firm's innovation capabilities on its innovation performance

A firm's technological ICs are crucial for both internal R&D (Perna *et al.*, 2015) and R&D cooperation (Najafi-Tavani *et al.*, 2018), often classified into product IC and process IC. *Product IC* refers to a firm's ability to introduce new products or services whereas *process IC* reflects a firm's ability to introduce new inputs or processes to its production operations (Damanpour, 1991). A firm can benefit from its product and process ICs in improving innovation performance in different ways (Najafi-Tavani *et al.*, 2018). Although academic knowledge is often tacit and difficult to transfer, a firm with strong product IC is equipped with a high degree of technological knowledge as well as orientation to innovation, and thus may effectively absorb and deploy a university's knowledge into innovative offerings (Camison and Villar-Lopez, 2014). There is evidence that a firm's technological capability leads to increased sales growth, innovativeness and success of technology transfer when aiming for product innovation development (Choonwoo *et al.*, 2001; Santoro and Bierly, 2006; Bierly *et al.*, 2009). While a firm's product IC is associated with a product

differentiation strategy, a firm's process IC is relevant to a cost-reduction strategy. A firm's process IC enables it to improve efficiency and production effectiveness (Damanpour *et al.*, 2009; Damanpour, 2010). Thus, collaboration with a university strengthens a firm's process IC and facilitates the transformation of a university's knowledge by offering an innovative way to generate new products, resulting in a reduction of production cost and an increase in overall profit (Najafi-Tavani *et al.*, 2018).

A firm's non-technological ICs comprise organisational IC - i.e. a firm's ability to introduce new organisational management and methods, and marketing IC, delineated as a firm's ability to introduce novel marketing techniques (modified from Foroudi *et al.*, 2016). A firm's organisational IC generally permits its flexibility and creativity, which in turn fosters the development of technological innovations (Mothe and Uyen Nguyen Thi, 2010). A firm's management IC enables it to overcome difficulties in developing new technological processes in inter-organisational collaboration by motivating employees to get involved in the development process and facilitating the coordinative activities and the decision making regarding the resource allocations (Hollen *et al.*, 2013). Anzola-Roman *et al.* (2018) also found that a firm benefits from the combination of its organisational innovation and externally sourced knowledge when pursuing such complex technological innovations. Collaboration with external partners also fosters a firm's management innovation and in turn, results in superior innovation performance (Kafetzopoulos *et al.*, 2021). Therefore, this study contends that organisational IC allows a firm to attain a certain level of flexibility and creativity in the UIC which is necessary for achieving science-based and cutting-edge outcomes. Such an ability to manage portfolios, projects, and changes, is critical for easing the UIC implementation process and shortening the development time (Buganza *et al.*, 2014).

The marketing component is one of the key components in the UIC implementation (Dill, 1990). Although the contributions regarding the impact of a firm's marketing IC on its innovation performance in the UIC context are still lacking, scholars emphasised the roles of a university's marketing capabilities in identifying opportunities for technology commercialisation and collaborative research (Lockett and Wright, 2005). Specifically, a firm with strong marketing capabilities shows a high degree of market knowledge and understanding of customers' demand, thus enabling a firm to effectively identify what knowledge is needed as well as the right university partners. Additionally, novel marketing techniques (e.g., marketing media, pricing, promotion) permit a firm to attain commercial benefits after absorbing and transforming academic into its ready-to-launch products.

Drawing upon the concept of a firm's absorptive capacity (Cohen and Levinthal, 1990), a firm necessarily needs to possess strong ICs to better acquire, assimilate, transform and exploit knowledge from universities (Frishammar *et al.*, 2012), thus

enhancing innovation performance. However, literature shows that a positive impact of a firm's technological capabilities is inconclusive (see, e.g., Eom and Lee, 2010; Chen *et al.*, 2016; Kobarg *et al.*, 2018). A university is often perceived as the main knowledge provider and thus it may be plausible that a firm's technological ICs are substituted by a university's research capabilities, thus making a firm's technological ICs less beneficial for the UIC. Alternatively, a firm may be required to leverage its technological ICs only up to a threshold which is adequate to absorb the university's knowledge. On the other hand, since a university often lacks such marketing capabilities (Ambos *et al.*, 2008; McAdam *et al.*, 2009; Escobar *et al.*, 2017), a firm's non-technological ICs may contribute to the collaboration or compensate a university's insufficient marketing capability. Consistent with the literature, a combination between a firm's market knowledge and a university's scientific knowledge in knowledge co-creation is critical (Etzkowitz and Leydesdorff, 2000; Perkmann and Salter, 2012). Hence, this paper posits that.

Hypothesis 1: *A firm's non-technological innovation capabilities are more likely to be associated with its higher innovation performance when engaged with a university than with technological innovation capabilities.*

3.3.2 The contingencies of the UIC channels

A certain firm's internal capability can achieve superior performance (Prahalad and Hamel, 1990; Barney, 1991), and particularly when it is steered to the right governance of collaboration (Makadok, 2003). Due to the heterogeneity of UIC channels, a firm may not benefit equally when engaging in different UIC channels. In other words, a certain type of a firm's ICs may be more vital for some channels than others in enhancing its innovation performance. For instance, a strong level of a firm's technological IC may be critical for engaging with universities via collaborative research since it favours an exchange of tacit knowledge (Santoro and Bierly, 2006; Todtling *et al.*, 2009; Arza, 2010). A firm's organisational IC may also mitigate management issues such as knowledge appropriation which often emerges from contract-based collaboration (Freitas *et al.*, 2013a; Sharma, 2020). Compared with knowledge acquisition (e.g., use of university's licenses or facilities), a firm's marketing IC is beneficial for knowledge co-creation (e.g., collaborative research) where marketing knowledge and skills are more needed (De Silva and Rossi, 2018). Given the interrelationships between a firm's different ICs and UIC channels, this paper thus hypothesises that.

Hypothesis 2a: *The effects of a firm's technological innovation capabilities on its innovation performance are more likely to be contingent on the types of university-industry collaboration channels deployed.*

Hypothesis 2b: *The effects of a firm's non-technological innovation capabilities on its innovation performance are more likely to be contingent on the types of university-industry collaboration channels deployed.*

3.4 Method and data

3.4.1 Research setting

3.4.1.1 UIC in the Thailand context

The Thai government has initiated science, technology and innovation policies as well as promoting the UIC to stimulate a firm's engagement in R&D and innovation (Carvalho de Mello *et al.*, 2016; Intarakumnerd, 2017). Nevertheless, the UIC in Thailand is often perceived as weak and slowly developed (Brimble and Doner, 2007). This is mainly due to the ineffective innovation policy which heavily relies on the *knowledge-push* model. For instance, resources from the Thai government are mainly allocated for strengthening universities' research capabilities; therefore, firms remain only a user of the universities' knowledge (Arnold *et al.*, 2000).

Besides the national innovation policy, the issues also emerge from both industry and university entities. Thai firms generally lack technological capabilities since they are absorbers of knowledge from developed countries in which the knowledge is provided through technology diffusion (Liefner and Schiller, 2008). In addition, the research capabilities of Thai academic researchers are rather poor and have little relevance to industry (Intarakumnerd *et al.*, 2002; Ratchukool and Igel, 2018). Most academic research outputs are sitting on the shelf, rather than being patented or commercialised (Numprasertchai and Igel, 2005), thus discouraging industry from engaging in R&D collaboration because universities are often regarded as unimportant sources of innovation (Schiller and Brimble, 2009). Policies in most Thai universities also demotivate researchers from engaging in the UIC due to the centralisation and fragmentation of Thai bureaucracy, overwhelming workload, complicated university policy, and undermined incentives (Brimble and Doner, 2007). The UIC in Thailand is thus mainly associated with short-term training, use of research consulting, and problem-solving, not for a long-term partnership (e.g., collaborative research project) (Intarakumnerd *et al.*, 2002; Pittayasophon and Intarakumnerd, 2016). Given that the joint research and the technology transfer are inefficient and thus less employed, provision of a university's service and consulting as well as informal modes (e.g., discussion, meetings, and conferences) are more popular than other collaboration channels (Brimble and Doner, 2007).

The Thai government has recognised the importance of increasing R&D capacity for enterprises and universities as R&D investment, thus targeting 2% of R&D investment per GDP by 2021 aimed at shifting into the knowledge-based economy (Shin and Limapornvanich, 2017). The Thailand Research Fund is also responsible for promoting the *Talent Mobility* programme as an incentive for matching funds to improve employee exchange between private and public sectors (Shin and Limapornvanich, 2017; Kongsoontornkijkul *et al.*, 2019). The policy includes enhancing joint programmes for commercialisation between universities and start-ups in addition to SMEs.

3.4.1.2 Thailand Community Innovation Survey

This paper used the data from the Community Innovation Survey (CIS) of Thailand, namely the Thailand Business R&D and Innovation Survey conducted by the National Science and Technology Development Agency (NSTDA) in 2015 and 2017. The survey instrument was designed following the guidelines of the Oslo Manual,1997. The survey sample for 2015 and 2017 was 12,918 and 13,597 firms, respectively. Firms were approached by post, email or fax. Following this, 4,797 (37.13%) in 2015 and 5,512 firms in 2017 (40.53%) completed and returned their questionnaires. This research focused on innovative and manufacturing firms, and thus the 2015/2017 panel contains 830 firms. The overview of the sample is presented in Table 3.1.

Table 3.1 Overview of the sample in Paper 2 (N = 1,660)

	N	Percentage
Type of industry		
High technology sector	158	9.52
Medium-high technology sector	490	29.52
Low-medium technology sector	284	17.11
Low technology sector	728	43.86
Number of employees		
1-100	405	24.70
101-500	782	47.68
501-1000	253	15.43
1001-3000	142	8.66
>3000	58	3.54
Age of company		
0 – 10	78	4.70
11-20	424	25.54
21-30	656	39.52
31-40	292	17.59
41-50	142	8.55
>50	68	4.10
Ownership of the company		
Wholly owned by Thais	1,132	68.19
51-99% owned by Thais	204	12.29
1-50% owned by Thais	164	9.88
Wholly owned by foreigners	160	9.64
Multinational corporation	1,397	84.16

3.4.2 Measures

3.4.2.1 Dependent variable

The dependent variable is a *firm's innovation performance* captured by the sales of new products[5] following prior studies (Kafouros *et al.*, 2015; Chen *et al.*, 2016) since the financial value of new products can represent the success of innovation commercialisation (Grimpe *et al.*, 2017). UIC implementation is normally a lengthy process, particularly in a joint research project, and hence the UIC outcomes may not be converted into a commercial gain in a short period. Nevertheless, it is also possible to realise a short-term outcome when collaboration is aimed at a minor improvement of innovation or problem solving, particularly in developing countries (Dutrénit *et al.*, 2010). Therefore, this paper postulated that the UIC outcomes may be commercially visible either in *the current year* of collaboration or *the subsequent year*. This study thus used lags for all independent variables for one year to alleviate potential simultaneity between UIC and innovation performance. To operationalise a firm's innovation performance, this paper used a natural logarithm of a firm's average two-year sales derived from new products (e.g., new to the market, new to the firm, and substantially improved products).

3.4.2.2 Independent variables

The first independent variable is the UIC channels. This study classified UIC activities into five channels based on several criteria (Table 3.2).

- *Research partnership*: This channel refers to collaborative research or joint research projects characterised by formal research agreements and the use of codified scientific and technological knowledge (D'Este and Patel, 2007). Research conducted in this channel is associated with highly exploratory, known as *blue-sky research* and open-ended collaboration goals (D'Este *et al.*, 2019).
- *Research service*: This channel consists of research consulting and research contracts characterised by a formal agreement in which the objectives are specified from the *beginning* of the contract (D'Este and Patel, 2007). The research in this channel is more application-based (D'Este *et al.*, 2019).
- *Technology transfer*: This channel refers to a firm's use of university-generated *intellectual* property associated with an exchange of codified knowledge (D'Este *et al.*, 2019).

[5] It is not appropriate to use the number of firms' patents as the proxy of innovation performance since firms in developing countries do not often patent their inventions (Chen *et al.*, 2016), and not all inventions are patentable (Kafouros *et al.*, 2015). The number of new products is also not suitable since it causes bias due to the different degrees of product novelty.

- *Research facility*: This channel refers to the use of a university's facilities and equipment for R&D or calibration (Ankrah and Al-Tabbaa, 2015). Using a university's research facilities can be regarded as a platform to form a relationship and future collaborations (Wang and Shapira, 2012).
- *Human resource transfer* (HR transfer): This channel includes a wide range of UIC activities such as the mobility of academic researchers, training provided by university staff, student internships, and informal meetings. HR transfer provides both parties opportunities to build social capital and trust resulting in a seamless knowledge transfer and long-term partnerships (Schartinger *et al.*, 2002).

Table 3.2 Characteristics of UIC channels

Characteristics	UIC Channels				
	Research partnership	**Research service**	**Technology-transfer**	**Research facility**	**HR transfer**
Collaboration activities	Joint research	Research contract, consulting	Use of a university's licenses	Use of a university's infrastructure, performing a test at universities	Placement, mobility, informal contact, meeting
Goal specificity	Open-ended	Targeted	Targeted	Targeted	Open-ended
Type of knowledge	More tacit	More codified	Codified	More codified	More tacit
Degree of formalisation	Formal	Formal	Formal	Formal	Formal & informal
Relational involvement	Personal-based	Transactional	Transactional	Transactional	Personal-based
Characteristic of interactions	Mutual benefits	Demand-pull	Knowledge-push	Demand-pull	Demand-pull

Adapted from Arza (2010), D'Este et al. (2019), Abreu and Grinevich (2013), Perkmann and Walsh (2007), and Freitas et al. (2013).

To operationalise the UIC channels, nine collaboration forms in Thai CIS were grouped into five categories: (i) research partnership (e.g., collaborative research), (ii) research service (e.g., contract research and consultancy), (iii) technology transfer (e.g., use of university's licenses), (iv) research facility (e.g., performing a test at a university or sharing the university's research facilities and equipment), and (v) human resource transfer (e.g., training, student placement, mobility of academic researchers, and personal contact). Each channel receives a binary code that takes the value of 1 if the firm collaborated through a given channel, and 0 otherwise.

The second independent variable is a firm's *innovation capabilities*[6] operationalised from 15 binary questions in the CIS (Appendix D). Using multiple measures to capture capabilities is appropriate since capabilities are multidimensional and complex by nature: *"if capabilities are complex assets based on combinations of routines, skills, organizational knowledge, and tangible assets, we need to use multiple indicators to capture the capabilities"* (, p. 226). The questions represent a firm's innovation activities or innovative outcomes regarded as a firm's ability or a means to develop and commercialise new products. The questions also reflect the degree of *changes or newness* of outcomes or relevant activities, allowing to distinguish a firm's innovation capabilities from its ordinary capabilities, thus satisfying the definition of innovation capabilities in this study. Based on Hair *et al.* (2009), the *Factor Analysis* technique was applied for categorising the questions into different innovation capabilities. *STATA16* software was used for the quantitative analysis.

The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy for 15 variables is 0.780, thus passing the suggested threshold of 0.50 (Hair *et al.*, 2009) and indicating that the sample size is large enough to extract factors reliably. The Chi-square value of Bartlett's test of sphericity is 6565.95 ($P < 0.001$) indicating that the correlation is not an identity matrix, and that factor analysis is appropriate for the data. Tetrachoric Correlation was then computed for a factor analysis since the latent continuous variables underlie the observed binary variables (Brown, 1977). Harman's Single-Factor test was first performed to check the common method variance by loading 15 items on one factor. The result reported that the total explained variance is only 39.27% and eight items suffered from poor factor loading below 0.7, indicating that no single factor accounts for most of the covariance in the items.

After performing the Factor Analysis, the number of items with high loadings on each factor was minimised by using *Promax oblique rotation*[7] (Finch, 2006). Finally, 15 items were classified into four factors, with an eigenvalue greater than one and accounting for 82.22% of the total variance observed, thus representing four innovation capabilities (Table 3.3). The Kuder-Richardson's coefficient (KR20), a special case of Cronbach's Alpha for binary items to test the internal consistency reliability of each factor (Kuder and Richardson, 1937), was computed for each factor. Table 3.3 shows that KR20 coefficients were higher than the threshold of 0.6, indicating that the internal consistency reliability was not a serious issue (Hair *et al.*, 2009).

[6] Innovation capabilities are mainly captured through quantifiable measures such as R&D intensity. However, the quantifiable measures do not provide much information on the degree of innovativeness compared with subjective measures (Romijn and Albaladejo, 2002).

[7] Promax rotation is more suitable for dichotomous items, particularly when each factor has a few items with high loadings and the rest with loadings near zero (Finch, 2006). However, the results from the *Varimax* rotation technique were similar to *Promax* rotation.

Table 3.3 Rotated factor loadings of a firm's innovation capabilities

Items in the survey	Loadings	Variance & KR20
Product innovation capability		
Developing inventions	0.9267	Variance = 4.105
Developing prototypes	0.9425	Proportion = 0.273
Launching pilot plants	0.8730	KR20 = 0.732
Process innovation capability		
Introducing new methods for producing goods	0.9688	Variance = 5.791
Introducing new methods for producing service	0.7985	Proportion = 0.386
Introducing new logistics delivery, or distribution methods	0.7638	KR20 = 0.615
Introducing new supporting processes	0.7663	
Organisational innovation capability		
Implementing a new corporate strategy	0.8227	Variance = 4.578
Implementing a new management technique	0.7268	Proportion = 0.305
Receiving externally certified standard	0.9306	KR20 = 0.752
Implementing major organisational changes	0.7295	
Marketing innovation capability		
Introducing changes in existing product design or packaging	0.4067	Variance = 3.569 Proportion = 0.238
Introducing new marketing media or techniques for promotion	0.8498	KR20 = 0.614
Introducing a new sales channel	0.8521	
Introducing a new pricing system	0.8602	

From Table 3.3, the first factor is product IC accounting for 27.3% of the variance and explaining the three causes concerning the development of inventions, prototypes and pilot plants[8]. The second factor is a firm's process IC accounting for the largest variation of 38.6% and contains four causes: the new methods for producing goods or services, supporting processes, logistics, and distribution. The third factor is organisational IC comprising a new corporate strategy, new management techniques, major organisational changes, and externally certified standards, with a total variance of 30.5%. The fourth factor is marketing IC, comprising the introduction of changes in existing product design or packaging[9], new marketing media or promotion techniques, a new sales channel, and a new pricing system, with the smallest total variance of 23.8%. Finally, the results from factor analysis allowed this paper to categorise product IC and process IC as *technological innovation capabilities*

[8] Different from prior research, an introduction of new products was not used to capture product IC since it can be partly a result of marketing IC, thus contradicting the aim of this paper to distinguish technological ICs from non-technological ICs. This paper considers that the firm's ready-to-commercialise outputs from R&D (e.g., invention, prototype and pilot plant) can represent the result of the firm's ability to innovate product innovation.

[9] In addition to traditional marketing strategies, innovative firms may also use marketing strategy products related to packaging to make products more appealing and attract customers. By acknowledging the shortcomings of dichotomous variables in factor analysis and following the literature (e.g., OECD and Communities, 2005; Naidoo, 2010; Vaculík *et al.*, 2019), this study included the item changes in existing product design or packaging as the construct of marketing IC although its loading is below 0.6.

and to clearly distinguish their effects from the non-technological ones (e.g., organisational IC and marketing IC). To operationalise innovation capabilities, this study formed the dummy of whether firms in the sample conducted *at least one innovation activity* related to each type of innovation capability derived from the factor analysis.

3.4.2.3 Control variables

This study introduced several control variables presented as follows.

- *Firm's size* (measured by using the natural logarithm of the number of employees, as previous research showed that a firm's size is seen as significant in the UIC (Bierly *et al.*, 2009).
- *Firm's age*: measured by the number of years elapsed from the year a firm was established to the year of data collection (Kafouros *et al.*, 2015).
- *R&D intensity*: measured by the ratio of a firm's R&D expenditure to a firm's total sales. Literature finds that a firm's R&D intensity has a positive effect on its innovation performance (Eom and Lee, 2010).
- *Original brand manufacturer (OBM)*: measured as a binary variable capturing whether a firm is an OBM. OBM firms may seek more technological knowledge from universities to launch their brand and sustain their market position than from other original equipment manufacturers (OEM) that only serve their parent companies.
- *Multinational cooperation firms (MNC)*: measured as a dummy variable - i.e. whether a firm is MNC. As revealed by Xu *et al.* (2011), the impact of a local firm's and a foreign direct investment firm's on their innovation performance is different.
- *Technology sector*: captured by a firm's industry presented as the four-digit code following the International Standard Industrial Classification of All Economic Activities (ISIC) (United Nations. Statistical, 2008). Following Galindo-Rueda and Verger (2016), four dummies were used to represent low, low-to-medium, medium-to-high, and high technology sectors, respectively.
- *Firm ownership*: measured as dummy variables indicating whether a firm is wholly owned by a Thai national, partially owned by a Thai national, or wholly owned by a foreign company. Realising the importance of a firm's ownership types is crucial, particularly in emerging countries, due to different institutional settings, including infrastructure, policy and management (Tsai and Wang, 2008).
- *Years of the survey*: captured by a dummy indicating the year associated with the data collection.

All variables used in this study are summarised in Table 3.4.

Table 3.4 Variable definition of Paper 2

Variables	Definition
Dependent variable	
Innovation performance	Natural Log (1+ average of 2-year new product sales).
Independent variables	
Product innovation capability	Dummy, equal to 1 if a firm developed inventions, prototypes or pilot plants.
Process innovation capability	Dummy, equal to 1 if a firm introduced new methods for producing goods, introduced new methods for producing services, new supporting processes, and new logistics delivery and distribution.
Organisational innovation capability	Dummy, equal to 1 if a firm implemented a new corporate strategy, a new management technique, or major organisational changes, or received externally certified standards.
Marketing innovation capability	Dummy, equal to 1 if a firm implemented changes in existing product design or packaging, new marketing media or promotion techniques, a new sales channel, or a new pricing system.
Research partnership	Dummy, equal to 1 if a firm adopted collaborative research.
Research service	Dummy, equal to 1 if a firm adopted either collaborative contract research or consultancy.
Technology transfer	Dummy, equal to 1 if a firm obtained licenses from a university.
Research facility	Dummy, equal to 1 if a firm either performed a test at a university or shared research facilities and equipment
Human resource transfer (HR transfer)	Dummy, equal to 1 if a firm were trained by academic staff, offered student placement, invited academic researchers to work within the firm, or used personal contact.
Control variables	
Firm's size	Natural Log (1 + the number of employees).
Firm's age	The number of years since the establishment.
R&D intensity	The ratio of R&D expenditure to the firm's total revenue.
OBM	Dummy, equal to 1 if a firm is an original brand manufacturer.
MNC	Dummy, equal to 1 if a firm is a multinational corporation firm.
Technology sector	Four dummies, equal to 1 if a firm is in the low, low-to-medium, medium-to-high, or high technology sector.
Ownership	Four dummies, equal to 1 if a firm is wholly-owned by Thais, 51-99% owned by Thais, 1-50% by Thais, or wholly-owned by foreigners.
Year	Two dummies, equal to 1 if associated with the corresponding year.

3.4.3 Economics model and estimation method

A firm's sales of new products were used as a proxy of its innovation performance. Nonetheless, half of the sample firms in the survey reported no sales of new products. Particularly for CIS data, the share of sales derived from new products could often be put equal to zero and become a censored variable (Mairesse and Mohnen, 2010)[10]. Hence, to

[10] This is common for a firm that already launched new products, but the commercial value was not known when the survey was conducted.

avoid potential selection biases, it is suggested that the Tobit estimation model is appropriate (Wooldridge, 2010; Yacoub *et al.*, 2020). In addition, since the total sales of new products is highly skewed, it was thus transformed to lognormal distribution to reduce the problem of non-normality of the residuals (Kafouros *et al.*, 2015).

For the economic model, this study chose random-effect models for the analysis since fixed-effects models are less efficient thanks to the lost degree of freedom (Wooldridge, 2010), and produce inflated standard errors for variables that exhibited little variation within units, thus creating biased estimates (Kafouros *et al.*, 2015), particularly when the period of the analysis is short (Heckman, 1981; Chintagunta *et al.*, 1991). As the data in this study cover only two years, fixed-effects models are considered as inappropriate. In addition, since the loglikelihood of the Tobit model is nonlinear and the likelihood estimator for the fixed effects is biased and inconsistent, therefore, fixed-effect estimates could not be realised in the panel Tobit model[11]. In contrast, random effects utilise between-unit variations and allow for different intercepts (Kafouros *et al.*, 2015).

3.5 Results

3.5.1 Descriptive statistics

Table 3.5 presents the descriptive statistics of the variables. The relatively low means of collaboration with universities in all channels (i.e. less than 0.6) indicate that the linkage between a firm and a university in Thailand is rather weak, in line with Brimble and Doner (2007). Yet, this should be regarded as common in emerging countries (Chen *et al.*, 2016). The results also report that at least half of the samples (e.g., mean value of 0.586) preferred to adopt the HR transfer channel to other channels. Regarding ICs, the result indicates that on average, Thai firms mainly developed organisational and marketing IC, whilst product IC and process IC remained at a relatively low level. Table 3.6 shows that the correlations among variables are not strong and the variance inflation factors (VIFs) range between 1.03 and 2.94 which are lower than a threshold of 4. Hence, there are no serious multicollinearity problems (Hair *et al.*, 2009).

[11] This is also the reason why the fixed-effect models are not available for the Tobit models in *STATA16* software.

Table 3.5 Descriptive statistics of Paper 2

Variables	Mean	SD	Min	Max
Innovation performance	9.414	9.263	0.000	24.455
Research partnership	0.058	0.235	0.000	1.000
Research service	0.061	0.240	0.000	1.000
Technology transfer	0.008	0.091	0.000	1.000
Research facility	0.058	0.233	0.000	1.000
Human resource transfer	0.586	0.493	0.000	1.000
Product innovation capability	0.161	0.368	0.000	1.000
Process innovation capability	0.098	0.297	0.000	1.000
Organisational innovation capability	0.646	0.478	0.000	1.000
Marketing innovation capability	0.542	0.498	0.000	1.000
Firm's size	5.585	1.300	1.609	10.597
Firm's age	27.02	11.557	6.000	86.000
R&D intensity	0.033	0.235	0.000	1.000
OBM	0.442	0.450	0.000	1.000
MNC	0.158	0.365	0.000	1.000

Table 3.6 Correlation coefficients and VIFs of Paper 2

Variables	VIF	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Research partnership	1.24	1.000						
(2) Research service	1.29	0.353*	1.000					
(3) Technology transfer	1.16	0.202*	0.278*	1.000				
(4) Research facility	1.31	0.301*	0.334*	0.288*	1.000			
(5) HR transfer	1.12	0.163*	0.149*	0.078*	0.13**	1.000		
(6) Product IC	1.09	0.044*	0.106*	0.103*	0.095*	0.083*	1.000	
(7) Process IC	1.16	0.091*	0.060*	0.058**	0.145*	0.034	0.148*	1.000
(8) Organisational IC	1.20	-0.014	0.016	0.013	-0.081*	0.141*	0.085*	0.078*
(9) Marketing IC	1.17	-0.003	-0.032	0.005	0.02	0.091*	0.101*	0.143*
(10) Firm's size	1.26	0.093*	0.093*	0.029	0.119*	0.211*	0.112*	0.109*
(11) Firm's age	1.09	0.02	0.054*	-0.018	-0.001	0.065*	-0.032	-0.004
(12) R&D intensity	1.03	0.080*	-0.013	-0.006	0.069*	-0.002	0.011	-0.004
(13) OBM	1.06	-0.003	0.026	0.004	0.028	-0.003	-0.060*	-0.003
(14) MNC	2.94	-0.059*	-0.042	-0.040	-0.016	0.000	-0.007	0.013
Variables		**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**
(8) Organisational IC		1.000						
(9) Marketing IC		0.280*	1.000					
(10) Firm's size		0.160*	0.063*	1.000				
(11) Firm's age		-0.028	0.002	0.150*	1.000			
(12) R&D intensity		-0.026	-0.012	-0.048*	-0.012	1.000		
(13) OBM		-0.063*	0.005	-0.056*	0.153*	0.049*	1.000	
(14) MNC		0.045	0.008	0.093**	-0.027	-0.043	-0.07**	1.000

Note: technology sectors, years of the survey, and ownership are included but not highly correlated. IC stands for innovation capability. **Correlation is significant at the 0.05 level (2-tailed).*

3.5.2 Regression results

The results of the Tobit models are shown in Table 3.7. Model 1 added all independent and control variables (e.g., innovation capabilities and UIC channels) serving as the baseline model. The results presented strongly and significantly positive effects of process IC (β = 3.393, *p-value* < 0.001), organisational IC (β = 2.430, *p-value* < 0.001), and marketing IC (β = 2.197, *p-value* < 0.001) on a firm's innovation performance. As opposed to prior research (Camison and Villar-Lopez, 2014; Ramadani *et al.*, 2019), this study did not find an effect of product IC despite a positive effect size. This may be because most Thai firms had a low level of technological capabilities (Pérez Cusó *et al.*, 2015), and hence tended to focus on production improvement (Intarakumnerd, 2017), reflected in the largest effect size of process IC. In line with Pino *et al.* (2016), firms in emerging economies tend to focus on non-technological innovations as a strategic way of enhancing their innovation performance. Thai firms might benefit from product IC in offering minor changes of products but mainly adopt *a cost-reduction strategy* by deploying process IC to increase production efficiency (Piening and Salge, 2015). Organisational IC may favour firms to manage the complexity in R&D, while marketing IC enables firms to apply new marketing techniques to obtain higher sales of new products as well as minimise costs through benchmarking against the rivals (Naidoo, 2010). Interestingly, firms did not benefit from any UIC channels in improving their innovation performance, thus consistent with Eom and Lee, 's (2010) finding that UIC in developing countries does not guarantee the success of product innovation.

The interaction terms associated with UIC channels and innovation capabilities were added in Model 2. The Chi-square value of Model 2 was the largest (*Wald Chi2* = 106.13, *p-value* < 0.01) indicating the highest explanatory power compared with the first model; thus, used for testing the hypotheses. In addition, the random-effects estimates were appropriate for the analysis since all *F* tests rejected the pooled model option (*p-value* < 0.01). Some interaction terms were significant indicating that the effects of collaboration with universities might be visible only with the presence of firms' ICs. However, only the interaction terms associated with non-technological ICs (e.g., organisational IC and marketing IC) were significant. Due to the absent effect of technological ICs, it was not infeasible to draw a statistical comparison between the effects of technological ICs and non-technological ICs and, therefore, there was no sufficient evidence to support Hypothesis 1 and Hypothesis 2a.

Table 3.7 Tobit models: Effects of firms' innovation capabilities on innovation performance

	Model1		Model 2	
	Coef.	SE	Coef.	SE
Product innovation capability	0.238	(1.098)	1.099	(1.776)
Process innovation capability	3.393***	(1.280)	4.547**	(2.006)
Organisational innovation capability	2.430***	(0.858)	0.979	(1.304)
Marketing innovation capability	2.197***	(0.809)	3.852***	(1.279)
Research partnership	-2.339	(1.851)	-1.705	(3.729)
Research service	1.137	(1.867)	-0.356	(3.438)
Technology transfer	-0.010	(4.53)	-2.743	(10.817)
Research facility	-1.377	(1.878)	-11.163***	(3.475)
HR transfer	1.311	(0.855)	3.145**	(1.509)
Product IC x Research partnership			3.485	(4.907)
Process IC x Research partnership			-0.217	(4.530)
Organisational IC x Research partnership			7.663*	(3.993)
Marketing IC x Research partnership			-9.325**	(3.835)
Product IC x Research service			2.252	(4.115)
Process IC x Research service			-3.314	(5.197)
Organisational IC x Research service			-6.411	(3.848)
Marketing IC x Research service			9.959***	(3.747)
Product IC x Technology transfer			0.090	(10.205)
Process IC x Technology transfer			6.889	(9.896)
Organisational IC x Technology transfer			5.136	(12.317)
Marketing IC x Technology transfer			-9.266	(9.860)
Product IC x Research facility			-5.409	(4.711)
Process IC x Research facility			-0.692	(4.319)
Organisational IC x Research facility			8.837**	(3.846)
Marketing IC x Research facility			9.224**	(4.134)
Product IC x HR transfer			-1.718	(2.206)
Process IC x HR transfer			-1.531	(2.575)
Organisational IC x HR transfer			0.967	(1.725)
Marketing IC x HR transfer			-3.360**	(1.629)
Control variables				
Firm's size	1.276***	(0.432)	1.301***	(0.433)
Firm's age	-0.014	(0.048)	-0.021	(0.048)
R&D intensity	-4.638	(3.771)	-5.076	(3.754)
OBM	3.115***	(1.063)	3.130***	(1.060)
MNC	3.474*	(1.934)	3.602*	(1.913)
Medium technology sector	0.032	(1.553)	-0.170	(1.558)
Medium-high technology sector	3.310**	(1.303)	3.264**	(1.309)
High technology sector	2.766	(1.918)	2.530	(1.923)
51-99% owned by Thais	-1.054	(1.707)	-1.128	(1.711)
1-50% owned by Thais	-5.243**	(2.308)	-5.087**	(2.295)
Wholly owned by foreigners	-3.877	(2.495)	-3.866	(2.485)
Year of survey	-0.934	(0.714)	-0.686	(0.706)
Constant	-8.517***	(2.750)	-8.721***	(2.836)
Observations	1,660		1,660	
Wald Chi^2 test	72.59***		106.13***	
Log-likelihood function	-4083.19		-4064.48	
Left-censored	804		804	
F test w.r.t. pooled Tobit	214.26***		220.73***	
Rho	0.578		0.596	

*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Low technology sector, 100% owned by Thais and year 2015 are the reference dummies for the technology sector, ownership, and year of survey, respectively.

The results reported that the effects of non-technological ICs varied among UIC channels, thus supporting Hypothesis 2b. Specifically, organisational IC has significantly positive effects on innovation performance when adopting research partnership (β = 7.663, *p-value* < 0.1) and research facility (β = 8.837, *p-value* < 0.05). The effects of organisational IC on innovation performance, when engaged in various channels, are illustrated in Figure 3.1. In addition, the effects of marketing IC on innovation performance are significantly positive when engaged in research service (β = 9.959, *p-value* < 0.01) and research facility (β = 9.224, *p-value* < 0.05), but negative in research partnership (β = -9.325, *p-value* < 0.05) and HR transfer (β = -3.360, *p-value* < 0.05). The results are also depicted in Figure 3.2. Nevertheless, there was no evidence supporting the significant effects of technological Cs and non-technological ICs on innovation performance when engaged in technology transfer. The main reason could be that only a small proportion of firms participated in this channel (e.g., mean value of 0.008 in Table 3.5), and thus the sample size was not large enough to capture the effects of innovation capabilities[12]. A low rate of engagement in technology transfer is common in both developed countries (Schartinger *et al.*, 2001; Agrawal and Henderson, 2002) and developing countries (Bekkers and Freitas, 2008; Lin, 2017). In addition, universities may not be able to capture the commercial value from technology licensing (Lockett *et al.*, 2005). This issue is even more pronounced in the case of Thailand where Thai academic researchers do not proactively commercialise their research (Intarakumnerd *et al.*, 2002; Pérez Cusó *et al.*, 2015).

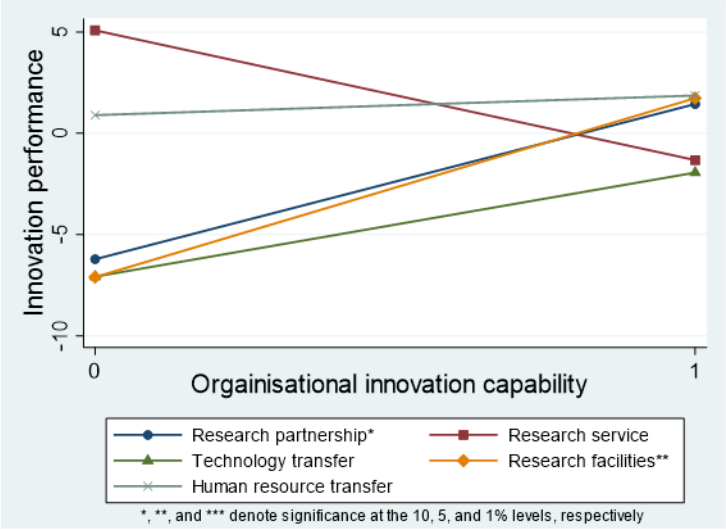

Figure 3.1 Effects of organisational innovation capability on innovation performance when engaged in different UIC channels

[12] the standard errors of interaction terms associated with technology transfer channel are the largest compared with other interaction terms (Table 3.7).

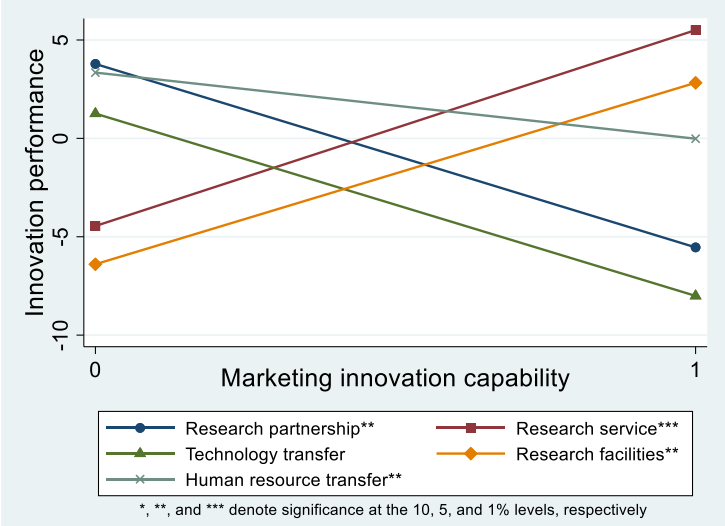

Figure 3.2 Effects of marketing innovation capability on innovation performance when engaged in different UIC channels

Regarding the control variables, large firms, OBM firms, MNC firms, and firms in the medium-to-high technology sector performed better than others in terms of innovation performance. Nonetheless, compared with purely Thai firms, firms that are less than 50% owned by Thais were likely to have lower innovation performance. To ensure that the results are robust, this paper performed the robustness check and discusses the results in the next section.

3.5.3 Robustness tests

Following prior research, the analysis was performed on the logarithm of the percentage of total sales derived from new products (Kafouros *et al.*, 2015) and an introduction of new products, employing a Tobit model and a Logistic model, respectively. The overall results in Table 3.8 indicate that the sign of all significant terms in Model 2 in Table 3.7 remained unchanged, but the p-values were larger making the terms statistically significant at a lower significance level, or insignificant. For example, interaction terms associated with marketing IC were significant at the significance level of 0.10 in HR transfer (Model 1, Table 3.8), research partnership and use of research facilities (Models 1 and 2, Table 3.8). Besides, different from Model 2 in Table 3.7, all interaction terms associated with organisational IC were insignificant except in research partnership (Model 1, Table 3.8). It is noteworthy that Thai firms might not be able to generate much revenue from the new products within a year of collaboration or even in the following year. Consequently, the ratio of new product sales to total sales can be relatively marginal. Similarly, an introduction of new products cannot capture a firm's true financial value. Therefore, it is appropriate to use a share of new products' sales to capture a firm's innovation performance. However, all additional analyses

in Table 3.8 at least confirmed the significant impact of marketing IC on innovation performance which is the main finding of this paper.

This study considered whether sample selection is an issue in the estimates in addition to using lagged measures for the dependent variables to mitigate issues associated with the omitted variables bias and reverse causality. Since firms that obtain sales of new products derived from the UIC might be primarily innovation-oriented, thus, the choice of engaging with universities is endogenous at the firm level. In other words, unobserved characteristics may be correlated with the firm's decision to invest in R&D with universities. Only firms that invest in R&D through the UIC may potentially obtain revenues from new products. To address this concern, this paper adopted a two-stage model introduced by Heckman (1979).

In the first stage, the Probit regression was estimated to investigate whether a firm reported positive R&D expenditure on the UIC based on two predictors. The first predictor was the importance of universities as a source of innovation. Since firms are motivated to collaborate with universities by the desire to seek scientific and technological knowledge (Barnes *et al.*, 2002), firms perceiving universities as *a source of innovation* are likely to engage with universities as observed from their expenditure on the UIC. This predictor was termed as *attitude* receiving the values ranging from 0 to 5, where 5 indicated that university was the most important source of innovation and 0 the least. The second predictor was the *research grant* as it is suggested that it motivates firms to engage with universities (Piva and Rossi-Lamastra, 2013; Aristei *et al.*, 2016). Grant was captured by the dummy variable measuring whether a firm received any funds from the government. This study then computed the Inverse Mills Ratio (IMR) used for correcting the selection bias.

In the second stage, this study estimated the ordinary least squares regression and included IMR in the model. The results in Model 2 (Table 3.9) show an insignificant effect of IMR at standard confidence levels, indicating that the sample selection bias was not an issue for this study. Thus, the results in Table 3.7 can be appropriately used for further discussion.

Table 3.8 Robustness test: Alternative measures for innovation performance

Variables	Model 1: Tobit (Share of new products sales)		Model 2: Logit (Introduction of new products)	
	Coef.	SE	Coef.	SE
Product innovation capability	0.375	(0.498)	0.034	(0.035)
Process innovation capability	1.576***	(0.573)	0.071*	(0.040)
Organisational innovation capability	0.329	(0.351)	0.025	(0.026)
Marketing innovation capability	0.898***	(0.345)	0.054**	(0.025)
Research partnership	-0.343	(1.058)	-0.055	(0.076)
Research service	0.183	(0.975)	0.030	(0.069)
Technology transfer	-1.442	(2.734)	-0.100	(0.208)
Research facility	-3.050***	(0.994)	-0.214***	(0.070)
HR transfer	0.765*	(0.409)	0.020	(0.031)
Product IC x Research partnership	0.063	(1.353)	-0.032	(0.100)
Process IC x Research partnership	-0.306	(1.228)	0.026	(0.092)
Organisational IC x Research partnership	2.043*	(1.111)	0.122	(0.082)
Marketing IC x Research partnership	-2.495**	(1.100)	-0.143*	(0.078)
Product IC x Research service	0.191	(1.136)	0.038	(0.082)
Process IC x Research service	-1.094	(1.452)	-0.179*	(0.104)
Organisational IC x Research service	-1.090	(1.078)	-0.085	(0.077)
Marketing IC x Research service	2.258**	(1.037)	0.160**	(0.075)
Product IC x Technology transfer	1.756	(3.058)	0.083	(0.203)
Process IC x Technology transfer	0.567	(3.353)	0.008	(0.195)
Organisational IC x Technology transfer	1.289	(3.261)	0.031	(0.237)
Marketing IC x Technology transfer	0.064	(3.085)	0.113	(0.192)
Product IC x Research facility	-0.429	(1.291)	0.002	(0.094)
Process IC x Research facility	-0.481	(1.199)	0.030	(0.086)
Organisational IC x Research facility	1.360	(1.036)	0.099	(0.077)
Marketing IC x Research facility	2.396**	(1.146)	0.138*	(0.083)
Product IC x HR transfer	-0.473	(0.622)	-0.034	(0.044)
Process IC x HR transfer	-0.805	(0.734)	-0.001	(0.051)
Organisational IC x HR transfer	0.247	(0.467)	0.046	(0.035)
Marketing IC x HR transfer	-0.750*	(0.444)	-0.068**	(0.033)
Control variables				
Firm's size	0.299**	(0.118)	0.013	(0.009)
Firm's age	-0.012	(0.013)	-0.001	(0.001)
R&D intensity	-1.407	(0.999)	-0.120	(0.079)
OBM	0.862***	(0.292)	0.045**	(0.022)
MNC	0.821	(0.518)	0.032	(0.039)
Medium technology sector	-0.025	(0.420)	-0.006	(0.033)
Medium-high technology sector	0.88**	(0.354)	0.056**	(0.028)
High technology sector	0.485	(0.511)	0.011	(0.041)
51-99% owned by Thais	-0.411	(0.462)	-0.03	(0.037)
1-50% owned by Thais	-1.492**	(0.618)	-0.100**	(0.048)
Wholly-owned by foreigners	-1.418**	(0.668)	-0.099*	(0.052)
Year	-0.095	(0.193)	0.013	(0.014)
Constant	-2.532***	(0.773)	-0.145**	(0.06)0
Observations	1,660		1,660	
Wald Chi2 test	80.66***		69.70***	
Log-likelihood function	-1765.57		-998.33	
Uncensored	1,048			
F test w.r.t. pooled Tobit	209.13***		185.86***	
Rho	0.651		0.682	

*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Low technology sector, 100% owned by Thais and year 2015 are the reference dummies for the technology sector, ownership, and year of survey, respectively.

Table 3.9 Robustness test: Heckman Selection Model

Variables	First stage Probit (Positive R&D expenditure on UIC)		Second stage OLS (Sales of new products)	
	Coef.	**SE**	**Coef.**	**SE**
Selected variables				
Research grant	1.164***	(0.300)		
Universities as a source of innovation	0.189**	(0.079)		
Independent variables				
Product innovation capability	0.458*	(0.268)	0.497	(0.878)
Process innovation capability	0.098	(0.331)	2.399**	(1.148)
Organisational innovation capability	-0.297	(0.241)	0.682	(0.694)
Marketing innovation capability	0.172	(0.245)	1.747**	(0.735)
Research partnership			-0.556	(1.731)
Research service			-0.139	(2.132)
Technology transfer			-1.685	(3.370)
Research facility			-4.678***	(1.448)
HR transfer			1.230	(0.749)
Interactions				
Product IC x Research partnership			1.130	(2.628)
Process IC x Research partnership			-0.155	(2.983)
Organisational IC x Research partnership			3.241*	(1.855)
Marketing IC x Research partnership			-4.528**	(2.119)
Product IC x Research service			0.102	(2.322)
Process IC x Research service			-0.918	(3.619)
Organisational IC x Research service			-2.653	(2.166)
Marketing IC x Research service			4.477**	(2.153)
Product IC x Technology transfer			-0.141	(4.001)
Process IC x Technology transfer			3.180	(4.673)
Organisational IC x Technology transfer			2.541	(3.675)
Marketing IC x Technology transfer			-2.391	(3.730)
Product IC x Research facility			-1.627	(2.436)
Process IC x Research facility			-1.040	(2.627)
Organisational IC x Research facility			3.706*	(2.176)
Marketing IC x Research facility			4.331**	(1.964)
Product IC x HR transfer			-0.981	(1.121)
Process IC x HR transfer			-0.660	(1.485)
Organisational IC x HR transfer			0.682	(0.901)
Marketing IC x HR transfer			-1.504*	(0.908)
Control variables				
Firm's size	0.281**	(0.118)	0.689**	(0.279)
Firm's age	-0.008	(0.012)	-0.007	(0.024)
OBM	0.110	(0.278)	1.758***	(0.524)
R&D intensity			-0.868	(0.653)
MNC	0.439	(0.606)	1.657	(1.083)
Medium technology sector	1.041***	(0.384)	-0.29	(0.981)
Medium-high technology sector	0.759**	(0.350)	1.298	(0.794)
High technology sector	0.754	(0.477)	0.636	(1.015)
51-99% owned by Thais	0.427	(0.360)	-0.588	(0.947)
1-50% owned by Thais	-0.216	(0.646)	-2.287*	(1.191)
Wholly-owned by foreigners	-1.198	(0.821)	-1.144	(1.435)
Year	-0.829***	(0.269)	-0.094	(0.586)
Constant	-5.241***	(1.119)	4.809	(3.480)
Observations	2,818		2,818	
Wald Chi2 test	31.02***		142.53***	
Rho	0.698		0.481	

Variables	First stage Probit (Positive R&D expenditure on UIC)		Second stage OLS (Sales of new products)	
	Coef.	SE	Coef.	SE
Log-likelihood function	-218.42			
F test w.r.t. pooled	27.96***			
R-squared			0.075	
IMR			-0.501	(0.593)

*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Low technology sector, 100% owned by Thais and year 2015 are the reference dummies for the technology sector, ownership, and year of survey, respectively.

3.5.4 Post hoc analysis

In addition to the main analysis, this study aims to further explore the effects of organisational IC in the research partnership channels. The results in Table 3.10 present that firms benefit from organisational IC when employing a research partnership and research facility. While firms may pursue these two channels for different purposes (i.e. seeking the development of scientific knowledge versus performing a calibration), it is also plausible that firms may employ these two mechanisms for a single project (Sá, 2011). This can also be observed from the data; that about one-third of firms adopted both channels simultaneously. To test the assumption, a three-way interaction (e.g., *Organisational IC x Research partnership x Research facility*) was included in the full model (Table 2.10). The results showed that the three-way interaction term is strongly significant (β = 22.629, *p-value* < 0.01), thus supporting the proposed argument.

Table 3.10 Post hoc analysis: A three-way interaction

Variables	Coef.	SE
Independent variables		
Product innovation capability	0.998	(1.759)
Process innovation capability	4.698**	(1.985)
Organisational innovation capability	1.071	(1.294)
Marketing innovation capability	3.732***	(1.267)
Research partnership	-0.505	(3.918)
Research service	-0.215	(3.414)
Technology transfer	-2.655	(10.831)
Research facility	-12.943***	(3.788)
HR transfer	3.063**	(1.496)
Interactions		
Product IC x Research partnership	-0.881	(5.115)
Process IC x Research partnership	-1.003	(4.566)
Organisational IC x Research partnership	3.307	(4.382)
Marketing IC x Research partnership	-9.177**	(3.839)
Product IC x Research service	2.269	(4.105)
Process IC x Research service	-5.29	(5.255)
Organisational IC x Research service	-7.604**	(3.836)
Marketing IC x Research service	9.668***	(3.743)
Product IC x Technology transfer	6.642	(10.354)
Process IC x Technology transfer	12.50	(10.002)

Variables	Coef.	SE
Organisational IC x Technology transfer	-0.201	(12.576)
Marketing IC x Technology transfer	-11.601	(9.924)
Product IC x Research facility	-5.336	(4.714)
Process IC x Research facility	-1.744	(4.303)
Organisational IC x Research facility	0.673	(4.429)
Marketing IC x Research facility	13.307***	(4.302)
Product IC x HR transfer	-1.457	(2.186)
Process IC x HR transfer	-1.116	(2.550)
Organisational IC x HR transfer	1.059	(1.708)
Marketing IC x HR transfer	-3.394**	(1.613)
Research partnership x Research facility	-0.787	(7.250)
Organisational IC x Research partnership x Research facility	22.629***	(8.807)
Control variables		
Firm's size	1.304***	(0.432)
Firm's age	-0.025	(0.048)
R&D intensity	-5.302	(3.736)
OBM	3.015***	(1.056)
MNC	3.499*	(1.899)
Medium technology sector	-0.314	(1.559)
Medium-high technology sector	3.188**	(1.309)
High technology sector	2.906	(1.924)
51-99% owned by Thais	-1.244	(1.712)
1-50% owned by Thais	-4.872**	(2.290)
Wholly owned by foreigners	-3.827	(2.476)
Year of survey	-0.589	(0.699)
Constant	-8.455***	(2.831)
Observations	1,660	
Wald Chi^2 test	121.23***	
Log-likelihood function	-4056.09	
Left-censored	804	
F test w.r.t. pooled Tobit	228.79***	
Rho	0.605	

*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively. Low technology sector, 100% owned by Thais and year 2015 are the reference dummies for the technology sector, ownership, and year of survey, respectively.

3.6 Discussion

Although the importance of a firm's technological and non-technological components on innovation creation in the UIC has long been discussed, most literature is biased towards a firm's technological capabilities and typical forms of UIC such as collaborative research, or simply established linkage. In exploring these issues, this paper goes beyond the traditional view of capability-based research in the UIC by providing empirical evidence of how a firm's technological and non-technological ICs affect its innovation performance when engaged in with universities.

A firm's ICs are crucial for reaping benefits from its in-house R&D and innovation activities as those capabilities are accumulated from the past learning and knowledge which are unique, valuable, and hard to imitate, thus increasing innovation performance (Barney,

1991). Acquisition of external knowledge to complement internal R&D is critical for sustaining a firm's competitive advantage (Cohen and Levinthal, 1990), in line with Eom and Lee (2010), who report that cooperation alone with university partners does not always mean that innovation performance will be achieved. This research reveals that when engaged in the UIC, a firm's innovation performance, is contingent on its ICs.

The results reveal the mixed effects of a firm's non-technological ICs on its innovation performance which vary among different UIC channels employed. In particular, a firm is likely to benefit from its organisational IC in improving innovation performance when adopting the research partnership or the research facility. In collaborative research projects in which the research is associated with highly tacit knowledge, obscure collaboration goals, conflicts in incentive, and IP-related issues (Fassio *et al.*, 2019; Sharma, 2020), a firm's organisational IC allows flexibility and creativity in the development of technological innovation (Mothe and Uyen Nguyen Thi, 2010). Therefore, a firm's organisational IC helps reconcile the conflicting issues and shorten the collaboration process, which in turn enhances its innovation performance, (Anzola-Roman *et al.*, 2018). A firm with organisational IC avoids relying on old routine and managerial procedures, but evolve its management techniques, culture, and strategies which is critical for exploratory research in collaborative research (Bierly *et al.*, 2009). In addition, since the collaboration in research partnership many involve the *mutual* knowledge transfer, it, thus, requires not only absorptive capacity but also the *desorptive capacity* for the success of bi-directional knowledge exchange (Lichtenthaler and Lichtenthaler, 2010). The recent evidence confirms the roles of a firm's management innovation in developing its desorptive capacity (van Doren *et al.*, 2021).

A firm also benefits from the development of its organisational IC when using a university's research facilities. A firm equipped with organisational IC tends to be more innovation-oriented – i.e. management innovation is a precondition for developing product, process and marketing innovation (Kafetzopoulos *et al.*, 2021). Thus, a firm may outsource its activities related to new product development to universities (e.g., calibration of equipment and testing products). Alternatively, it is plausible that a firm may use a university's research facilities and engage in a joint research project with universities in tandem or in succession. The post hoc analysis reveals that a firm with organisational IC benefits greatly from cooperation with university researchers when participating in research the partnership and the research facility in conjunction. The finding echoes the literature suggesting that using a university research facility can be a pathway for a collaborative R&D university (Sá, 2011). A firm is also likely to work with academic researchers who are familiar with the facilities and equipment used by a firm (Lai and Lu, 2016).

The analysis reveals intriguing findings that a firm's marketing IC might either alleviate or hamper its innovation performance when engaged with universities. Specifically, a firm only captures financial gain from its marketing IC when using a university's research services (e.g., research contract and consulting) or research facility. These two channels share common characteristics whereby the transferred knowledge is associated with applied research and the collaboration objective is more promising and pre-determined (Arza and Vazquez, 2010; D'Este *et al.*, 2019). Thus, the use of a university's services may be employed in response to a firm's R&D outsourcing strategy as a part of new product development. Once the solutions received from a university are translated into the product development process, a firm's marketing IC then plays important role in selling its products to customers. Alternatively, a firm packaged with marketing IC may use a university's service regarding the marketing purpose – i.e. as an instrument to certify products' compliance with standards, thus gaining customer confidence (Medda *et al.*, 2006).

A firm's marketing IC is not without a negative side if engaging in research partnership and HR transfer channels. The findings seem to contrast with its core function - i.e. to market new products and capture financial value. However, it is plausible that excessive marketing IC creates adverse effects rather than benefits. Regarding their characteristics, research partnership and HR transfer are similarly relevant to a lower degree of goal specificity (e.g., the open-ended objective of collaboration) (D'Este *et al.*, 2019; Fudickar and Hottenrott, 2019), thus allowing both parties more flexibility to amend or even abandon the collaboration if the project is lack of technology potential or the commercial value is unlikely to be visible. A firm equipping with marketing IC tends to possess intensive marketing knowledge and thus performs better in evaluating the market potential but tends to reject unpromising projects in technology alliance in another way (Vaculík *et al.*, 2019). Thus, in a research partnership associated with uncertainties and ambiguous outcomes, a firm with marketing IC which seeks a warranted outcome from the collaboration may terminate the collaboration too soon to avoid a large cost of opportunity if the collaboration success tends to be less feasible. This phenomenon is not uncommon in R&D cooperation (Greco *et al.*, 2020).

HR transfer is often operated under the inbound open innovation when a firm initiates the contacts (Goel *et al.*, 2017). A firm thus relies on the goodwill of academic researchers and at the same time have greater autonomy to terminate the collaboration. Despite the positive impact, marketing IC may lead to the *not-Invented-here syndrome*. This negative attitude results from the belief of managers and marketers that a firm's internal knowledge is superior to a university's knowledge. A firm with overemphasising marketing IC can be short-sighted when it comes to strong market knowledge, thus undervaluing knowledge mobilised by university researchers.

Although there is no evidence confirming the impact of a firm's technological ICs on its performance when engaged in UIC, this finding is unsurprising as it is similar to other studies focusing on a firm's technological capabilities of firms in developing countries (e.g., Su *et al.*, 2009; Eom and Lee, 2010; Xu *et al.*, 2011; Chen *et al.*, 2016). Several reasons have been proposed, despite no empirical investigation, such as substitution effects - i.e. a firm's knowledge is obsolete and replaced by academic knowledge (Daghfous, 2004a; Kobarg *et al.*, 2018), the crowding-out effect of a closer relationship with a university (Xu *et al.*, 2011), and a firm's weak absorptive capacity (Su *et al.*, 2009; Chen *et al.*, 2016).

This paper offers several explanations in addition to the prior studies' assumptions. *First*, given that Thai firms generally act as users of universities' knowledge (Arnold *et al.*, 2000), a high level of a firm's technological ICs may not be necessarily required when engaged with universities. *Second*, a firm, especially in developing countries, tends to focus on the development of its non-technological capabilities because this requires fewer economic and regulatory resources (Scotchmer, 2004; Perez *et al.*, 2019). Plus, employing a *dual-innovation strategy* – i.e. developing both technological ICs and non-technological ICs in tandem – is found to create disadvantages rather than benefits (Grimpe *et al.*, 2017; Henao-García and Montoya, 2021). *Third*, a firm in developing countries collaborates with universities to substitute its in-house R&D (Eom and Lee, 2010). Therefore, the weaker a firm's technological ICs, the more likelihood of its engagement with universities. This study underlines that despite an absent effect of a firm's technological ICs, it can benefit from UIC under the right mix between its non-technological capabilities and UIC channels.

Last, regarding the control variables, being large firms, OBM firms, MNC firms, and firms in the medium-to-high technology sector are likely to achieve superior innovation performance. Compared with smaller firms, larger firms tend to have better access to internal and external resources and can benefit from economies of scale and scope (Teece, 1986; Veugelers, 1997). OBM firms can also generate more capital, and possess higher innovation capabilities than non-OBM firms (Yan *et al.*, 2014), thus pinpointing a need for Thai enterprises to transform from OEM to OBM. In addition, being subsidiaries of MNCs may have more advantages than other local firms in their innovation process in terms of accessing, sharing and creating knowledge within the networked corporation. Firms in the medium-to-high technology sector (e.g., machinery, vehicles, etc.) are richer in terms of technological knowledge intensity and human capital than are firms in the lower technology sector; thus, they have stronger innovation capabilities. Nevertheless, firms that are less than 50% Thai-owned tend to have lower sales of new products. Particularly in the context of Thailand, foreign enterprises tend to establish firms in Thailand or partner with Thai firms to benefit from cheap labour costs. Thus, the development of new products may not be a

core focus for firms mainly owned by foreign enterprises since the R&D unit is often located at the head office.

3.7 Conclusions of the chapter

This paper unpacks the black box regarding the roles of a firm's non-technological capabilities on its innovation performance when engaged in a variety of UIC channels which, to date, has received less attention in current literature. The paper reports on the Thailand Innovation Community Survey in 2015 and 2017, drawing on a sample of 830 manufacturing firms and adopting the Tobit regression for the analysis. The analysis reveals that the effects of a firm's non-technological innovation capabilities on its innovation performance, expressed as sales of new products, are contingent on which UIC channels are employed. Specifically, a firm with organisational IC achieves better innovation performance when adopting collaborative research or using universities' facilities. In addition, a firm's marketing innovation capability has a positive impact on its innovation performance in research service channels (e.g., consulting and contract), but in not collaborative research and human resource transfer channels.

This research makes several theoretical contributions. *First*, this research substantiates the theoretical argument on the importance of technological and non-technological components in innovation in the UIC (Dill, 1990; Etzkowitz and Leydesdorff, 2000; Perkmann and Salter, 2012), and adds insightful knowledge of a firm's non-technological capabilities to the UIC literature that is biased towards a firm's technological capabilities. In addition, this study echoes prior findings that the UIC cannot guarantee the success of innovation without the presence of substantial capabilities (e.g., Choonwoo *et al.*, 2001; Eom and Lee, 2010; Apa *et al.*, 2020). *Second*, this study goes beyond the literature on capabilities in the UIC that mainly focuses on the typical channels such as collaborative research, or the existence of the linkage and stresses that UIC channels and capabilities should not be considered in isolation. *Third*, this study also adds to the findings based on developing countries that a firm's technological capability may be less important for R&D collaboration with the university in developing countries (e.g., Su *et al.*, 2009; Eom and Lee, 2010; Xu *et al.*, 2011; Chen *et al.*, 2016) by shedding light on the fact that, while the impact of technological ICs is absent, a firm may benefit from its non-technological ICs in cooperation with university partners. *Last*, this paper contributes to scant evidence on the UIC in Thailand by unravelling the crucial roles of a firm's ICs for the UIC in response to Thailand's innovation policy, shifting into the knowledge-based economy and innovation-driven economic development (Shin and Limapornvanich, 2017).

This paper recommends that policymakers encourage firms to engage in the UIC and fund the UIC projects. Policymakers need to bear in mind that firms can succeed in R&D cooperation with universities only with a presence of ICs, especially a non-technological ICs as evidenced by this study. Hence, R&D instruments should be implemented; for example, policymakers can increase the scope of the R&D tax credits to cover a firm's non-technological innovation activities or provide a research grant for the development of non-technological innovation. Given that the effects of a firm's non-technological ICs vary among UIC channels, the government should encourage universities to offer a wide range of UIC channels. While promoting the engagement in all UIC channels can be challenging, such channels as research contract, consulting and the use of a university's facilities and HR transfer can be a priority given a lower degree of formalisation compared with a research partnership and promising benefits when being orchestrated with a firm's organisational and marketing ICs.

Regarding managerial implications, firm managers interested in establishing the linkage with a university should be aware that the full potential of the UIC can be realised only if they have sufficient ICs. In addition, there is no such *one-size-fits-all* approach to reaping innovation benefits from an engagement with universities and thus, a firm's UIC strategies should be shaped differently based on the configuration of ICs and a variety of UIC channels. A firm is also encouraged to develop innovative culture and corporate strategies and improve management innovation, which is critical when using a university's services (e.g., research contact, consulting and a university's facilities). Firms that are knowledgeable about marketing and sales techniques may outsource their R&D or technical problems to universities through contract or consulting agreements as they tend to succeed in monetising their product solutions. Nevertheless, managers should beware of the downside of marketing IC, particularly when firms are engaged in research partnership and HR transfer channels. This study does not suggest that firms discard these channels but rather be cautious about issues arising from marketing IC such as the not-invented-here syndrome, which can be detrimental to their innovation performance. Last, although the results report no effects of a firm's technological ICs on innovation performance when engaged in any UIC channels, managers should bear in mind that a firm cannot exclude the development of technological ICs as they are still necessary for in-house R&D. Instead, firm managers should perceive the UIC as a means of complementing and improving a firm's internal capabilities (Tsai, 2009).

This paper offers several future research avenues based on limitations. *First*, in addition to sales of new products, future research may extend the variable innovation performance to cover incremental and radical innovation and also use alternative measures (e.g., patent counts and speed of innovation). *Second*, thanks to the nature of the dataset,

this study can only use one-year lagged measures for the variables to mitigate simultaneity issues. Thus, future research should use at least three-year lagged variables since most collaborative projects are financially measurable during this timeframe (Belderbos *et al.*, 2004). *Third*, the dataset only provides a limited number of UIC channels. Future studies should thus include other UIC mechanisms such as PhD supervision and spin-offs. *Fourth*, since this study is limited to manufacturing firms in Thailand, future work should include a range of countries and sectors to allow greater generalisability of the results. *Fifth*, this work does not cover the co-occurrence between different types of ICs and, therefore, suggests that future research explores this issue. *Sixth*, university researchers' non-research capabilities (e.g., entrepreneurial and marketing capabilities) are addressed as crucial for the UIC but are often found lacking. Future studies should explore how these capabilities can be developed as well as their impact on performance in the UIC. *Last*, the results are based on a quantitative approach and thus, cannot support the causation. Future research should conduct an in-depth interview to verify the findings of this study.

Chapter 4

Appropriability and Firm's Engagement in University-Industry Collaboration (*Paper 3*)

Abstract

Although scholars have paid attention to the effects of firms' appropriability mechanisms on firms' engagement in the UIC, the findings are contradictory. For instance, firms' formal appropriability mechanisms not only encourage firms to collaborate with university partners but also discourage them from doing so. This study aims to reconcile the mixed and conflicting findings by exploring the relationship between the firm's appropriability and openness in the UIC context. Drawing upon a sample of 10,860 manufacturing firms in the Thailand Community Survey during the period 2015-2018, the analysis reveals an inverted U-shaped relationship between a firm's appropriability strength and its engagement in UIC, expressed as collaboration breadth and propensity to engage in contractual and relational channels. In addition, the effect of a firm's appropriability strength on an engagement in the UIC is contingent on whether a firm is a product or process innovator. Specifically, being a product innovator strengthens an inverted U-shaped relationship between appropriability and UIC breadth while being a process innovator weakens the relationship by showing a convex shape to that relationship. While excessive appropriability discourages a product innovator to engage in relational channels, a process innovator tends to shift its interest from relational channels to contractual channels. The paper finally explores the implications of these findings for policies and management aimed at facilitating UIC.

Keywords: university-industry collaboration, appropriability, breadth, governance, product innovation, process innovation

4.1 Introduction

Scholarly communities have highlighted the importance of university-industry collaboration (UIC) since it helps improve the firm's innovation capabilities and competitiveness (Etzkowitz *et al.*, 2000; Sengupta and Ray, 2017). To achieve UIC success, firms need to share their knowledge with university partners. However, due to the transformation of the universities' roles from being research-based to more entrepreneurial (Abreu and Grinevich 2013), firms, thus, unavoidably face a risk of unwilling outgoing spillovers - i.e. universities may share knowledge with firms' rivals, or become a competitor by creating a university spinoff (Bonaccorsi and Piccaluga, 1994). The university's opportunistic behaviour may thus discourage firms from collaborating with the university partners. This dilemma of sharing versus protecting knowledge when engaged in external collaboration is commonly known as *the paradox of openness* (Laursen and Salter, 2014).

Whereas employing such legal protection methods (e.g., patent) mitigates appropriability issues and thus encourages firms' engagement with university partners (Veugelers and Cassiman, 2005; Roud and Vlasova, 2020), some scholars find contrasting results (López, 2008; Abramovsky *et al.*, 2009). Prior research has revealed that it is not puzzling that firms may be inclined or decline to participate in R&D collaboration in the light of the appropriability mechanisms already employed since the firm's engagement is contingent on the strength of appropriability reflecting what strategies they pursue (e.g., defensive versus collaborative) (see, e.g., Laursen and Salter, 2014; Yu *et al.*, 2020). Previous studies have found a curvilinear relationship between the firm's appropriability strength and openness of R&D. Yet, UIC researchers predominantly rely on a linear perspective and thus, the possible non-linear relationship between the firm's appropriability and the firm's propensity to engage with universities remains undetected.

The need for further exploration of the impact of the firm's appropriability on its engagement with the university is further accentuated by a narrow view of openness in the UIC context. The implementation of UIC is not sufficiently grounded on whether firms should collaborate or not, but through which mechanisms (e.g., contract-based versus relationship-based), and how many mechanisms should be employed (e.g., breadth of collaboration) to achieve the collaboration goal. Scholars have presented a close relationship between the firm's appropriability strategies and types of UIC governance (Freitas *et al.*, 2013a; Garcia-Perez-de-Lema *et al.*, 2017) and collaboration breadth (Bruneel *et al.*, 2010). Nevertheless, the empirical work on this issue is scarce as most studies focus on the established linkage between firms and universities.

This paper explores how appropriability strength influences a firm's engagement in different UIC governance modes as well as UIC breadth (e.g., the number of UIC channels employed). Drawing upon 10,860 manufacturing firms in the Thailand Community Survey in 2015, 2017 and 2018, the results reveal that the relationship between a firm's appropriability and its engagement in the UIC in terms of a propensity for engagement and UIC breadth is an inverted U-shaped one. This curvilinear relationship is also contingent on the firm's innovation heterogeneity. For instance, being a product innovator poses an inverted U-shaped relationship whereas being a process innovator exhibits a convex relationship between a firm's appropriability strength and UIC breadth. In addition, while excessive appropriability discourages a product innovator to engage in relational channels, a process innovator tends to shift its interest from relational channels to contractual channels.

A key contribution of this paper is, by adopting a non-linear perspective, to confirm the curvilinear relationship between the impact of the firm's appropriability and the firm's openness in the UIC, thus reconciling the inconsistent results from the previous studies. This paper also goes beyond the tradition by extending the concept of openness in the UIC from the established linkage between university and industry to the collaboration governance and collaboration breadth. This paper finally draws the attention of firm managers to be aware of the downside of overemphasising knowledge protection as well as the influence of a firm being a product or process innovator on the relationship between appropriability and openness in the UIC.

The rest of this paper is organised as follows. The following section presents the theoretical background by reviewing the streams of UIC literature on a firm's appropriability, governance modes, and collaboration breadth. Section 3.3 presents the development of relevant hypotheses while Section 3.4 explains the analytical approach. Section 3.5 presents the findings which are later discussed in Section 3.6. The last section draws conclusions and offers implications, limitations, and directions for future research.

4.2 Theoretical background

4.2.1 Tension between a firm's appropriability and the UIC

Knowledge transfer between universities and firms is often plagued with conflicts of interest; while universities primarily want to disclose knowledge, often in the form of publications, firms tend to keep it secret (Lee, 2000; Brown and Duguid, 2017). Firms thus alleviate this issue by employing such contract-based governance as well as clarifying the intellectual property-related issues before entering the collaboration agreement (Mora-Valentin *et al.*,

2004; Fassio *et al.*, 2019). Scholars argued that knowledge appropriation in the UIC might not be a serious issue since universities are non-competitors, and thus the risk of unwilling outgoing spillovers is lower compared with other partners (Belderbos *et al.*, 2004; Veugelers and Cassiman, 2005; Veer *et al.*, 2016). Notwithstanding, in this era of academic entrepreneurship (Etzkowitz, 2003; Abreu *et al.*, 2016), a firm may lose its marketing position due to unwilling spillovers if universities cooperate and share the firm's knowledge with the firm's rivals, or a university spinoff if created from the knowledge generated from the collaboration outcomes (Bonaccorsi and Piccaluga, 1994). Increased risk of opportunism finally disheartens firms from engaging with universities (Bruneel *et al.*, 2010).

Appropriability refers to the firm's ability to protect knowledge and capture the value from the firm's innovative effort (Cohen *et al.*, 2000; James *et al.*, 2013), often classified into *formal mechanisms* (e.g., patents, utility models, trademarks, and copyrights) and *informal mechanisms* (e.g., secrecy, lead time, complementary assets, and complexity) (Arbussà and Coenders, 2007; Bahemia *et al.*, 2018). Several researchers have long sought answers to 'what' and 'why' questions relating to a firm's reasons to engage in R&D cooperation through the lens of appropriability (Becker and Dietz, 2004; Veugelers and Cassiman, 2005; Henttonen *et al.*, 2016; Monteiro *et al.*, 2017). Laursen and Salter (2014) examined the *paradox of openness* and referred to the firm's dilemma of being necessarily open to external R&D collaboration while also protecting knowledge from being leaked. Their study revealed that inadequate or excessive appropriability strength leads to a low level of a firm's openness to R&D cooperation. The relationship between a firm's appropriability and openness is also explored in the UIC context (Table 4.1).

Although collaboration with universities is less involved with the difficulty of knowledge appropriation since universities are perceived as a non-competing partner (Belderbos *et al.*, 2004; Veer *et al.*, 2016), scholars revealed that firms are willing to share their knowledge with universities only if the knowledge can be protected from the university's opportunistic behaviours and with a strong IPR regime (Veugelers and Cassiman, 2005; Bercovitz and Feldman, 2007; Dachs *et al.*, 2008; Aristei *et al.*, 2016; Roud and Vlasova, 2020). Nevertheless, some studies found that formal legal protection rather discouraged firms from engaging with the university (e.g., López, 2008; Abramovsky *et al.*, 2009), or had no effects at all (Cassiman and Veugelers, 2002; Serrano-Bedia *et al.*, 2010; Chun and Mun, 2012; Badillo and Moreno, 2016) (see, Table 4.1). None of the studies has offered compelling and empirical evidence to disentangle the mixed findings. If the knowledge appropriation in the UIC is of less concern, *why do firms still need to adopt legal methods to protect their knowledge when engaged with universities?* On the other hand, if knowledge protection is crucial for dealing with opportunism, *why are those firms that*

employ such appropriability mechanisms still discouraged from collaborating with universities? These questions remain unanswered.

Table 4.1 Literature on a firm's appropriability and its engagement in the UIC

Study	Effect of appropriability on an engagement in UIC		Sample characteristics
	Legal protection	Strategic protection	
Cassiman and Veugelers (2002)	0	0	CIS data; Belgian manufacturing & innovative firms
Veugelers and Cassiman (2005)	+	0	CIS data; Belgian manufacturing & innovative firms
Bercovitz and Feldman (2007)	+	N/A	Canadian data; firms in Canada's 100 Top Corporate R&D Spenders List 2003
Dachs *et al.* (2008)	+	+	CIS data; Finnish manufacturing firms
López (2008)	-	+	CIS data; Spanish manufacturing & innovative firms
Abramovsky *et al.* (2009)	-	+	CIS data; 4 EU countries; manufacturing & service firms
Serrano-Bedia *et al.* (2010)	0	+	CIS data; Spanish manufacturing & service firms
Chun and Mun (2012)	0	+	CIS data: Korean manufacturing and innovative SMEs
Aristei *et al.* (2016)	+	N/A	EFIGE survey; 7 EU countries; manufacturing & innovative firms
Badillo and Moreno (2016)	0	N/A	Spanish data; manufacturing & service firms
Roud and Vlasova (2020)	+	+	Russian CIS data; manufacturing & innovative firms

Remark: + positive, - negative, 0 insignificant, N/A not applicable (not included in the study), * legal and strategic protection methods are merged into the appropriability variable.

What matters more is probably relevant to *why* use the appropriability strategies rather than *whether* those strategies are used (Grimaldi *et al.*, 2021). For example, formal appropriability (e.g., legal protection methods) may be used in response to a firm's diverse appropriability strategies such as a *defensive IP strategy* – to create barriers for the rivals (Heger and Zaby, 2018), *collaborative IP strategy* – to facilitate the knowledge exchanges with the partners (Chesbrough *et al.*, 2006) or *impromptu IP strategy* – without a specific purpose (Rivette and Kline, 2000). In line with, Henkel (2006), firms might not need to share

all knowledge or fully retain legal control over it, but selectively use legal protection to signal their innovation capabilities and technological opportunities to attract potential partners. Firms also use this strategy when they want to attract prestigious universities for R&D cooperation (Fontana *et al.*, 2006). Literature on the openness of firms (see, e.g., Laursen and Salter, 2014; Yu *et al.*, 2020) explained a firm's appropriability strategies (e.g., collaboration versus protectionism) based on the appropriability *strength* and the analysis was performed based on the non-linear assumption. Previous studies finally confirmed the curvilinear relationship between appropriability strength and openness of R&D.

In the light of findings from the literature on openness, this paper argues that the relationship between a firm's appropriability and engagement with university partners may also be curvilinear. This paper suggests that the conflicting evidence may be that most studies are predominantly based on a linear assumption, and thus possible curvilinear relationships cannot be detected. Yet, none of the research has empirically investigated this issue; thus, an understanding of what causes the mixed results goes into a black box.

4.2.2 Governance modes of the UIC

Heide, (1994, p. 72) defined governance as *"those tools that are used to establish and structure exchange relationships"*. Governance is crucial, in addition to the absorptive capacity and complementary asset, for achieving the benefit of collaboration if effectively employed (Gesing *et al.*, 2015). Regarding knowledge appropriation, governance acts as the safeguards to ensure the protection against the partner's opportunistic behaviour as well as resource allocation (Bradach and Eccles, 1989; Dyer, 1997; Hoetker and Mellewigt, 2009). According to Fassio *et al.* (2019), governance can be classified into *contractual* and *relational* modes. In the UIC context, contractual governance is associated with formal contracts (e.g., patent or license, contract research, research consulting, and shared facilities), while relational governance refers to the interactions characterised as unilateral knowledge exchange and not necessarily dependent on formal agreements (e.g., joint publication, joint supervision, student placement, training, meeting, and recruitment of graduates).

In the UIC context, firms often prefer to adopt contractual governance to relational governance as it leads to superior returns on innovation (Gesing *et al.*, 2015). However, both governance modes are often implemented in tandem due to their complementary effects. For instance, relational governance is employed as an establishment of the pre-existing ties and then oriented towards contractual governance (Hemmert *et al.*, 2014; Gesing *et al.*, 2015; Garcia-Perez-de-Lema *et al.*, 2017; Fassio *et al.*, 2019; Apa *et al.*, 2020). In addition, relational governance offers trust-building which in turn mitigates the conflicts of interest among the partners (Bruneel *et al.*, 2010).

Prior UIC studies have shown the interconnection between governance modes of collaboration and knowledge appropriation. Contractual governance is normally aimed at the exploration and exploitation of scientific and technological knowledge whereas relational governance focuses on the development of social ties and trust between firms and universities, thereby mitigating the risk of opportunism (Garcia-Perez-de-Lema *et al.*, 2017). In addition, contractual governance is mainly stipulated by institutional contract management by the university administration while, under relational governance, a contract may not be necessary or, if needed, is signed directly by the academic researchers, without involving the university's process (Bodas Freitas *et al.*, 2012; Freitas *et al.*, 2013a; Fassio *et al.*, 2019). Contractual governance thus involves the negotiation relevant to collaboration objectives and how collaboration results are shared. This may be associated with such difficulties as a firm's unwillingness to share knowledge and higher costs for preventing and monitoring knowledge leakage. In contrast, relational governance is unilateral and initiated by firms, allowing firms some autonomy to manage the collaboration and appropriate collaboration results.

In sum, governance modes in the collaboration play important roles in mitigating the need to rely heavily on the appropriability mechanisms, which in turn reduce the intention to leave the collaboration or act opportunistically. Hurmelinna-Laukkanen (2011) has called for further investigation regarding the interplay of appropriability mechanisms and governance mechanisms; however, this issue is still under the radar, particularly in the UIC context.

4.2.3 The matter of university-industry collaboration breadth

The interactions between university and industry can be manifested through various forms such as collaborative research, contract, consulting, and meetings, among others. (Perkmann and Walsh, 2007; Ankrah and Al-Tabbaa, 2015). While a major stream of UIC literature has paid attention to specific forms of collaboration, another stream has focused on the breadth of collaboration – i.e. a range of varied UIC channels (D'Este and Patel, 2007; Bruneel *et al.*, 2010; Iorio *et al.*, 2017; Lin, 2017; Hu *et al.*, 2020).

Broadening the spectrum of collaboration channels is regarded as crucial for firms since it permits them to improve technological capabilities by integrating the university's knowledge, embedded in each collaboration channel, with the firm's existing knowledge (Ahuja and Katila, 2004; Bierly *et al.*, 2009; de Wit-de Vries *et al.*, 2019), and alleviate orientation conflicts – i.e. firms seek private gain whereas university researchers tend to disseminate knowledge publicly, by strengthening social capital and building trust relationships (D'Este and Patel, 2007; Bruneel *et al.*, 2010; Grimpe and Hussinger, 2013; Garcia-Perez-de-Lema *et al.*, 2017; Robertson *et al.*, 2019).

Nevertheless, engaging in a variety of UIC channels can be a double-edged sword since firms may be distracted from their core innovation activities or lack capabilities to effectively absorb knowledge from each collaboration channel, thus attenuating innovation performance (Ahuja and Katila, 2004; Hu *et al.*, 2020). As suggested by Bruneel *et al.* (2010), immoderate collaboration breadth can also exacerbate intellectual property issues. For instance, the more UIC channels adopted, the more conflicts of interest, cost of IP negotiations, and complexity arising from the different universities' rules and procedures. Importantly, greater UIC breadth requires firms to increasingly disclose knowledge which may aggravate the risk of universities' opportunism behaviour.

While employing a variety of UIC channels seems to ameliorate firms' opportunities to improve technological capabilities, it also draws the attention of firms to be aware of the risk of involuntary outgoing spillovers. It is suggested that firms improve their appropriability conditions to mitigate the extent of outgoing spillovers (Aristei *et al.*, 2016; Fassio *et al.*, 2019). While a firm's appropriability and UIC breadth should not be understood in isolation, empirical study on this relationship is still lacking.

4.3 Development of hypotheses

4.3.1 Effects of a firm's appropriability strength on the UIC

The firm's ability to retain its financial benefits derived from the exploitation of an innovation including the collaboration results, called *appropriability*, is among the important incentives for R&D cooperation as it mitigates the cooperation failures (Lhuillery and Pfister, 2009). Specifically, firms with strong appropriability conditions are more likely to engage with universities for innovation creation since it mitigates the involuntary outgoing spillovers (Aristei *et al.*, 2016) and, on the other hand, ensures the benefit of incoming spillovers (Cassiman and Veugelers, 2002). According to the *selective revealing* proposed by Henkel (2006), firms might not need to disclose everything but choose to reveal their knowledge selectively - i.e. in a form of legal protection such as patents. Selectively disclosing is regarded as an important strategy since it signals information such as sufficient technical details about problems and opportunities as well as the firm's innovation capabilities to the potential collaborators (Pollok *et al.*, 2019) including prestigious universities for the collaboration (Fontana *et al.*, 2006).

Nevertheless, excessive appropriability might adversely affect the likelihood that the firm will cooperate with external partners. Firms overemphasising appropriability might demand more strict requirements, often associated with legal procedures, to ensure a sufficient level of knowledge protection, leading to a lengthy negotiation process and a delay

in the collaboration (Chesbrough, 2006; Laursen and Salter, 2014). The firm's appropriability mechanisms may also hamper the internalisation of knowledge exchange, thus discouraging firms from cooperating with universities (López, 2008). This concern could be more pronounced for the extensive breadth of the UIC since it exacerbates issues related to sharing intellectual property, negotiation processes, and the cost of monitoring the outgoing spillovers (Bruneel *et al.*, 2010). As a result, firms with strong appropriability might be discouraged about collaborating with the universities, limiting the UIC channels as well as the likelihood to collaborate with universities. This study thus hypothesises that:

Hypothesis 1a: *The firm's appropriability strength exhibits an inverted U-shaped relationship with the UIC breadth.*

Hypothesis 1b: *The firm's appropriability strength exhibits an inverted U-shaped relationship with the firm's propensity to collaborate with universities through contractual and relational channels.*

4.3.2 Moderating effects of being product and process innovators

In addition to its main focus, outlined above, this paper also examines the moderating effects of a firm being a product or process innovator on the relationship between appropriability and openness in the UIC as the firm's innovation heterogeneity has been revealed as influencing the relationship between the firm's appropriability and openness (Yu *et al.*, 2020).

Firms' technological innovation capabilities are highlighted as crucial for the UIC as they encourage a firm to engage with university researchers (Freitas *et al.*, 2013a; de Moraes Silva *et al.*, 2017), ensure the success of technology transfer (Santoro and Bierly, 2006; Bierly *et al.*, 2009), and enhance a firm's innovation performance (Kobarg *et al.*, 2018). Sufficient technological innovation capabilities permit firms to leverage absorptive capacity to absorb and utilise academic knowledge (Fabrizio, 2009; Garcia-Perez-de-Lema *et al.*, 2017). Technological innovation capabilities can be classified into *product* and *process* innovation capabilities (Sen and Egelhoff, 2000; Camison and Villar-Lopez, 2014; Najafi-Tavani *et al.*, 2018). *Product innovation capability* refers to a firm's ability to introduce new products or services in response to the market while *process innovation capability* reflects an introduction of new inputs or processes to the firm's production operations (Damanpour, 1991). For the analysis, this study refers to firms equipped with product innovation capability and process innovation capability as '*product innovator*' and '*process innovator*', respectively.

The product innovator firm adopts a product-differentiation strategy aiming at increasing customers' satisfaction by offering product novelty in terms of function,

appearance, or experience (Aliasghar *et al.*, 2019). On the other hand, the process innovator firm employs a cost-reduction strategy by investing in the improvement in manufacturing processes (Un and Asakawa, 2015). However, firms typically implement both types of innovation in conjunction to benefit from the synergy effects (Benner, 2002). Regarding appropriability mechanisms, legal protection methods (e.g., patents) are more beneficial for protecting product innovation, while informal appropriability methods (e.g., secrecy) are more effective for process innovation (Arundel, 2001; Holgersson and Wallin, 2017; Barros, 2021). Product innovators also tend to use formal appropriability in response to *a defensive IP strategy* to mitigate the risk and consequences of infringing others' IPR than that of process innovators (Bercovitz and Feldman, 2007; Chung *et al.*, 2019).

Being a product or process innovator is associated with a choice of UIC channels selected by firms. Particularly, product innovators tend to employ collaborative research and research contracts (Santoro and Bierly, 2006; Kobarg *et al.*, 2018), whereas process innovators may benefit from such relational channels as training university graduates for employment in the industry aiming at improving the production process (Arza and Vazquez, 2010; Dutrenit and Arza, 2010; Fernandes *et al.*, 2010). Although the interrelationship among appropriability, openness and a firm's innovation capabilities is largely under-researched, Yu *et al.* (2020) found that the effect of a firm's appropriability strength on openness is contingent on the heterogeneity of the firm's capabilities. Specifically, the product innovator exhibits a *convex* relationship between appropriability strength and openness while process innovation shows an inverted U-shaped relationship.

Based on the conceptualisation, this study thus expects that being a product or process innovator will show moderating effects on the relationship between a firm's appropriability strength and an engagement in the UIC. This paper also posits that the magnitude of moderating effects between product and process innovators is different. As a result, hypotheses are developed as follows.

Hypothesis 2a: *Being a product or process innovator has a moderating effect on the relationship between appropriability strength and the UIC breadth.*

Hypothesis 2b*: The nature and extent of moderating effects of being a product innovator and a process innovator are likely to be different on the relationship between the firm's appropriability strength and the firm's propensity to collaborate with universities through contractual and relational channels.*

4.4 Method and data

4.4.1 Data and sample

This study used data from the Community Innovation Survey (CIS) of Thailand; namely, the Thailand Business R&D and Innovation Survey. This survey has been conducted periodically since 1990 by the National Science and Technology Development Agency (NSTDA) following the guidelines of the Oslo Manual (OECD) 1997. In the Thai case, the sampling methodology was developed based on the business online database comprising comprehensive information of approximately 50,000 establishments in the manufacturing and service sectors registered with the Commercial Registration Department (Chaminade *et al.*, 2012).

Table 4.2 Overview of the sample in Paper 3 (N = 10,800)

	No. of Obs.	Percentage
Type of industry		
High technology sector	1,013	9.38%
Medium-high technology sector	2,823	26.14%
Medium technology sector	1,877	17.38%
Low-medium technology sector	4,548	42.11%
Low technology sector	539	4.99%
Number of employees		
1-100	4,861	45.01%
101-500	4,142	38.35%
501-1000	958	8.87%
1001-3000	632	5.85%
>3000	207	1.92%
Age of company		
0 - 10	913	8.45%
11-20	3,369	31.19%
21-30	3,430	31.76%
31-40	1,987	18.40%
41-50	741	6.86%
>50	360	3.33%
Multinational cooperation firms	1,450	86.57%

The data from Thai CIS used in this paper have a period of three years (2015, 2017 and 2018) offering sufficient information relevant to innovation activities, and the UIC as the core focus of this study. To conduct the survey, NSTDA first defined the size of the total firm population which was 104,296, 92,669 and 95,430 in 2015, 2017 and 2018, respectively. The NSTDA then sent the questionnaires to 12,918 firms in 2015, 13,597 in 2017, and 14,281 in 2018 by post, email or fax, and received the responses from 4,797 firms in 2015 (37.13%), 5,512 firms in 2017 (40.53%), and 5,762 firms in 2018. The overall response rate approximately ranges from 37% - 40% which is deemed satisfactory. This study limited the

data to manufacturing firms since only those firms actively conducted innovation activities, deployed the appropriability strategies, and collaborated with universities. Finally, the dataset consisted of 10,800 firms. The overview of sample firms in this study is shown in Table 4.2.

4.4.2 Measures

4.4.2.1 Dependent variables

Two dependent variables are used in this study. First, this study measured UIC breadth as the number of UIC channels that firms adopted annually, similar to the previous research (see, e.g., D'Este and Patel, 2007; Bruneel *et al.*, 2010). The variable UIC breadth was formed from the question asking the participants to indicate whether they employed UIC channels and, if so, which ones[13]: (1) joint research, (2) research contract, (3) research consultancy, (4) temporary personal exchange, (5) student internship, (6) training, and (7) meeting, conference, and informal personal contact. Each channel was coded as a binary variable indicating the firm's use of the UIC channel with 0 indicating no use, and 1 indicating use. Table 4.3 shows that the correlation among seven channels was less than 0., indicating that all channels were largely non-overlapping, and each form of collaboration was unique. To delineate the UIC breadth, seven channels were simply summed with the firms scoring 0 if no channel was used and 7 if all channels were used.

Table 4.3 Correlation coefficients of UIC channels

UIC channels	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Joint research	1.000						
(2) Research contract	0.318	1.000					
(3) Research consultancy	0.211	0.380	1.000				
(4) Research mobility	0.106	0.112	0.106	1.000			
(5) Student internship	0.103	0.070	0.084	0.011	1.000		
(6) Training	0.165	0.147	0.142	0.024	0.242	1.000	
(7) Meeting, conference, personal contact	0.194	0.173	0.181	0.055	0.150	0.259	1.000

[13] This paper focused on UIC channels where both parties actively exchange knowledge which require the firms to ensure their sufficient appropriability conditions. Thus, this paper disregarded transactional channels (e.g., use of university's license, use of research facilities, and performing a test at the universities).

The second dependent variable is the firm's engagement with universities in either contractual or relational governance modes. Following previous studies (see, e.g., Bruneel *et al.*, 2010; Garcia-Perez-de-Lema *et al.*, 2017), channels such as joint research, research contract, research consultancy and research mobility were grouped as *contractual governance* while *relational governance* included student internship, training, meeting or conference and informal personal contact. The results from the Factor Analysis (Table 4.4) confirmed that the classification of governance modes was appropriate and consistent with the literature. Finally, each governance was coded as binary, which takes the value of 1 if the firm reports having used at least one channel associated with that governance, and 0 otherwise.

Table 4.4 Factor analysis of UIC governance modes

Governance modes	UIC channels	Loadings
Contractual governance	Joint research	0.6354
	Research contract	0.7893
	Research consultancy	0.6898
	Research mobility	0.7312
Relational governance	Student internship	0.6718
	Training	0.7556
	Meeting, conference, personal contact	0.5601

4.4.2.2 Explanatory variables

The main explanatory variable is the firm's appropriability strength. Appropriability strength is often measured as the sum of the degree of importance of formal and informal appropriability mechanisms to the firm (Laursen and Salter, 2014). However, Thai CIS only reported the number of formal appropriability mechanisms. Based on Tuppura *et al.* (2010), the strength of appropriability was characterised by several criteria (e.g., the degree of exclusivity and enforcement, industrial and innovative scope, and value captured from the IP). It should be, therefore, noted that the term '*appropriability'* appearing from this section refers to *formal appropriability mechanisms*[14]. To capture the appropriability strength, each IPR was assigned the value based on its strength (e.g., patent – 5, utility model – 4, industrial design – 3, copyright and trademark - 2, and other means – 1). Besides, the

[14] Although informal appropriability mechanisms are not available in Thai CIS, it should be commonly understood that firms use informal appropriability, at least secrecy and confidential agreement, mechanisms spontaneously (Barros, 2021). Therefore, although firms reported no formal appropriability mechanisms, they would still receive a score of appropriability equal to 1, indicating purely use of informal appropriability mechanisms.

number of each IPR was coded as binary indicating whether a firm used the IPR with 1 indicating yes, and 0 otherwise. Finally, the appropriability strength can be defined as the following expression.

$$\text{Appropriability strength} = \sum_{i=1}^{5} x_i y_i,$$

where x_i is equal to 1 if a firm used IPR i, and 0 otherwise. y_i is the score of IPR i (i = 1, …, 5). Based on the above formula, the appropriability strength ranges from 1 to 15 where 15 indicates that a firm used all types of IPR.

For the moderator variables, this study employed dummy variables for firms being product or process innovators. Product innovator takes the value of 1 if a firm reported introducing new products, and 0 otherwise. Similarly, a process innovator takes the value of 1 if a firm improved methods for production or supply of goods or services, and 0 otherwise.

4.4.2.3 Control variables

Given the influence on collaboration breadth and the firm's propensity to engage with universities reported by the previous studies, this paper, hence, employed several control variables as follows.

- *Firm size*: Firm size was measured in terms of the number of employees expressed in natural logarithms. Large firms foster the links with universities to explore innovative ideas (Laursen and Salter, 2014) while small firms are engaged with universities for applied research and short-term benefits, particularly in the developing countries (Arza and López, 2011).
- *Firm age*: Firm age was measured as the number of years elapsed from the year that a firm was established to the year of data collection. Compared with young firms, older firms are more inert and inflexible to their in-house innovation activities and therefore more likely to engage in R&D cooperation (Yun and Lee, 2013).
- *Multinational cooperation (MNC)*: MNC was measured as a dummy variable - i.e. whether the firm is MNC. MNC firms may be less likely to collaborate with universities due to the high cost of collaboration (Von Zedtwitz and Gassmann, 2002), or a better benefit from access to the foreign technologies at headquarters or foreign universities (Arza and López, 2011; De Fuentes and Dutrenit, 2012).
- *Original brand manufacturing firms (OBM)*: OBM was captured by the proportion of products manufactured by OBM. OBM firms may invest more in R&D and tend to engage with universities than with other types of firms.
- *Knowledge intensity*: A firm's knowledge intensity is reported as having an impact on the relationship between a firm's appropriability and collaboration (Yacoub *et al.*,

2020). High-knowledge-intensity firms such as pharma and biotechnology firms are more likely to collaborate with universities than others (Klevorick *et al.*, 1995; Segarra-Blasco and Arauzo-Carod, 2008; Levy *et al.*, 2009). The firms' industry types expressed as two-digit divisions in International Standard Industrial Classification (United Nations. Statistical, 2008) were coded into four different technology sectors. Next, firms in low and low-medium technology sectors were grouped and named as *low-knowledge-intensive firms*. The rest of the industries were combined and termed as *high-knowledge-intensive firms*. Finally, knowledge intensity was measured as a binary variable receiving the value of 1 if the firm had high knowledge intensity, and 0 otherwise.

- *R&D intensity*: R&D intensity was measured as the ratio of a firm's R&D expenditure to the total revenue. Firms with R&D capacity tend to engage with universities due to a high level of absorptive capacity (Cohen and Levinthal, 1990).
- *R&D unit*: a firm's R&D unit was measured as a dummy variable taking the value of 1 if the firm owned an R&D unit and 0 otherwise.
- *Importance of universities as a source of innovation (Uni Imp)*: *Uni Imp* was measured as the scores from 0 to 5 (5 - highly important, 1 - least important, and 0 is not important). Firms seeking scientific and technological knowledge tend to collaborate with universities (Barnes *et al.*, 2002).
- *Research grant*: Grant was measured by a dummy variable indicating whether a firm received any funds for the government. Firms are generally encouraged to engage with the university if they receive public funds (Aristei *et al.*, 2016).
- *Year of the survey*: Year of the survey was measured as dummy variables receiving the value 1 if the firm was associated with the Year 2015, 2017 and 2018, respectively.

All variables and their definition are presented in Table 4.5.

4.4.3 Economics model and estimation method

This study estimated the regressions with fixed effects as confirmed by the Hausman tests (Hausman, 1978) and suggested that the unobserved heterogeneity be accommodated in panel data analysis (Sayrs, 1989; Greene, 2008). Since the dependent variables are count and binary, two different regression models were employed to perform hypotheses testing. Although Poisson regression, Negative Binomial regression and Generalized Binomial regression are commonly used for count variables (Hilbe, 2014), Laursen and Salter (2014) argued that these techniques were not applicable since the breadth was restricted by an upper bound and thus suggested the use of *the fractional logit regression*, introduced by Wooldridge (2010). The fraction of UIC breadth was obtained by dividing the number of UIC

channels a firm employed by the total number of UIC channels. This study adopted the generalised estimation equations (GEE) regression, estimated via quasi maximum likelihood, as suggested for panel data by Papke and Wooldridge (2008). Following Pan (2001), this paper adopted the independence model criterion (QIC) - i.e. the modification of AIC based on the quasi-likelihood estimation[15]. A model with the smallest QIC should be chosen as the best-fitting model in GEE analyses. For the binary dependent variable, logistic regression was performed to test the hypothesis.

Table 4.5 Variable definition of Paper 3

Variables	Type	Description
Dependent variable		
UIC breadth	Continuous	The fraction of UIC breadth obtained by dividing the UIC breadth (the number of UIC channels that the firms used) by 7 which was the maximum number of UIC channels
Contractual channels	Binary	1 if the firm used joint research, research contract or consultancy, 0 otherwise
Relational channels	Binary	1 if the firm collaborated with universities through research mobility, a student internship, personal contact, use of university's facilities and equipment, or performing a test at a university, 0 otherwise
Independent variable		
App	Continuous	Score derived from the strength of IPR ranging from 0 to 14
Moderator		
Product innovator	Binary	1 if the firm introduced new products, 0 otherwise
Process innovator	Binary	1 if the firm improved methods for production or supply of goods or services new products, 0 otherwise
Control variables		
Firm size	Continuous	Natural logarithm of the number of employees
Firm age	Continuous	The number of years since the establishment
MNC	Binary	1 if the firm is multinational cooperation, 0 otherwise
R&D unit	Binary	1 if the firm established an R&D unit/department, 0 otherwise
R&D intensity	Categorical	The ratio of the firm's R&D expenditure to its total revenue
OBM	Continuous	The proportion of products manufactured by the original brand manufacturer
Grant	Binary	1 if the firm received a research fund from the government, 0 otherwise
Uni Imp	Continuous	Scores from 0 to 5 how important universities are for the firm's source of innovation
Knowledge intensity	Binary	1 if the firm was high-knowledge-intensive, 0 otherwise
Year	Categorical	Whether the observation is associated with the Year 2015 (= 0), Year 2017 (= 1) and Year 20178 (= 2)

[15] Pan (2001) argued that since GEE is a non-likelihood-based estimation method, the pseudo-R-squared and Akaike's information criterion (AIC) for the model selection were not applicable. Using the Wald Chi-Squared test is also not appropriate for GEE models since it overlooks the number of parameters in the model.

4.5 Results

4.5.1 Descriptive statistics

Table 4.6 summarises descriptive statistics of explanatory variables. The average UIC breadth was only 0.643 indicating that most firms employed a few UIC channels. From Table 4.7, 53.04% of the firms did not collaborate with universities indicating that Thai firms may prefer in-house R&D or cooperation with other external partners. Those who engaged in the UIC mainly collaborated through a single UIC channel (34.66%). Table 4.8 presents that firms mostly preferred to participate in relational channels (45.73%) to contractual channels (4.80%). In line with Dutrenit and Arza (2010), firms in developing countries tend to adopt human-resource transfer channels. Table 4.9 displays the correlations among the variables included in the analysis. The coefficients among the explanatory variables were below 0.5 which are not sufficiently strong to require further investigation. Variance inflation factors (VIFs) range from 1.008 to 1.482 which are below the ceiling of 10 suggesting no multicollinearity issue (Hair *et al.*, 2009).

Table 4.6 Descriptive statistics of Paper 3 (N = 10,806)

Variables	Mean	SD	Min	Max
UIC breadth	0.643	0.857	0.000	7.000
Contractual channels	0.048	0.213	0.000	1.000
Relational channels	0.457	0.498	0.000	1.000
Appropriability	1.236	0.983	1.000	14.000
Product innovator	0.230	0.421	0.000	1.000
Process innovator	0.088	0.283	0.000	1.000
Firm size	4.930	1.446	0.693	11.810
Firm age	25.192	11.828	3.000	101.000
MNC	0.134	0.341	0.000	1.000
R&D unit	0.390	0.488	0.000	1.000
R&D intensity	0.016	0.182	0.000	10.918
OBM	0.361	0.480	0.000	1.000
Grant	0.063	0.242	0.000	1.000
Uni Imp	0.139	0.716	0.000	5.000
Knowledge intensity	0.355	0.479	0.000	1.000

Table 4.7 Frequency of UIC channels adopted by firms

UIC channels	Frequency	Percentage
0	5,732	53.04%
1	3,745	34.66%
2	956	8.87%
3	268	2.48%
4	58	0.54%
5	17	0.16%
6	19	0.18%
7	8	0.07%

Table 4.8 Frequency of UIC governance modes adopted by firms

	Non-relational	Relational	Total
Non-contractual	5,732 (53.05%)	4,555 (42.15%)	10,287 (95.20%)
Contractual	132 (1.22%)	387 (3.58%)	519 (4.80%)
Total	5,864 (54.27%)	4,942 (45.73%)	10,806 (100%)

Table 4.9 Correlation coefficients of Paper 3

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) UIC breadth	1.000							
(2) Contractual	0.499***	0.130***						
(3) Relational	0.785***	0.094***	1.000					
(4) Appropriability	0.105***	0.087***	0.055***	1.000				
(5) Product innovator	0.137***	0.105***	0.121***	0.135***	1.000			
(6) Process innovator	0.133***	0.086***	0.064***	0.089***	0.134***	1.000		
(7) Firm size	0.260***	0.047***	0.296***	0.038***	0.163***	0.065***	1.000	
(8) Firm age	0.067***	-0.025***	0.052***	-0.010	0.045***	-0.013	0.187***	1.000
(9) MNC	0.001	0.122***	0.017*	-0.017*	-0.017*	0.035***	0.125***	-0.065***
(10) R&D unit	0.234***	0.023**	0.229***	0.069***	0.339***	0.038***	0.314***	0.124***
(11) R&D intensity	0.014	0.044***	0.007	0.024**	0.023**	-0.002	-0.013	-0.008
(12) OBM	0.090***	0.147***	0.068***	0.025**	0.123***	0.002	0.050***	0.096***
(13) Grant	0.210***	0.209***	0.115***	0.091***	0.074***	0.107***	0.062***	0.004
(14) Uni Imp	0.186***	0.005	0.077***	0.037***	0.055***	0.058***	0.035***	-0.003
(15) Knowledge	-0.022**	0.130***	-0.022**	0.019**	0.043***	-0.010	-0.045***	-0.011

Variables	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(9) MNC	1.000						
(10) R&D unit	-0.054***	1.000					
(11) R&D intensity	-0.028***	0.072***	1.000				
(12) OBM	-0.107***	0.184***	0.030***	1.000			
(13) Grant	-0.013	0.096***	0.009	0.069***	1.000		
(14) Uni Imp	-0.016*	0.069***	-0.004	-0.022**	0.058***	1.000	
(15) Knowledge	0.168***	0.051***	0.020**	-0.033***	-0.008	0.015	1.000

N = 10,785, *** correlation is significant at the 0.01 level (2-tailed), ** correlation is significant at the 0.05 level (2-tailed).

4.5.2 Regression results

There are three main analyses for testing the hypotheses regarding the effects of a firm's appropriability strength on three dependent variables. Each analysis comprises four models. The *first* model tests the linear relationship between the effects of a firm's appropriability strength on the dependent variables. The *second* model tests the curvilinear relationship by including the squared term of appropriability strength. The remaining models include the interaction terms associated with the product and process innovation which the

third model tests the linear relationship while the *fourth* model examines the curvilinear relationship. The results are presented in Table 4.10.

4.5.2.1 Effects of a firm's appropriability strength on the UIC breadth

In Table 4.10, Although Model 1 presented the significant positive effects of appropriability strength on the UIC breadth (b = 0.048, p < 0.01), Model 2 confirmed the inverted U-shaped relationship since the squared term of appropriability strength squared was significantly negative (b = -0.004, p < 0.05), thus supporting Hypothesis 1a. Figure 4.1 depicts the predictions on UIC breadth based on Model 2 and showed that initially, as strength of appropriability increases, firms increase UIC breadth. At a point of approximately 10 on the scale of appropriability strength, UIC breadth reaches a peak and then gradually declined as the strength of appropriability continued to increase.

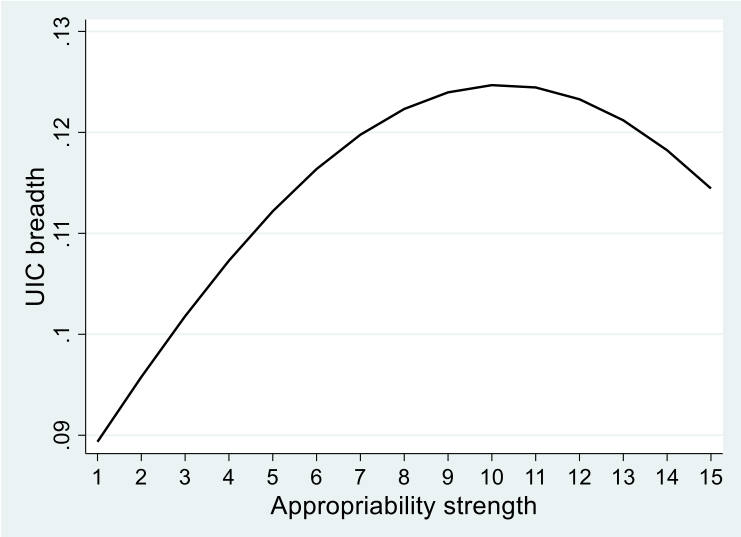

Figure 4.1 Relationship between firms' appropriability strength and the UIC breadth

4.5.2.2 Effects of a firm's appropriability on the propensity to collaborate with universities

The results (Table 4.10) confirmed the inverted U-shaped relationship between the firm's appropriability strength and propensity to engage in both contractual (Model 6, b = -0.025, p < 0.05) and relational channels (Model 10, b = -0.019, p < 0.05), thus supporting Hypotheses 1b and 1c. Based on Model 6 and Model 10, Figure 4.2 illustrates that, initially, firms were likely to engage in contractual and relational channels when the appropriability strength is higher. However, after reaching a point of approximately 7 on the appropriability scale, the propensity to adopt either channel declines. Particularly, after a point of 11 on the

appropriability scale, the propensity to engage in relational channels decreases dramatically more than in contractual channels stressing the inverted U-shaped relationship in relational channels.

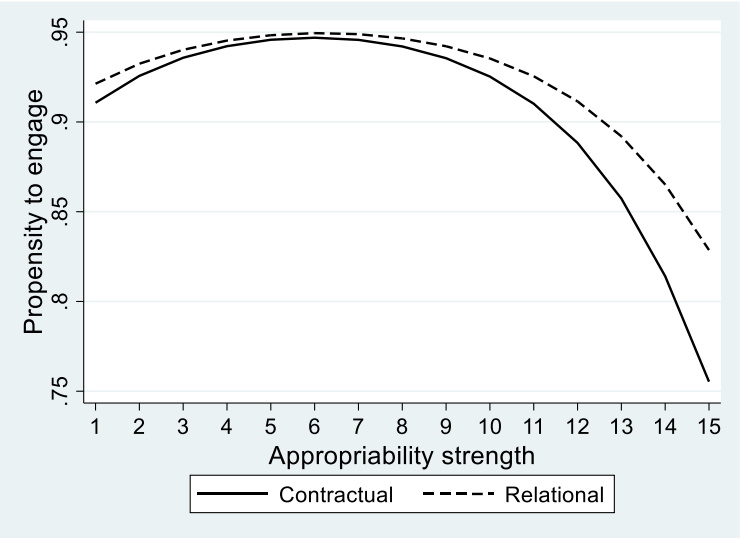

Figure 4.2 Relationship between firms' appropriability strength and the propensity to engage in the UIC

4.5.2.3 Moderating effects of being a product innovator or a process innovator on the relationship between a firm's appropriability and the UIC

Regarding *UIC breadth*, Model 4 (Table 4.10) presents that the interaction term between being product innovator and appropriability strength squared was significantly negative (b = -0.010, p < 0.05) while the interaction terms between process innovator and appropriability strength squared were significantly positive (b = 0.011, p < 0.05), thus supporting Hypothesis 2a. Particularly, being a product innovator exhibits the inverted U-shaped relationship while being a process innovator shows the convex relationship between appropriability strength and UIC breadth. Figure 4.3 depicts the inverted U-shaped curve indicating that product innovators with low appropriability strength tended to increase the UIC breadth, but gradually limited the UIC breadth when the appropriability strength is approximately equal to 7. On the other hand, despite the imperfectly U-shaped curve, process innovators tended to increase UIC breadth when appropriability strength was about 6 on the 15-point scale of appropriability strength.

In respect of *the propensity to engage with universities*, being a product innovator or process innovator only moderated the relationship between appropriability and the propensity to collaborate through the relational channel, thus partially supporting Hypothesis 2b. Particularly, in Model 12, the interaction term between product innovator and appropriability squared was negative (b = -0.040, p < 0.10) thus confirming the inverted

U-shaped relationship. The interaction effect between process innovator and appropriability was significantly negative (b = -0.496, p < 0.05), but the quadratic term was significant. To help illustrate, Figure 4.4 shows that, for product innovators, the figure presented an imperfectly inverted-U shape despite a significant quadratic term. In particular, the propensity to engage in relational channels marginally increased, but dramatically decreased after the point of 10 on the appropriability strength scale. For process innovators, firms steadily decreased the propensity to engage in relational channels when appropriability strength increased.

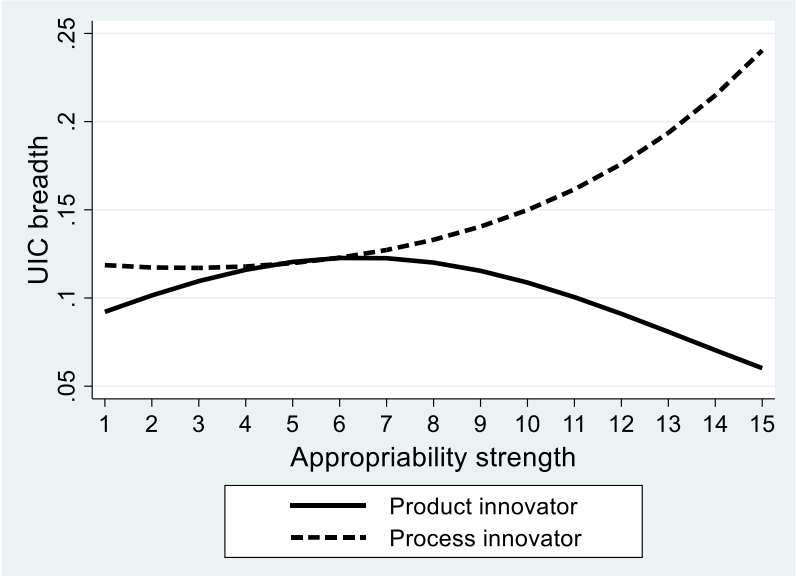

Figure 4.3 Relationship between firms' appropriability strength and the UIC breadth moderated by a product or process innovator

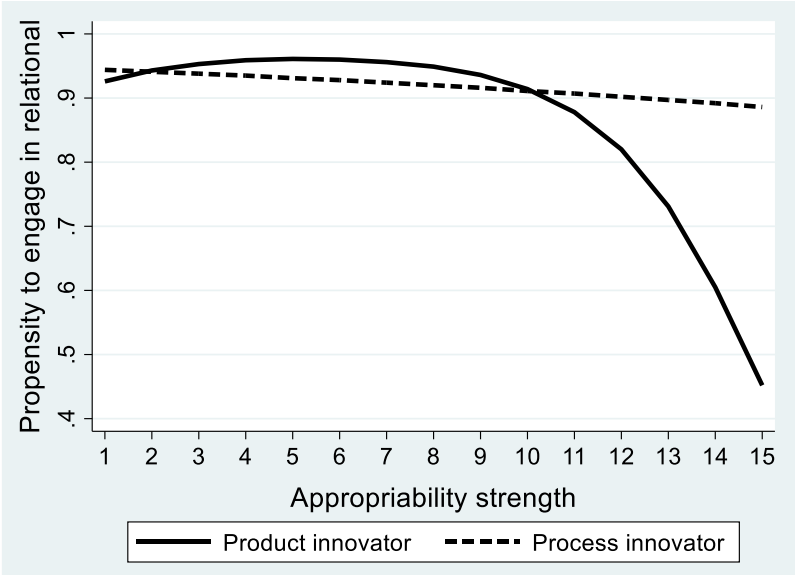

Figure 4.4 Relationship between a firm's appropriability strength and the propensity to engage in relational channels moderated by a product or process innovator

4.5.2.4 Effects of control variables

Regarding the control variables, it is found that firm size, R&D unit, research grant, and the firms' perception towards universities as a source of innovation exhibit positive effects on all dependent variables and all selected models in Table 4.10at the standard significance level. Larger firms often have their R&D unit indicating sufficient R&D capabilities and resources to initiate the collaboration with universities, likely through multiple channels (Lee, 2000; Laursen and Salter, 2014). In addition, as UIC is often perceived as a means to innovation creation (Eun *et al.*, 2006; D'Este and Patel, 2007), firms perceiving universities as a source of innovation were likely to employ multiple channels of UIC to acquire scientific and technological knowledge. In line with previous studies, grants from the government motivated firms to engage in the UIC (Piva and Rossi-Lamastra, 2013; Aristei *et al.*, 2016). Specifically, the Thai government often granted the funding to firms under the UIC funding schemes – i.e. collaborating with university researchers is an initial requirement stated in the agreement before the funding is granted.

The results further revealed a positive effect of OMB firms on the propensity to engage in both UIC governance modes. In the case of Thailand, original equipment manufacturer (OEM) firms attempt to transform themselves into OBM firms (Huang and Intarakumnerd, 2019). In doing that, OEM or any firms wishing to offer product novelty to customers under their own brand may need to seek R&D cooperation, and hence, increase the propensity to collaborate with universities. Surprisingly, high-knowledge-intensity firms were less likely to collaborate with universities in contrast to previous studies (Segarra-Blasco and Arauzo-Carod, 2008; Levy *et al.*, 2009). However, this could be because Thai firms in the high technology sector might tend to rely on in-house R&D or other external partners besides universities. This phenomenon was common in Thailand where the linkage between firms and universities is weak (Brimble and Doner, 2007).

Table 4.10 Fractional and Logistic models: Effects of firms' appropriability strength on UIC breadth and UIC governance

Variables	Fractional logistic regression DV = UIC breadth				Logistic regression DV = Contractual channels				Logistic regression DV = Relational channels			
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**	**Model 10**	**Model 11**	**Model 12**
App	0.048***	0.092***	0.070***	0.096***	0.033	0.295**	0.087	0.316	0.070**	0.228***	0.113**	0.138
	(0.009)	(0.024)	(0.012)	(0.032)	(0.052)	(0.140)	(0.078)	(0.194)	(0.035)	(0.086)	(0.050)	(0.135)
App^2		-0.004**		-0.003		-0.025**		-0.019		-0.019**		-0.003
		(0.002)		(0.003)		(0.012)		(0.016)		(0.009)		(0.016)
Product innovator	0.055*	0.050	0.092**	-0.006	0.274	0.250	0.527*	0.096	0.225**	0.213**	0.270*	-0.097
	(0.032)	(0.032)	(0.043)	(0.061)	(0.201)	(0.203)	(0.269)	(0.423)	(0.106)	(0.106)	(0.143)	(0.227)
Process innovator	0.318***	0.313***	0.397***	0.502***	0.392	0.373	0.144	1.267	0.405***	0.386***	0.678***	0.992***
	(0.046)	(0.046)	(0.060)	(0.085)	(0.249)	(0.250)	(0.357)	(0.776)	(0.140)	(0.141)	(0.200)	(0.298)
Interaction effects												
App x Product innovator			-0.023	0.065			-0.145	0.250			-0.035	0.311
			(0.018)	(0.045)			(0.103)	(0.330)			(0.066)	(0.192)
App^2 x Product innovator				-0.010**				-0.050				-0.040*
				(0.004)				(0.038)				(0.023)
App x Process innovator			-0.044**	-0.144**			0.130	-1.044			-0.163*	-0.496**
			(0.022)	(0.056)			(0.147)	(0.768)			(0.083)	(0.233)
App^2 x Process innovator				0.011**				0.160				0.041
				(0.005)				(0.114)				(0.026)
Control variables												
Firm size	0.210***	0.212***	0.211***	0.212***	0.509**	0.526**	0.493**	0.507**	0.314***	0.318***	0.318***	0.319***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.202)	(0.204)	(0.202)	(0.202)	(0.080)	(0.080)	(0.080)	(0.080)
Firm age	0.001	0.001	0.001	0.001	-0.016	-0.018	-0.016	-0.020	-0.008	-0.008	-0.008	-0.008
	(0.001)	(0.001)	(0.001)	(0.001)	(0.026)	(0.026)	(0.026)	(0.027)	(0.014)	(0.014)	(0.014)	(0.014)
MNC	0.006	0.006	0.006	0.007	0.048	0.045	0.009	0.008	0.061	0.062	0.067	0.072

Variables	Fractional logistic regression DV = UIC breadth				Logistic regression DV = Contractual channels				Logistic regression DV = Relational channels			
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**	**Model 10**	**Model 11**	**Model 12**
	(0.041)	(0.041)	(0.041)	(0.041)	(0.436)	(0.439)	(0.443)	(0.447)	(0.168)	(0.168)	(0.168)	(0.169)
R&D unit	0.366***	0.366***	0.364***	0.364***	0.601*	0.643*	0.581	0.614*	0.973***	0.967***	0.965***	0.948***
	(0.032)	(0.032)	(0.032)	(0.032)	(0.352)	(0.355)	(0.354)	(0.358)	(0.157)	(0.157)	(0.158)	(0.158)
R&D intensity	0.001	0.002	-0.001	-0.001	0.336	0.366	0.329	0.300	-0.028	-0.025	-0.030	-0.033
	(0.043)	(0.042)	(0.044)	(0.044)	(0.281)	(0.277)	(0.281)	(0.284)	(0.152)	(0.152)	(0.151)	(0.151)
OBM	0.156***	0.155***	0.156***	0.157***	-0.186	-0.170	-0.213	-0.224	0.080	0.090	0.088	0.091
	(0.031)	(0.031)	(0.031)	(0.031)	(0.268)	(0.269)	(0.270)	(0.272)	(0.114)	(0.115)	(0.114)	(0.115)
Grant	0.625***	0.622***	0.621***	0.618***	0.876***	0.880***	0.843***	0.849***	0.515***	0.513***	0.514***	0.527***
	(0.049)	(0.049)	(0.049)	(0.049)	(0.253)	(0.255)	(0.253)	(0.258)	(0.167)	(0.167)	(0.167)	(0.168)
Uni Imp	0.204***	0.205***	0.206***	0.207***	0.505***	0.501***	0.514***	0.543***	0.151**	0.158**	0.151**	0.159***
	(0.018)	(0.018)	(0.018)	(0.018)	(0.105)	(0.104)	(0.106)	(0.112)	(0.061)	(0.061)	(0.061)	(0.061)
Knowledge intensity	-0.065**	-0.066**	-0.065**	-0.064*	-0.419	-0.422	-0.477	-0.517	0.325	0.329	0.339	0.346
	(0.033)	(0.033)	(0.033)	(0.033)	(0.535)	(0.533)	(0.546)	(0.550)	(0.274)	(0.275)	(0.274)	(0.274)
Year 2017	-0.116***	-0.122***	-0.119***	-0.126***	-1.097***	-1.134***	-1.121***	-1.153***	0.514***	0.501***	0.512***	0.502***
	(0.033)	(0.033)	(0.033)	(0.033)	(0.196)	(0.198)	(0.197)	(0.201)	(0.086)	(0.086)	(0.086)	(0.087)
Year 2018	-0.075**	-0.079**	-0.080**	-0.082**	-0.291*	-0.327*	-0.299*	-0.325*	0.128	0.123	0.122	0.124
	(0.035)	(0.035)	(0.035)	(0.035)	(0.170)	(0.172)	(0.170)	(0.173)	(0.085)	(0.085)	(0.085)	(0.085)
Constant	-3.754***	-3.799***	-3.782***	-3.810***								
	(0.067)	(0.071)	(0.068)	(0.075)								
QIC	6348.88	6348.94	6348.54	6378.75								
Wald Chi^2	1508***	1491***	1495***	1510***	143.9***	148.1***	146.7***	155.1***	185.4***	189.5***	189.4***	198.0***
Pseudo R^2					0.232	0.238	0.236	0.250	0.0821	0.0839	0.0838	0.0876
Log-likelihood					-238.7	-236.6	-237.3	-233.1	-1037	-1035	-1035	-1031
No. of observations	10,800	10,800	10,800	10,800	860	860	860	860	3,141	3,141	3,141	3,141

Standard errors are reported in parentheses, DV = Dependent variable

* significant at $p < 0.1$, ** significant at $p < 0.05$, *** significant at $p < 0.01$

4.5.3 Post hoc analysis

4.5.3.1 The breadth of contractual governance versus breadth of relational channels

The main analysis revealed that the moderating effects of being a product or process innovator existed for the collaboration through relational channels, but no evidence for contractual channels. This study conducted additional investigation by introducing two dependent variables – the breadth of contractual channels and the breadth of the relational channel – captured by the sum of associated UIC channels expressed as a fraction. In Appendix E.1, focusing on the interaction terms associated with appropriability squared, being a process innovator exhibited a convex relationship for contractual channels (Model 1, b = 0.024, p < 0.05). Consistent with the results when the dependent variable is the propensity, being a product innovator exhibited an inverted U-shaped relationship for relational channels (Model 2, b = -0.010, p < 0.05). Figure 4.5 and Figure 4.6 helped illustrate the findings. Importantly, the findings add to previous findings associated with the UIC breadth (Hypotheses 2a and 2b) that a product or process innovator not only moderates the impact of a firm's appropriability on the breadth of UIC, but also differs when going deeper into the breadth of different forms of UIC governance. In particular, the moderating effect of being a product innovator is present in the relational channels, while the moderating effect of being a process innovator is found in the contractual channels.

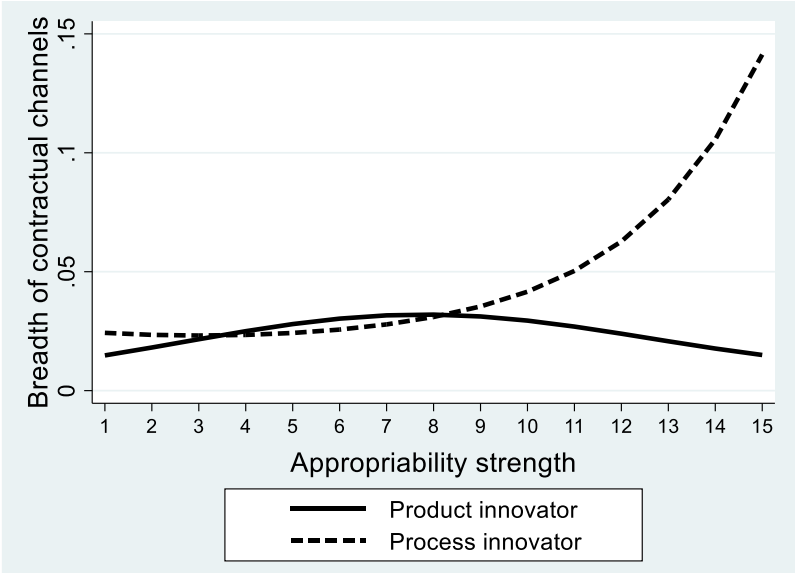

Figure 4.5 Relationship between firms' appropriability strength and the breadth of contractual channels

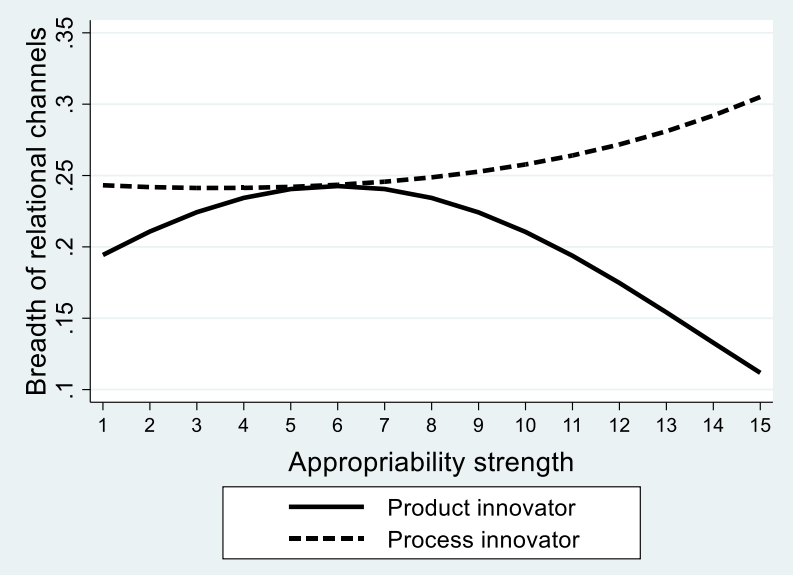

Figure 4.6 Relationship between firms' appropriability strength and the breadth of relational channels

4.5.3.2 The effects of a firm's appropriability on an engagement with other external partners

The results from the main analysis revealed that the firm's decision to engage with universities depends on its appropriability strength. While one explanation may lie in the firm's appropriability strategies, another may be sought from how a firm chooses partners for its R&D cooperation. This study, hence, investigated the impact of appropriability on the propensity to engage with other R&D partners. In Appendix E.2, Model 8 reports a negative effect of appropriability squared on the propensity to collaborate with suppliers (b = -0.032, p < 0.01) indicating an inverted U-shaped relationship, illustrated in Figure 4.7. There was no evidence showing an impact of appropriability on a firm's engagement with customers, public research institutes, and other companies (Appendix E.3). Additionally, in Appendix E.4, there were positive relationships between a firm's appropriability strength and the propensity to collaborate with consultants (Model 1, b = 0.172, p < 0.10) and competitors (Model 5, b = 0.247, p < 0.05) illustrated in Figure 4.8.

Figure 4.7 presents that firms generally had a lower interest in collaboration with suppliers than with universities at every point on the appropriability scale. Particularly after a point of 10 on the appropriability scale, collaborating with the suppliers is increasingly unattractive for firms compared with collaboration with universities. On the other hand, Figure 4.8 depicts that, as the appropriability strength increased, firms tended to collaborate with consultants and competitors. The results help explain the findings from the main analysis and are discussed in the next section.

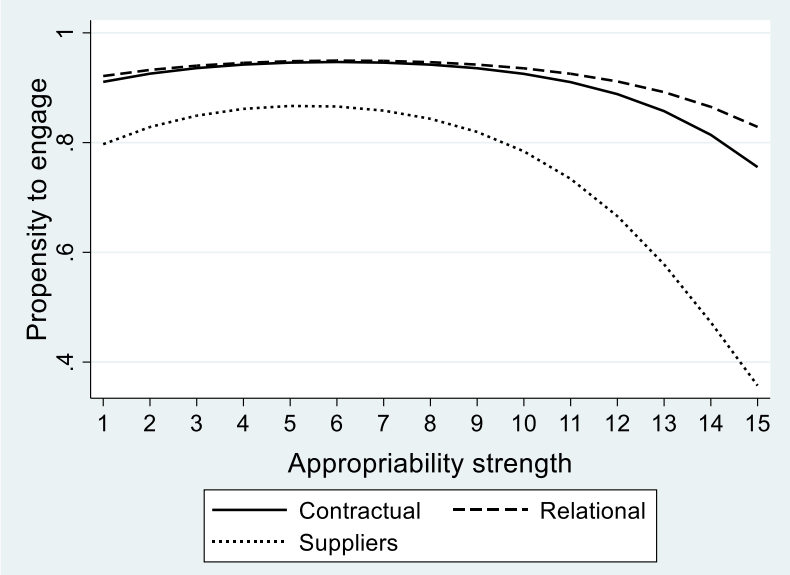

Figure 4.7 Relationship between firms' appropriability strength and the propensity to engage with universities and suppliers

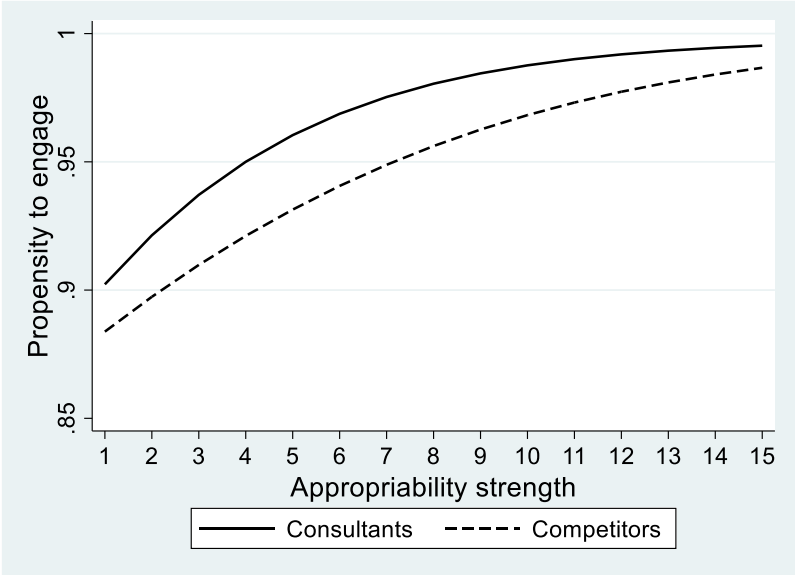

Figure 4.8 Relationship between firms' appropriability strength and the propensity to engage with consultants and competitors

4.6 Discussion

Despite several studies of firms' appropriability in the UIC context, existing research is biased towards a linear perspective and the findings from the previous studies remain controversial (see, e.g., Veugelers and Cassiman, 2005; Aristei *et al.*, 2016; Roud and Vlasova, 2020). This study explores the impact of a firm's appropriability on the openness in the UIC, expressed as the breadth and propensity to engage in contractual or relational

governance mode in view of a non-linear relationship. The results are summarised and presented in Table 4.11. Importantly, this study reveals that the relationship between the firm's appropriability strength and the firm's engagement with universities is curvilinear, thus reconciling the mixed results in the literature. Furthermore, this paper underlines that the effects of the firm's appropriability strength on openness in the UIC are contingent on whether a firm is a product innovator or a process innovator. The results are further discussed below.

Table 4.11 Summary of the results in Paper 3

	UIC breadth	The propensity of a firm's engagement	
		Contractual channels	**Relational channels**
Appropriability	• Inverted U-shaped relationship	• Inverted U-shaped relationship	• Inverted U-shaped relationship
a product innovator as a moderator	• Strengthening an inverted U-shaped relationship • The inverted U-shaped relationship is prominent when focusing on the breadth relational channels	• Not applicable	• Inverted U-shaped relationship
a process innovator as a moderator	• U-shaped relationship • The U-shaped relationship is prominent when focusing on the breadth of contractual channels	• Not applicable	• Negative relationship

For ease of discussion, this paper divides 15 points of the appropriability scale into a low level (score from 1 to 9) and a high level (score from 10 to 15). Three types of firms are also introduced.

- *Type I (Less innovative firms with a low level of appropriability strength)*. These firms have any IPRs, solely or in combination, *except patents*. Located in developing countries with weak IP regimes, they are generally less innovative to apply for a patent (Kammoun and Rahmouni, 2014), and may rely on other IPRs such as trademark and design as well as informal appropriability (e.g., secrecy) as sources of competitiveness Barros, 2021.
- *Type II (innovative firms with a low level of appropriability strength).* These firms at least have a patent, solely or in combination with other IPRs, which reflects their innovation capability (Hall *et al.*, 2014; Wang *et al.*, 2017).
- *Type III (innovative firms with a high level of appropriability strength).* Firms have a patent and several IPRs in combination. These firms can be more innovative than other types. They also perceive IPRs as sources of competitive advantages and

thus adopt several IPRs to benefit from economies of scope when managing issues related to IPRs (Pitkethly, 2001).

4.6.1 To what extent does a firm's appropriability strength affect a firm's decision to engage in the UIC?

The findings reveal that the relationship between a firm's appropriability strength and an engagement in the UIC is an inverted U-shaped relationship, similar to the literature on R&D cooperation (Huang *et al.*, 2014; Laursen and Salter, 2014; Yu *et al.*, 2020). *Type I* and *Type II* firms may proactively seek technological knowledge from universities to compensate for their low level of innovation capabilities (Henkel, 2006; Laursen and Salter, 2014). However, since *Type II* firms have at least *a patent* which is an active and voluntary form of knowledge disclosure, they may use patents for signalling their innovation capabilities to attract potential university partners, particularly prestigious universities (Fontana *et al.*, 2006). Thus, at a low level of appropriability strength, firms (both *Type I* and *Type II*) increase the number of UIC channels as appropriability strength increases since a greater breadth of UIC channels is highlighted as facilitating the development of technological capabilities (de Wit-de Vries *et al.*, 2019), and reducing the conflicts of interest between partners (D'Este and Patel, 2007).

In contrast, *Type III* firms tend to lower their interest in collaborating with university partners as well as reducing the number of UIC channels possibly due to *two* reasons. *First*, firms may strongly rely on the *'defensive IP strategy'* by adopting various IRRs to avoid knowledge spillovers and thus build barriers to competition (e.g., Huang *et al.*, 2014; Laursen and Salter, 2014). Given an attitude towards protectionism, these firms may demand more legal requirements from their partners (Chesbrough, 2006; Laursen and Salter, 2014; Yu *et al.*, 2020) and unintentionally signal mistrust to partners, thus preventing knowledge sharing (Miozzo *et al.*, 2016; Wang *et al.*, 2017). *Second*, firms may employ an '*impromptu strategy of IP'* – i.e. registering IPRs without any clear appropriability strategy (Grimaldi *et al.*, 2021). This strategy creates a barrier to knowledge since firms with no strategy to capture value from their inventions may rely on their own internal R&D and reject other partners (Laursen and Salter, 2014). In addition, regardless of any strategies, maintaining a variety of IPRs and excessive UIC breadth in conjunction is costly in terms of coordinating and controlling existing IPs as well monitoring knowledge leakage in all collaboration channels (Bruneel *et al.*, 2010; Huang *et al.*, 2014). Thus, firms with stronger appropriability strength tend to limit the number of UIC channels to reduce the overall cost.

Compared with relational channels, firms' propensity to engage contractual channels is always lower in any level of appropriability strength (Figure 4.2). This may be because engaging in relational channels is easier and cheaper than engaging in contractual

channels. Particularly, if knowledge leakage is the main concern, firms relying on protectionism may remain engaged in relational channels to build trust with universities as a foundation for contractual governance (Garcia-Perez-de-Lema *et al.*, 2017).

The post hoc analysis reveals intriguing findings that, at a greater level of appropriability strength (*Type III*), while firms are less likely to collaborate with universities (Figure 4.7), they are prone to collaborate with competitors and consultants (Figure 4.8). It may be that firms are more *pecuniary*-oriented and, therefore, adopt the '*selling'* approach in light of *outbound open innovation* by licensing out their IPs in the marketplace (Dahlander and Gann, 2010). Although this approach is infrequently employed, its financial contributions are generally larger than the income derived from the exploitation of external knowledge in the inbound open innovation (Ahn *et al.*, 2016). Therefore, compared with collaboration with universities, firms with strong appropriability may be better off selling IPs to their rivals. Accordingly, sufficient appropriability mechanisms ensure the effectiveness of knowledge protection between firms and competitors (Ritala and Hurmelinna-Laukkanen, 2009). In addition, since co-creation with competitors is not easy, consultants (e.g., technology and business service providers, intellectual property organisations, industry associations, etc.) could play an auxiliary role in helping to smooth the collaboration and IP-related processes (Chen *et al.*, 2016).

4.6.2 To what extent does being a product innovator or a process innovator moderate a relationship between a firm's appropriability strength and the UIC breadth?

The findings reveal that being a product innovator exhibits an inverted U-shaped relationship between appropriability strength and UIC breadth while being a process innovator weakens that relationship by showing a convex shape. The results are opposite to Yu *et al.* (2020) which focused on the impact of a firm's appropriability on *openness* in R&D cooperation with multiple partners. However, these opposing findings should be regarded as specific for the UIC context.

At a low level of appropriability strength, product innovators (*Types I and II*) may use formal appropriability mechanisms to signal their innovation capabilities to attract university partners or obtain funding from the government for collaborative projects with universities. However, at a higher level of appropriability strength, product innovators (*Type III*) are likely to limit their range of UIC channels probably due to the costs arising from managing existing IPRs (Huang *et al.*, 2014), a combination of firm's and university's technological knowledge (Lin, 2017), and dealing with IP issues in the collaboration (Bruneel *et al.*, 2010) which in turn outweighs the benefit from a greater breadth of UIC channels. Kafouros *et al.* (2015) revealed that over-engaging with universities may diminish a firm's innovation performance,

particularly in developing countries with a weak appropriability regime, due to limited absorptive capacity. This is later evidenced by Hu *et al.* (2020) showing that firms can only benefit from engaging with universities in a single or a few channels in terms of product innovation performance. Therefore, in addition to the issues relevant to the IPRs, excessive UIC breadth causes cooperation with universities that is unattractive for a product innovator.

In contrast to product innovator, the relationship between a firm's appropriability strength and UIC breadth is U-shaped for a process innovator. Figure 4.3 shows that an inverted U-shaped curve is imperfect, indicating that firms (*Types I and II*) remain engaged in the same number of UIC channels at the low level of appropriability strength. In this case, it is plausible that formal appropriability may not influence a process innovator's decision regarding the expansion of the UIC breadth since process innovation is more internally focused (Un and Asakawa, 2015) and often protected by informal appropriability mechanisms (Holgersson and Wallin, 2017; Paula and Da Silva, 2019). On the other hand, a process innovator with stronger appropriability strength (*Type III*) tends to widen the range of UIC channels. Although the acquisition of IPRs may be more critical for product innovation while process innovation is more effectively protected by informal appropriability, this paper speculates that in this case, a process innovator may be oriented towards not only process but also product innovation. Hence, a process innovator develops innovation capabilities, come up with inventions, and then apply IPRs to signal *product innovation capabilities* to gain attention from university partners or attract government funding for UIC projects, resulting in a greater breadth of UIC channels. Regarding process innovation, collaboration through multiple UIC channels accumulates a firm's collaboration experiences and organisational memory, thus fostering *absorptive capacity* (Zahra and George, 2002) which is crucial for achieving process innovation when engaged in the UIC (Aliasghar *et al.*, 2019).

4.6.3 To what extent does being a product innovator or a process innovator moderate a relationship between a firm's appropriability strength and an engagement in contractual or relational governance?

Going deeper into the governance modes, the analysis only reveals the moderating effects of being a product innovator or a process innovator on the relationship between a firm's appropriability strength and propensity to engage in *relational channels*. Figure 4.4 shows that at a low level of appropriability strength, a product innovator (*Types I and II*) slightly increases the propensity to collaborate with university partners. For this case, formal appropriability may be mainly used for signalling a firm's innovation capabilities to collaborate with universities rather than rigidly protecting knowledge. In addition, relational channels are aimed at building trust and a rudimentary path to contractual channels (Garcia-

Perez-de-Lema *et al.*, 2017). On the contrary, when appropriability strength increases, a product innovator (Type *III*) is dramatically less interested in engaging in relational channels. Firms that are product innovation-oriented often seek to be the first mover in the market (Short and Payne, 2008), and thus may obtain IPRs in response to defensive IP strategy. Since knowledge in relational channels is insufficiently protected (Fassio *et al.*, 2019) and translated into product innovation when compared with contractual channels (Garcia-Perez-de-Lema *et al.*, 2017), relational channels are thus unattractive for a product innovator with strong appropriability strength.

On the other hand, the results reveal that a process innovator is unlikely to employ relational channels as appropriability strength gets stronger (Type *III*). A process innovator can adequately rely on informal appropriability mechanisms to protect process innovation knowledge so that formal appropriability mechanisms may not significantly matter for process innovation. However, recalling the argument previously proposed in Section 4.6.2, a process innovator with strong appropriability strength may be inclined to employ a '*dual strategy of innovation'* – i.e. pursuing both product and process innovation (Henao-García and Montoya, 2021). It is evidenced by the results from the post hoc analysis that while process innovators decrease the likelihood to collaborate in the relational channels as their appropriability gets stronger (Figure 4.4), they instead *switch* to contractual channels as observed from an expansion of the UIC breadth (Figure 4.5). It can be implied that process innovators may have a stronger level of innovation capabilities and thus, pursue a *dual strategy of innovation* by focusing on both product and process innovations (Henao-García and Montoya, 2021), thus employing contractual governance which contributes to exploratory research and the product novelty more than relational governance.

4.7 Conclusions of the chapter

This paper investigates the impact of firms' formal appropriability strength on firms' engagement in UIC. Based on the analysis of 10,860 manufacturing firms in the Thailand Community Survey, the findings reveal that the relationship between the firm's appropriability strength and the firm's engagement in the UIC (both breadth and propensity to employ either contractual or relational governance) is inverted U-shaped. Having investigated the firm heterogeneity of innovation, a product innovator strengthens an inverted U-shaped relationship between appropriability strength and UIC breadth while being a process innovator weakens that relationship by exhibiting a convex shape. While excessive appropriability discourages a product innovator to engage in relational channels, a process innovator tends to shift its interest from relational channels to contractual channels.

This study makes several contributions to the UIC literature. *First*, this paper investigates the relationship between a firm's appropriability and openness in the UIC from a non-linear perspective while the majority of studies are biased towards a linear relationship. This study confirms an inverted U-shaped relationship and thus reconciles the conflicting findings relevant to the legal protection methods and openness in the UIC (see, e.g., Veugelers and Cassiman, 2005; Roud and Vlasova, 2020 López, 2008; Abramovsky *et al.*, 2009). *Second*, this paper deepens the openness in the UIC into different governance modes and breadth of collaboration. *Third*, this study reports that the effect of a firm's appropriability on the engagement in the UIC is contingent on whether a firm is a product innovator or a process innovator, pointing out the need for consideration of the firm's innovation capabilities and appropriability in tandem.

This study offers several policy implications. It is a vital concern for policymakers to recognise that a firm's appropriability is an antecedent of a firm's engagement in the UIC and a proper way to understand the relationship between them is through an inverted U-shaped function. There is no *one-size-fits-all* approach to appropriability and openness in the UIC and thus public policies should be tailored to fit with a firm's characteristics. Given that firms with weak appropriability - i.e. obtaining a few intellectual property rights (IPRs), tend to engage with universities, the government should provide supporting infrastructure as well as stimulate universities to engage with industry. Firms with strong appropriability generally have a high level of innovation capabilities which are critical for national technological upgrading (Liefner and Schiller, 2008) but tend to lean towards protectionism or collaboration with competitors. Therefore, to boost the UIC opportunities for firms with strong appropriability, a policy should provide incentives to encourage firms to cooperate with universities and ensure sufficient knowledge protection and benefit-sharing. The policy should also spur universities to proactively seek potential industrial partners and propose the projects that outweigh the benefits from cooperation with competitors. This policy should also be targeted at firms that are more oriented to product innovation. Given that the process innovators tend to switch the governance model of the UIC as their appropriability strength changes, an advocate for a variety of UIC channels for process innovators can be beneficial.

From a management perspective, in seeking cooperation with universities, firm managers should be cautious about their influence of appropriability strength on the decision to engage in UIC. Particularly, strengthening appropriability strength by obtaining a few IPRs not only helps ensure sufficient knowledge protection, but also signals the firm's innovation capability to attract potential university researchers, and increase opportunities to collaborate through a variety of UIC channels. In contrast, the downsides of a firm's excessive appropriability strength should be considered with caution. To be specific, if a

firm aspires to promote knowledge spillovers and exchanges with the university, the control over legal protection methods should be somewhat relaxed. Firms that are more oriented to product innovation need to be sensitive to the negative side of excessive protectionism whereas firms mainly pursuing process innovation can rely on informal appropriability mechanisms (e.g., secrecy), and also widen their range of registered IP to increase opportunities to collaborate with universities through multiple forms, particularly in contractual channels.

This paper is not free of limitations. *First*, this paper captures appropriability only from the use of legal protection methods and thus suggests that future studies include informal appropriability mechanisms. *Second*, the explanation in this paper is mainly based on a firm's IP strategies (e.g., defensive versus collaborative) without empirical evidence due to the unavailability of the data. Thus, incorporating the firm's IP strategies is recommended for enriching the results in line with Hurmelinna-Laukkanen (2011). *Third*, as argued by D'Este and Patel (2007), breadth of collaboration alone may not efficiently capture a variety of UIC channels and, therefore, measures such as the dept of collaboration captured through the frequency of the interactions may be included within the framework of this study. *Last*, future research should use alternative methodological approaches such as in-depth interviews or mixed methods as well as replicating this study across other countries and sectors to permit greater generalisability of the results.

Chapter 5 Conclusions

5.1 Objectives and findings

This PhD thesis is motivated by a growing amount of literature focusing on the university-industry collaboration (UIC) as important means to create knowledge spillovers and improve technological upgrading in a national economy (Eun *et al.*, 2006; D'Este and Patel, 2007; Liefner and Schiller, 2008; Hemmert *et al.*, 2014). In particular, the thesis aims to open up ongoing debates *on what drives a firm and a university to engage in the UIC and what makes the UIC successful* by focusing on a firm's *capabilities* and *appropriability*. To achieve the purpose, this thesis undertakes a collection of three papers. The *first* paper employs a systematic literature review to explore ambiguities and complexities in the debate on the relationship between a firm's and a university's capabilities and their performance in the UIC context. The *second* paper investigates the effects of a firm's technological and non-technological innovation capabilities (ICs) on its innovation performance when engaged in different UIC channels. Finally, the *third* paper investigates the effect of a firm's appropriability on the collaboration with universities expressed as the propensity to adopt contractual and relational channels and the breadth of the UIC.

The findings from a systematic literature review reveal that UIC scholars have examined various kinds of a firm's and a university's capabilities and performance, mostly captured by quantifiable measures. In addition, a firm's absorptive capacity is confirmed to be a prerequisite for absorbing and exploiting a university's knowledge successfully which its effects are contingent on several factors (e.g., market competition, proximity, knowledge explicitness, uncertainties, UIC channels and collaboration objectives). Similarly, the literature agrees that a university's research capabilities, at the individual, faculty, and university level, are crucial to attaining academic and commercial outcomes. Especially at the early and commercialisation phases of development, a firm's non-technological capabilities and a university's research capabilities (e.g., management and marketing capabilities) are critical for UIC success.

This thesis synthesises and consolidates the findings from a systematic review into a framework that points out several under-researched areas. For example, *first*, future work is encouraged to measure and analyse absorptive capacity from the dynamic view following prior studies (Brehm and Lundin, 2012; Melnychuk *et al.*, 2021). *Second*, scholars should measure performance as a direct result of the UIC and include spillovers as well as other *soft* performance measures (e.g., collaboration partners' satisfaction or relationship productivity) as a construct of UIC success. *Third*, a firm's non-technological capabilities

and a university's non-research capabilities should receive more scholarly attention for empirical investigation. *Fourth*, the complementary effects of different capabilities of a firm and a university on their performance when engaged in the UIC are inadequately explored. *Fifth*, future work should pay more attention to the bidirectional relationship – i.e. knowledge exchange. A synergy effect between a firm's absorptive capacity and a university's desorptive capacity on UIC performance should be a promising research area.

Based on the empirical results, there is insufficient evidence to support that a firm can benefit from its technological ICs in improving its performance when engaged in the UIC; this is possible because a firm in the countries where the UIC is emerging and immature, mostly developing countries, is mainly a user of a university's knowledge (Arnold *et al.*, 2000), and its technological ICs (e.g., organisational and marketing ICs) are often substituted by the cooperation with universities (Eom and Lee, 2010). Instead, a firm can benefit from its non-technological ICs depending on which UIC channels are employed. For instance, organisational IC allows a firm that engages in a research partnership to have sufficient flexibility and innovative strategy for a collaborative project associated with blue-sky research (Bierly *et al.*, 2009). This also holds for a firm with organisational IC that uses a university's facilities and outsource its R&D activities (e.g., calibration of equipment or product testing). A firm's marketing IC also helps it to make the solutions financially visible when using a university's consulting or making a research contract with a university.

Nevertheless, the effects of a firm's non-technological ICs are a double-edged sword. A firm's marketing IC diminishes its innovation performance when engaged in collaborative research since a firm may reject the projects too soon if the commercial values are not warranted (Vaculík *et al.*, 2019; Greco *et al.*, 2020). Similarly, in *human resource transfer* (e.g., placement, mobility, conference, meeting, and informal contact), overemphasising marketing IC may lead to some issues such as the *not-invented-here syndrome* - i.e. firms are short-sighted when it comes to strong market knowledge, thus undervaluing knowledge mobilised by university researchers. Firm managers are thus recommended to avoid a one-size-fits-all approach and to steer a firm's different ICs to the right UIC channels in which a firm's innovation performance is increasingly improved.

This thesis confirms that a firm's appropriability acts as a driver for a firm engagement with a university. Specifically, the relationship between a firm's appropriability strength and its engagement with universities is inverted U-shaped. Particularly, at a low level of a firm's appropriability strength, a firm may proactively seek technological knowledge from universities to compensate for its low level of innovation capabilities or use its IP to signal innovation capability to attract potential university partners. In contrast, at a higher level of appropriability strength, a firm may obtain IPRs to exercise 'protectionism' – i.e. employing the '*defensive IP strategy*', to build barriers to competition and to rely on its

in-house R&D. For alternative explanation, thanks to the inbound open innovation, since the financial contributions from a firm's rival are generally large, cooperation with (or selling IPs to) competitors may be more attractive than with universities (Ahn *et al.*, 2016) meanwhile a firm can get support from technology and business consultants. A firm's propensity to adopt contractual governance is lower than in relational governance regardless of appropriability strength. Engaging in relational governance is less complicated and beneficial for a trust-building between a firm and a university, thus often employed as a foundation for contractual governance (Garcia-Perez-de-Lema *et al.*, 2017).

The relationship between a firm's appropriability and its engagement is also contingent on a firm's heterogeneity of innovation orientation. Particularly, a product innovator exhibits the inverted U-shaped relationship between a firm's appropriability and the UIC breadth and its engagement in relational channels. On the contrary, being a process innovator weakens the inverted U-shaped relationship between a firm's appropriability strength and UIC breadth, by exhibiting a convex shape.

To be specific, product innovators with a high level of appropriability strength are likely to adopt the IP defensive strategy, thus lowering their engagement with universities. This is possible due to higher costs from managing IPRs and knowledge in the collaboration (Bruneel *et al.*, 2010; Huang *et al.*, 2014; Lin, 2017), or the risk of knowledge leakage when engaged in relational governance (Fassio *et al.*, 2019). While this phenomenon is also similar in the case of process innovators, process innovators' interest in engaging with universities switches from relational governance to contractual governance as appropriability strength increases. In other words, process innovators with a high level of appropriability strength may employ a *dual strategy of innovation* – i.e. focusing on both product innovations and process innovations (Henao-García and Montoya, 2021), thus employing contractual governance as it delivers more product novelty than relational governance.

Overall, this thesis uncovers the ambiguities regarding the measures and effects of a firm's and university's capabilities on their performance when engaged in the UIC. This thesis also highlights the impact of a firm's non-technological capabilities on its performance which is conceptually acknowledged but receives less attention from empirical research. This thesis additionally takes a step forward in reconciling the inconsistent findings in the literature on the relationship between a firm's appropriability and its engagement with a university, which is highly biased towards a linear assumption. More importantly, while most relevant literature is based on *developed countries*, this thesis provides insights from developing countries where the relevant topics remain poorly understood. Figure 5.1 presents the interconnections among the thesis's objectives, findings, theoretical contributions, and practical implications.

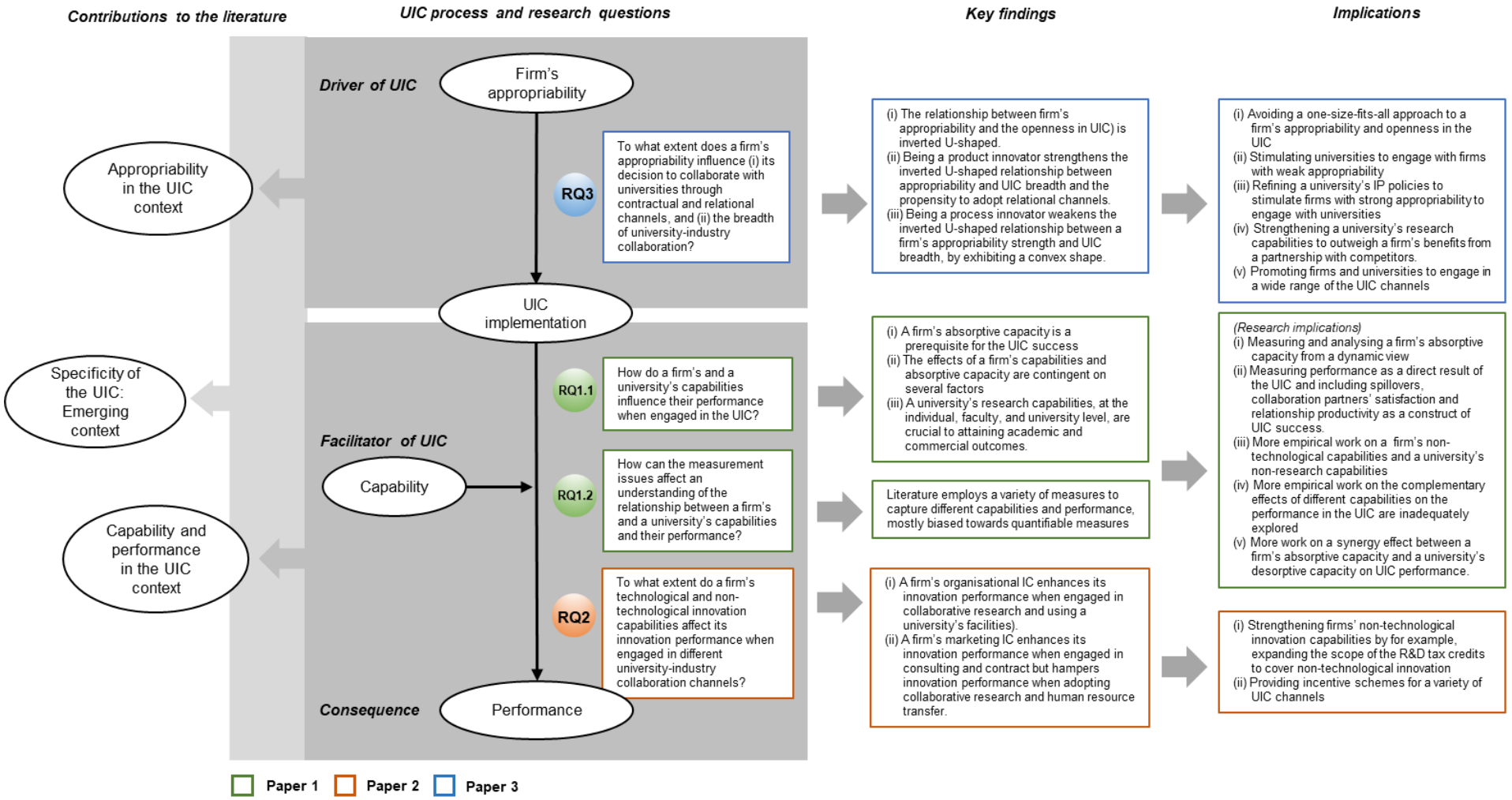

Figure 5.1 Summary of thesis

5.2 Theoretical contributions

This thesis claims to make theoretical contributions to three streams of literature.

5.2.1 Contributions to the literature on capability and performance in the UIC context

This thesis adds to prior reviews on the UIC (see, e.g., Ankrah and Al-Tabbaa, 2015; Nsanzumuhire and Groot, 2020) by conducting a systematic literature review on the relationship between capabilities and performance in the UIC context from both a firm's and a university's perspectives. Specifically, this thesis elucidates *what is known* about capabilities in terms of measures, effects on performance, and a relationship between capabilities and other relevant factors. The review illustrates where the knowledge is fragmented and conflicting which can be theoretical and empirical obstacles for progressing further research in the field. Importantly, this thesis takes one step beyond a simple review by establishing a framework that underpins key components in the relationship between capability and performance and points out *what is poorly known or unknown* in the literature, thus offering several avenues for future research.

This thesis also contributes to the UIC literature on the impact of a firm's capabilities on its innovation performance by providing insights from the empirical research (see, e.g., Kobarg *et al.*, 2018; Apa *et al.*, 2020; Guerrero and Urbano, 2021; Melnychuk *et al.*, 2021). Specifically, this thesis substantiates the theoretical argument on the importance of a firm's technological and non-technological components on its innovation creation under the UIC implantation (Dill, 1990; Etzkowitz and Leydesdorff, 2000; Perkmann and Salter, 2012). This thesis adds novel insights into the scant body of knowledge on a firm's non-technological capabilities by revealing that a firm can also benefit from its non-technological ICs despite an absent impact of its technological ICs when engaged with a university. This thesis thus echoes prior arguments by providing empirical evidence that a partnership with a university alone cannot guarantee the success of innovation without the presence of innovation capabilities (Choonwoo *et al.*, 2001; Eom and Lee, 2010).

This thesis also responds to the criticism of an overemphasis on specific collaboration channels such as collaborative research and patenting, and a lack of an investigation into various knowledge transfer activities, particularly into informal linkages between an industry and a university (Choonwoo *et al.*, 2001; Arvanitis and Woerter, 2009; De Fuentes and Dutrenit, 2012; Kafouros *et al.*, 2015) by embracing a diverse range of UIC channels in all three papers. The results of this thesis substantiate the theoretical arguments stating that *different types of firm's capabilities are more critical for some UIC channels than*

others (see, e.g., Arza and Vazquez, 2012; Brehm and Lundin, 2012; Dezi *et al.*, 2018; Fudickar and Hottenrott, 2019; Apa *et al.*, 2020).

5.2.2 Contributions to the literature on appropriability in the UIC context

This thesis makes advancements in the UIC research by shedding light on the existence of such *a paradox of openness* (i.e. a firm's dilemma of sharing versus protecting knowledge when engaged in external collaboration) in the context of UIC; this can be captured through a firm's appropriability strength, similar to studies elsewhere (Laursen and Salter, 2014; Yu *et al.*, 2020). Specifically, this thesis reconciles the conflicting findings relevant to equivocal effects of a firm's formal appropriability on its decision to partner with universities (see, e.g., Veugelers and Cassiman, 2005; Roud and Vlasova, 2020 López, 2008; Abramovsky *et al.*, 2009) by showing that acquisition of IPRs does not always encourage firms to collaborate with universities as evidenced by an inverted U-shaped relationship between a firm's appropriability and its openness in the UIC. On the other hand, moderate strength of a firm's appropriability is likely to motivate firms to engage in the UIC. This thesis further advances the UIC literature on the appropriability-openness relationship by revealing that this relationship is contingent on whether a firm is a product innovator or a process innovator. One of the unique findings is that a process innovator tends to behave strategically by shifting its interest in engaging with university partners through relational governance to contractual governance as appropriability strength gets stronger.

While most literature focuses only on whether a firm engages with a university or not, this thesis shows that it is insufficient for understanding how a firm's appropriability influences its engagement with universities since a firm's decisions on electing *the governance modes* of UIC or widening its *UIC breadth* are contingent upon its firm's appropriability (Bruneel *et al.*, 2010; Garcia-Perez-de-Lema *et al.*, 2017). Importantly, the diversity in terms of UIC activities should not be considered in isolation when it comes to an exploration of such issues relevant to a firm's appropriability in the UIC context.

5.2.3 Contributions to the literature on emerging UIC

This thesis contributes to a better understanding of emerging UIC – i.e. of those countries where the UIC is emerging and under-researched. Thailand is selected as a case study of emerging UIC due to its similar characteristics to other countries with immature UIC. This thesis *first* shows that in the countries with emerging UIC where the appropriability regime is weak, even a strong level of legal protection methods may not ensure sufficient knowledge protection, thus discouraging a firm from engaging with academic partners. On the contrary, although a firm mostly relies on its informal appropriability conditions, it is likely to partner with universities if being incentivised to obtain IPRs. *Second*, this thesis also

uncovers the black box regarding an insignificant impact of a firm's technological capabilities on its performance when engaged with universities (e.g., Su *et al.*, 2009; Eom and Lee, 2010; Xu *et al.*, 2011; Chen *et al.*, 2016) by revealing that a firm in the countries where the UIC is immature can benefit from its non-technological ICs despite the absent impact of its technological ICs. *Last*, insights from the empirical work are expected to greatly contribute to scholars and policymakers in Thailand as well as other countries with the emerging UIC, who are striving to strengthen the UIC as an important means to escaping the middle-income trap (Intarakumnerd, 2017; Shin and Limapornvanich, 2017; Intarakumnerd and Liu, 2019).

5.3 Practical implications

5.3.1 Policy implications

The thesis offers several implications for policymakers. *First*, the results from the review suggest that policymakers take the indicators of capabilities and performance as a guide to establish a robust assessment for strengthening the UIC in their countries and for selecting the recipients of the grants for UIC projects. Adopting multiple and more sophisticated indicators besides common measures (e.g., a firm's R&D intensity and academic publication intensity) is recommended.

Second, the government should attach importance to promoting the UIC. In addition to fundamental factors as an antecedent of the UIC, the UIC policy can also be tailored to suit a firm's appropriability strategy. In other words, policymakers should thus avoid a one-size-fits-all approach to a firm's appropriability and its openness in the UIC. Government should also design policies to suit a firm's characteristics.; for instance, the government can provide supporting infrastructure as well as stimulate universities to engage with firms with a weak appropriability as they tend to engage with universities for seeking opportunities to enhance their innovation capabilities. On the contrary, for a firm that is oriented towards protectionism as reflected by its strong appropriability, instruments should stimulate its engagement in the UIC and refine a university's policies regarding knowledge appropriation and IP ownership. Since universities may become unattractive partners for firms with strong appropriability, therefore, policymakers should incentivise universities to reimage themselves by strengthening research capabilities, proactively seeking potential industrial partners, and proposing commercial and achievable projects which in turn outweighs the benefits from a partnership with competitors. This thesis stresses a need to implement this policy as a priority since a drawback of excessive appropriability strength is more pronounced for product innovator firms.

Third, policies should aim at strengthening a firm's capabilities. Given the results from Paper 2, policymakers should bear in mind that a firm can succeed in R&D cooperation with universities only with the presence of its non-technological innovation capabilities (ICs). Policymakers should expand the scope of the R&D tax credits to cover a firm's non-technological innovation activities or provide a research grant for the development of non-technological innovation to stimulate a firm to build its non-technological ICs.

Fourth, the policy should support a wide range of the UIC channel. This suggestion is strengthened by the findings that process innovators tend to switch from relational channels to contractual channels as their appropriability strength gets stronger. In addition, given that the effects of a firm's non-technological ICs are contingent on UIC channels, incentive schemes such as funding should not be granted to only collaborative research projects but also should be available to other channels. Notwithstanding, the government should encourage universities to implement UIC policies that encompass the diversity of collaboration activities and incentivise firms to employ UIC channels based on their needs and capabilities.

Last, this thesis provides suggestions for policies in the countries where the UIC is emerging and immature like Thailand. Given that Thai firms do not benefit from their technological innovation capabilities possibly due to their lack of technological ICs, policies should be aimed at strengthening a firm's technological capabilities by encouraging it to increase R&D spending and to advocate for science and technology research. This is critical for such countries in which the UIC is being promoted as a means of upgrading to the higher-value segment of economic activity and overcoming the middle-income trap (Asian Development Bank, 2015). To achieve this, policy should also depart from a knowledge-push model – i.e. universities act as knowledge producers while firms are knowledge users. Incentives should be provided to support bidirectional flows of resources and capabilities between firms and universities (Schaeffer *et al.*, 2021).

5.3.2 Managerial implications

From a management perspective, managers seeking cooperation with universities to level up a firm's capabilities or pursue knowledge co-creation should be aware of the influence of appropriability. A firm with weak appropriability should strengthen its appropriability by obtaining IPRs. This will encourage a firm to improve its innovation capabilities and also signal innovation capabilities to attract potential university researchers. In contrast, a firm with strong appropriability, especially a product innovator firm, should be cautious about the downsides of excessive appropriability. To be specific, a firm is suggested relaxing its orientation towards protectionism. Process innovators should also acquire IPRs in addition

to informal appropriability mechanisms as found beneficial in increasing opportunities to collaborate with universities in contractual channels.

When the collaboration agreements are made, firm managers should be aware that the full potential of the UIC can be realised only if they have sufficient ICs. Firm managers should avoid a one-size-fits-all approach and seek the right mix between different ICs and UIC channels. This thesis suggests that firm managers create an innovative culture and corporate strategies and improve their management innovation, particularly which using a university's services (e.g., research contact, consulting and a university's facilities). A firm equipped with such marketing and sales techniques may benefit from the UIC by outsourcing its R&D or technical problems to universities via research contracts or consulting.

Nevertheless, for a firm looking for engaging in research partnership or human resource transfer, it should be cautious about some issues arising from marketing IC such as *not-invented-here syndrome*, which can be detrimental to its innovation performance. Last, despite the absent effects of a firm's technological ICs on its performance when engaged in the UIC, firm managers should develop both technological and non-technological ICs since they are all-important for in-house R&D. The UIC should be perceived as a means of complementing and improving a firm's internal capabilities, not the core R&D activities (Tsai, 2009).

5.4 Limitations and future research avenues

This thesis has several limitations that provide opportunities for future research avenues. Regarding Paper 1, the *first* limitation is that this paper only selects the articles published in the journals listed in the Academic Journal Guide 2021. Therefore, a future review is suggested considering other journal quality lists such as the *VHB-JOURQUAL* published by the German Academic Association for Business Research (VHB) or the *ABDC* Journal Quality List published by the Australian Business Deans Council, to increase the coverage of relevant papers. *Second*, due to voluminous articles, the scope of this paper is limited to the impact of a firm's and a university's capabilities on their performance. Future should extend the scope of the review to the roles of capabilities as an antecedent of the UIC as addressed by prior studies (see, e.g., de Moraes Silva *et al.*, 2017; De Silva and Rossi, 2018; Orazbayeva *et al.*, 2019). *Third*, besides a firm and a university, future work should include other stakeholders such as technology transfer offices (TTOs) as their capabilities are found as critical for the UIC implementation (e.g., Markman *et al.*, 2005; Soares and Torkomian, 2021). *Fourth*, a systematic literature review is qualitative by nature; thus, researchers are encouraged to employ other quantitative approaches (e.g., a meta-analysis

or bibliographic analysis). *Fifth*, this paper does not review the research philosophy as it is not the scope of the review, and therefore suggests future work to do so. Although most studies do not report explicitly on the research philosophy adopted, further review may possibly infer the research philosophy based on *the problematisation (or theoretical background) and the methodology* of the article. Little is known about what research philosophy is being dominant in the current literature, the research design explained from the view of research philosophy, and possibilities to conduct research in other paradigmatic approaches.

Paper 2 is not free of limitations. *First*, this paper does not investigate the synergy effects between a firm's technological and non-technological innovation capabilities (ICs) despite having been addressed by the non-UIC literature (Gunday *et al.*, 2011; Camison and Villar-Lopez, 2014; Tavassoli and Karlsson, 2015; Lee *et al.*, 2019). Therefore, while the effects of a firm's *technological ICs* are ambiguous, they might instead show a complementary role to a firm's *non-technological ICs*. *Second*, this paper operationalises the variables in a limited capacity due to the nature of the Thai CIS. In addition to sales of new products, future study is suggested using patent counts or the degree of novelty (e.g., incremental versus radical innovation) to capture a firm's innovation performance (Eom and Lee, 2010; Kobarg *et al.*, 2018). Furthermore, a firm's ICs should be captured through the *Likert scale* to improve the construct validity. *Third*, to mitigate simultaneity issues efficiently, future research is suggested using at least three-year lagged variables since most UIC projects are financially measurable during this timeframe (Belderbos *et al.*, 2004). Despite no endogeneity issues, scholars are encouraged to use other instrumental variables such as a top manager's education and the availability of university partners in the region as suggested by Okamuro and Nishimura (2013). *Fourth*, this analysis is only based on a firm's perspective due to the data limitation. Therefore, future research is recommended to incorporate the information from a university's perspective, particularly focusing on the influence of different characteristics of universities. Although public and private universities are well active in engaging with the industry (Kondo, 2008; Lee, 2014), they are different in terms of research capabilities which are likely to influence the firm's performance as well as the UIC outcomes (Klofsten *et al.*, 2019; Ho and Lee, 2021). *Last*, future research should explore the impact of a university's research and non-research capabilities to enrich an understanding of capabilities in the UIC literature. Especially a university's non-research capabilities (e.g., marketing and entrepreneurship capabilities) are addressed as crucial for the UIC, but are often lacking (Ambos *et al.*, 2008; Golish *et al.*, 2008; McAdam *et al.*, 2009).

Regarding Paper 3, *first*, only a firm's formal appropriability is available in the Thai CIS. Therefore, future research is suggested including a firm's informal appropriability mechanisms (e.g. secrecy, complexity, complementary asset, etc.) as found associated

with its cooperation with universities (Roud and Vlasova, 2020) and complementary to formal appropriability methods (Amara *et al.*, 2008). *Second*, scholars should incorporate the dept of collaboration (i.e. the frequency of the interactions) in addition to the UIC breadth as suggested by D'Este and Patel (2007). *Third*, this paper explains the results based on a firm's intellectual property strategies (e.g., defensive and collaborative IP strategies) but falls short in providing empirical evidence due to data limitations. Future work should, therefore, incorporate a firm's intellectual property strategies in the analysis to enrich the findings as suggested by Hurmelinna-Laukkanen (2011).

Regarding the methodological and contextual issues, since Papers 2 Paper 3 are mainly based on a quantitative approach, future work is recommended to employ an in-depth interview or case studies to deepen the findings. In addition, since the Thai CIS provides a limited range of UIC channels, future research should include other UIC channels such as co-PhD supervision and spinoffs. Finally, while the sample is confined to manufacturing firms in Thailand, there may be some effects arising from different contexts (e.g., country and industry sector) that cannot be accounted for. Future studies should replicate the results across countries and sectors to permit more robust comparisons and greater generalisability of the results.

Appendix A Inclusion and exclusion criteria of a systematic literature review

Criteria	Inclusion	Exclusion
Language	Articles published in English	Non-English articles
Type of publication	Peer-reviewed journal articles	Books, working papers, proceedings, grey literature
Field of study (For Scopus)	Business management and accounting, social sciences, economics, econometrics and finance	Other fields of study
Subject *(For Web of Science)*	Management, business, education, educational research, economics, operation research management science, social sciences interdisciplinary	Other subjects
Subject *(For Science Direct and EBSCO)*	Subjects relevant to business management and UIC*	Other subjects
Date of publication	Articles published on any date	None
Journal quality	ABS journal ranking 2015	All other journals
ABC classification	Articles in A category (highly relevant): addressing the impact of firm or university's capability on performance (or output) in the UIC context	Articles in B category (moderately relevant - an article is related to capability in the UIC but not performance) Articles in C category (not relevant - an article is not related to capability and performance)

Remark: *academic engagement, academic-industrial collaboration, business & education, business enterprises, business partnerships, case studies, collaboration, commercialization, commercialization, economic development, economics, education, empirical research, engagement, entrepreneurial university, entrepreneurship, government policy, higher education, industrial management, industrial research, industries, innovation, innovation policy, innovations in business, intellectual property, knowledge management, knowledge transfer, management, open innovation, patents, r&d, research, research & development, research institutes, science & industry, small business, technological innovations, technology, technology transfer, third mission, triple helix, triple helix model, triple-helix, universities, universities & colleges, university, university research, university-industry, university-industry collaboration, university-industry cooperation, university-industry interaction, university-industry linkages, university-industry relations, university-industry relations*

Appendix B Tabular summary of articles reviewed

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
1	Choonwoo *et al.* (2001)	To examine how Korean start-up companies' internal capabilities and external networks affect firm performance.	Survey of 137 Korean technological start-up's CEOs.	Regression	1. Entrepreneurial orientation (e.g., R&D employees, products/services, risky R&D projects, expenditure on a risky R&D project, first-move products). 2. Technological capability (e.g., inventions, patents, utility models, industrial, designs, quality assurance marks, cost and expenses from R&D).	Sales growth of start-up companies.	Internal capabilities have a positive effect on a start-up's growth of sales.
2	Daghfous (2004a)	To examine how a firm's learning activities and prior knowledge contribute to the benefits of a university-industry technology transfer project.	A Survey of 120 plant managers or contact persons participated in technology transfer project from the Pennsylvania State University, US.	Correlation analysis & Regression	1. Prior technical knowledge (e.g., knowledge about existing technology). 2. Prior organisational knowledge (e.g., incentive & reward system, job's relation to other organisational activities, and skills and technologies for technology transfer projects).	1. Technology transfer benefit. 2. Operation benefit (e.g., meet the objective, implement a solution, trouble-free, new scientific knowledge).	A firm's prior technical knowledge has a marginal effect on operation benefits, but no effect when considering technical uncertainty. A firm's prior organisational knowledge does not affect operational benefits.
3	Daghfous (2004b)	To explore the roles of the learning processes and prior knowledge in each stage of the university-industry	A technology transfer project from a university's engineering	Case study analysis	Absorptive capacity (e.g., prior technical and organisational knowledge).	1. Intended benefit (e.g., increase in throughput). 2. Unintended benefit (e.g., better technological knowledge, building a learning	To achieve technology transfer success, an adequate level of prior knowledge is required. Technical knowledge is increased from one stage to the

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
		technology transfer project.	research centre to a private firm in the USA.			alliance, better project management).	next through organisational learning.
4	Medda *et al.* (2004)	To investigate the effects of various R&D investments on the total productive growth of manufacturing firms in Italy.	Survey of 2,268 firms during 1992-1994, and 2,217 firms during 1995-1997.	Heckman's sample selection model.	Absorptive capacity (e.g., a firm's external R&D expenditure on UIC over sales).	Total productivity growth (e.g., growth net of contributions of factor inputs).	A firm's R&D expenditure on the UIC does not affect the total productivity growth.
5	Lockett and Wright (2005)	To investigate the impact of a university's capabilities on the creation of spin-out companies.	Survey of 120 top universities in the UK as ranked by research income.	Regression	Business development capabilities (e.g., marketing, technical, negotiating of staff, a clear process of IP right due diligence and spinouts, availability of university staff to manage the commercialisation).	1. The number of spinoffs. 2. The number of spinoffs with equity investments.	A university's business development capabilities have a significantly positive influence on the number of spin-out companies. The effect is more pronounced for spinouts with equity investment.
6	Santoro and Bierly (2006)	To determine factors facilitating the knowledge transfer between firms and university research centres (URCs).	A survey of 173 US firms involved in a URC relationship.	OLS	1. Technological capability (e.g., R&D intensity: R&D investment/ sales). 2. Technological relatedness (e.g., accessed expertise from URC strengthen firm's core area of business and outside facilities from URC)	Knowledge transfer (e.g., learned from knowledge transfer, assimilated to product/service, resulted in new products).	Technology capability and technology relatedness facilitate the knowledge transfer especially for the project associated with tacit knowledge.
7	Ambos *et al.* (2008)	To examine the extent to which organisational and individual factors affect the commercialisation of university research.	Survey data of 207 academic research projects funded by a major	Regression	Scientific excellence (e.g., score attributed to the university department, a total no. of citations referring to the principal investigator's research).	Commercial outputs (e.g., patents, licenses or spinouts)	Scientific excellence at both individual and organisational levels has a positive effect on commercial outcomes.

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
			research council in the United Kingdom.				
8	Arvanitis *et al.* (2008)	To examine the effects of knowledge transfer activities (KTTs) on the determination of a firm's innovation and labour productivity.	Survey of 2,428 firms in Switzerland.	Regression	1. Human capital (e.g., the share of employees with tertiary-level education). 2. Physical capital (e.g., investment expenditure per employee).	1. Innovation performance (e.g., R&D intensity, the sales share of new products) 2. Economic performance (e.g., labour productivity)	A firm's human capital has a positive effect on its propensity to collaborate with universities. KTT activities in turn can raise the effectiveness of R&D with respect to innovation and economic performance.
9	Liefner and Schiller (2008)	To propose a framework to understand the roles of academic capabilities in developing countries in contributing to technological upgrading and structural change.	A sample of 72 professors and administrators at 5 public universities in Thailand.	Interviews	Academic capabilities (e.g., teaching, research, outreach).	Technological upgrading (e.g., basis for increased productivity and obtaining higher income).	To improve the technological upgrading, there is a need to integrate three functions (e.g., teaching, research, and outreach) as well as improve the organisational capability (budgeting, management and institution building).
10	Arvanitis and Woerter (2009)	To examine the determinations of a firm's knowledge and technology transfer (KTT) strategies between firms and universities and the KTT strategies on a firm's innovation performance.	A survey of 669 involved in knowledge transfer activities with universities in Switzerland.	Regression	Absorptive capacity (e.g., frequency of R&D activities, the share of employees with tertiary education on total employees).	Innovation performance (e.g., patent applications, Share of new products on total sales).	In a presence of high absorptive capacity, employing core contacts (e.g., use of university infrastructure, employing graduates, contracts) seem to have a new product than firms with loose contacts if an involved firm has a high absorptive capacity.

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
11	Barbolla and Corredera (2009)	To assess the success factors of university-industry research projects.	A sample of 30 researchers at the Technical University of Madrid, Spain.	Descriptive statistics analysis and interviews	1. A firm's and academic researcher's knowledge. 2. A firm's absorptive capacity. 3. Relationship between two players.	The success of technology transfer (a firm's adoption of technology).	The success of technology transfer is not defined by a single factor, but by a combination of favourable circumstances.
12	Bierly *et al.* (2009)	To examine the effects of various organisational factors on a firm's ability to apply external knowledge from university research centres for explorative and exploitative innovations.	A survey of 180 US firms involved in a URC relationship.	Regression	1. Learning capabilities (e.g., experience, technological capability, technological relatedness). 2. Strategic capabilities (strategic posture, financial leverage).	1. Explorative application (e.g., new products, processes developed – offered – not being easily imitated, patents). 2. Exploitative application (major & minor product and process improvements).	The firm tends to achieve exploratory innovations given an entrepreneurial orientation and financial resource favours, but not technological overlapping. Prior collaboration experience is more effective for tacit knowledge while technological capability facilitates the transfer of tacit knowledge for exploratory innovations.
13	Fabrizio (2009)	To investigate the impact of a firm's absorptive capacity on the effectiveness of external collaboration.	A panel data set of 83 firms in the biotechnology and pharmaceutical industries during the 1976–1999 period.	Regression	Absorptive capacity (e.g., the number of publications by a firm's researchers to a firm's expenditures on R&D).	1. Pace of innovation (e.g., time lag between the cited patents or publications and the invention). 2. Invention importance (a count of forward citations received by a patent).	Investment in internal basic research and collaboration with university scientists provide search benefits in terms of both pace of innovation and performance of the results inventions.
14	McAdam *et al.* (2009)	To apply an absorptive capacity perspective on the proof-of-concept process within the university science park	A sample of 6 Proof of Concept projects within a university	Multiple case study	Absorptive capacity	Commercialisation outcomes (e.g., prototype, ready product, spinouts, licensing opportunities,)	Factors of absorptive capacity (e.g., levels of R&D investment, prior knowledge base and integration of stakeholder and technology planning) affect the

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
		incubator for improving the commercialisation.	science park Incubator in the UK.				development of each stage of absorptive capacity and PoC outcomes.
15	Su *et al.* (2009)	To investigate the impact of a firm's internal capabilities on innovativeness when collaborating with external partners	A survey of 79 Taiwanese firms in the biotechnology industry.	Regression	A firm's R&D capability.	Innovativeness (e.g., product innovation and process innovation)	There is no synergy effect between a firm's R&D capability and partnership with a university on firm innovativeness.
16	Tsai (2009)	To investigate the impact of a firm's absorptive capacity on the relationship between different R&D partners and product innovation performance.	A survey of 1,346 manufacturing firms in Taiwan.	Regression	Absorptive capacity (e.g., a ratio of R&D investment to total employees).	Product innovation performance (e.g., sales of new products divided by a total number of employees: technologically new or improved products vs. marginally changed products).	Absorptive capacity negatively moderates the relationship between the UIC and performance of technologically new or improved products, but positively moderates the relationship between the UIC and performance of marginally changed products.
17	Arza and Vazquez (2010)	To examine the relationship between different forms of interactions between the firm and public research organisation as well as their interaction with the firm's innovative capability or researcher's skill on different types of benefits.	A sample of 592 Argentinian firms in the ENIT survey and 136 researchers from the SICyTAR database.	Heckman two-step model.	1. Researcher's skills and knowledge (e.g., proportion of post-graduate researchers in the group and proportion of students). 2. Firm's innovation capabilities (e.g., a ratio of firm's R&D expenditure to sales).	1. Researcher's intellectual and economic benefits. 2. Firm's innovation and production benefits.	Different channels trigger different benefits. Researchers with a higher level of skills and knowledge benefit from the bi-directional channel in terms of intellectual benefits but not from service channels. Firms with a higher level of innovation capability benefit from bidirectional and traditional channels in terms of innovation and production benefits.

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
18	Eom and Lee (2010)	To investigate the determinants of industry-university-government (IUG) cooperation and the impact of IUG linkage on firm innovation performance.	A sample of 538 Manufacturing firms from the 2002 Korea Innovation Survey.	Regression	Absorptive capacity (e.g., a ratio of average R&D expenditure to sales).	Innovation probability (e.g., whether a firm succeeds in technological innovation)	R&D intensity (as a proxy of absorptive capacity) does not influence a firm to engage in IUG and has no impact on the introduction of firm technological innovation.
19	Petruzzelli (2011)	To investigate the impact of technological relatedness, prior collaboration ties and geographical distance on the value of university-industry joint innovations.	A sample of 796 U-I joint patents developed by 33 Universities located in 12 European countries.	Regression	Technological relatedness (e.g., means of the degree of overlapping between an organisation's technological bases in terms of the technological field in which they patent).	Innovation performance (e.g., forward citations).	Prior ties and geographical enhance the innovative outcomes while technological relatedness exhibits a concave relationship with the innovation value.
20	Xu *et al.* (2011)	To examine the relationship between university tie (local firms vs. FDI firms) on innovation, and the moderating effects of R&D capacity and firm size on that relationship.	A survey of 226 Chinese firms.	Regression	1. University tie (close personal relationship with a professor, scientist, and engineer at the local). 2. R&D capacity (a ratio of the number of employees in the R&D department to total employees).	Firm innovation (no. of patents, utility patents, design patents).	University tie has a positive effect on the innovation of both local and foreign firms when engaged in UIC. R&D capacity does not moderate the relationship between university tie and local-firm innovation, but positively moderates that relationship for FDI firms.
21	Brehm and Lundin (2012)	To investigate the role of absorptive capacity on the firm's competitive advantages when engaged in different	A sample of 20,000 large- and medium-sized firms	Regression	Absorptive capacity (e.g., acquisition of external knowledge and R&D capacity – R&D staff).	Competitive advantage (e.g., the revenue of new products, export value of new products, no. of Industry patents).	Adopting graduates, scientific articles, patents, and technology transfer have a positive relationship with a firm's absorptive capacity while university R&D personnel and

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
		university-industry collaboration activities.	for 31 provinces in China during 1998 and 2004.				research networks have a negative relationship.
22	von Raesfeld *et al.* (2012)	To examine the impact of technology and partner diversity on firm performance derived from the collaborative public R&D projects.	A sample of 169 research projects from the European Patent Office (EPO) from 1995 to 2002.	Regression	Technology diversity (e.g., the degree to which there is complete coverage of the eight main patent classes).	1. Application development (e.g., the degree to which the projects lead to a tangible product). 2. Commercial performance (e.g., the degree to which the projects create revenues).	Technology diversity does not affect application development but exhibits a convex relationship with the project's commercial performance.
23	Wang Wang and Shapira (2012)	To investigate the impact of intellectual capital, social capital, and positional capital of universities' scientists on the technology potential of new technology-based firms in the nanotechnology industry.	A panel dataset of 230 new US nanotechnology-based firms during 1996 and 2005.	Regression	Intellectual capital (e.g., total journal publications divided by the number of publishing career years).	1. The number of small business innovation research programs. 2. Pre-venture funding awards.	University scientists' intellectual capital productivity has a positive effect on the firm's acquisition of pre-venture funding awards.
24	Belso-Martinez *et al.* (2013)	To examine the effects of a firm's capabilities and innovation experience on the usefulness of the UIC.	A survey of 521 manufacturing firms in Spain.	Regression	1. Technological capability. 2. Design capability. 3. Managerial capability.	Usefulness (e.g., meeting firm needs for innovation activities, overcoming obstacles and fostering the firm's product innovation).	A firm's technological capability tends to have a positive effect on usefulness while design capability tends to lower usefulness.

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
25	Grimpe and Hussinger (2013)	To examine the impact of formal and informal university knowledge and technology transfer modes on firm innovation performance.	A sample of 2,092 German manufacturing firms from the Mannheim Innovation Panel (MIP).	Regression	Absorptive capacity (e.g., a ratio of R&D expenditure to employment).	Innovation performance (e.g., innovation sales over total sales).	Absorptive capacity is critical for engaging in both formal and informal technology transfer from the universities. Only simultaneous collaboration through formal and informal knowledge transfer modes enhances firm innovation performance.
26	Buganza *et al.* (2014)	To investigate how SMEs' capabilities play roles in different phases of a new product development collaboration with universities.	A survey of 28 SMEs and 5 case studies in Italy.	case study analysis	1. Technology management capability. 2. Project management capability.	Technology transfer success	Technology and project management capabilities are important for managing complex forms of collaboration with universities and they increase over the progress of the development process.
27	Soh Soh and Subramanian (2014)	To investigate the relationship between a firm's internal R&D focus and university collaboration.	Patent and publication data from 222 biotechnology firms.	Regression	1. Technology recombination focus (e.g., breadth of patented technologies recombined in developing an innovation). 2. Scientific research focus (e.g., publication intensity).	Patent performance (e.g., forward citations).	Technological recombination positively moderates the relationship between university collaboration and patent performance while scientific research focus has a negative moderating effect.
28	Arvanitis and Woerter (2015)	To investigate the determinants of exploration and exploitation of knowledge in collaboration with universities and their effects on a firm's	Survey of 1,728 firms in Switzerland.	Regression	Absorptive capacity 1. Human capital (e.g., investment per employee, the share of the employee with tertiary-level formal education) 2. Physical capital (e.g., the existence of R&D department, R&D cooperation).	Innovation performance (e.g., the sales share of innovative products).	Absorptive capacity has a positive relationship with both activities but is stronger in exploration. Exploitation-oriented activities are stronger positively correlated with innovation performance than exploration-oriented activities.

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
		innovation performance.					
29	Kafouros *et al.* (2015)	To investigate the effect of collaboration with universities on the innovation performance of firms in an emerging economy.	A sample of 1,125 Chinese manufacturing firms in Innovation-Oriented Firms Database.	Regression	Research quality of URIs (e.g., the average number of academic papers published in international journals per academic in a given region).	Innovation performance (e.g., share of sales of new products to domestic and foreign markets over total sales).	The research quality of URIs has a positive moderating effect on the relationship between academic collaboration and firm innovation performance.
30	Toole *et al.* (2015)	To investigate how university research alliances and other university connections and absorptive capacity affect the start-up employment growth.	A sample of 14,844 German firms from the Mannheim Foundation Panel (MFP) of the Centre for European Economic Research (ZEW).	Heckman selection model	Scientific absorptive capacity (e.g., research-experienced academic founder).	Employment growth (e.g., annualized logarithmic change in the number of employees).	Scientific absorptive capacity has a moderating effect on the relationship between research alliances (collaborative R&D projects) and start-up's employment growth but no effect on the relationship between the university connections.
31	Belderbos *et al.* (2016)	To explore the impact of scientific absorptive capacity on firm innovation performance when engaged in direct or indirect collaboration with universities.	A panel dataset of 33 pharmaceutical firms in the EU, US, and Japan during 1995–2002.	Regression	Absorptive capacity (e.g., the number of basic scientific publications on which the firm are listed as the affiliation of one of the authors).	Innovation performance (e.g., forward patent citations).	Direct university collaboration is more beneficial for firms with high scientific absorptive capacity, while only mediated ties are associated with greater innovative performance for firms with relatively low scientific absorptive capacity.

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
32	Chen *et al.* (2016)	To examine the synergy effects between a firm's internal R&D and different types of external collaborations on innovation performance.	A survey of 478 manufacturing firms in China.	Regression	R&D capability (e.g., ratio of R&D expenditure to firm's sales).	Innovation performance (e.g., percentage of total sales from new or substantially improved products).	There are no complementary effects between a firm's internal R&D and collaboration with universities on firm innovation performance.
33	Han and Kim (2016)	To investigate the impact of factors on the university's outputs from technology transfer	A sample of 135 Korean universities from the IUCF database.	Regression	University research competency 1. Knowledge asset (e.g., no. of patents granted) 2. Research productivity of faculty (e.g., no. of papers published in journals per faculty) 3. Tendency to be research-oriented (e.g., the proportion of graduate students from total no. of students)	The average amount of revenue through university technology transfer over 3 years.	University research competency in terms of knowledge asset and research productivity has a positive effect on the amount of technology transfer.
34	Salimi *et al.* (2016)	To investigate the effects of success factors such as project management, communication, and supervision characteristics on the success of PhD projects.	A survey of 191 PhD candidates at The Eindhoven University of Technology, the Netherlands.	Regression	Level of university or collaborating partner supervision's knowledge.	Project success (e.g., level of knowledge transfer to partner, resulted in academic publication, knowledge was patented, a subsequent job offer from a university, a subsequent job offer from collaborating partners, collaboration on was followed).	Management decisions, supervision and communication characteristics have a significant impact on the ultimate success of PhD project.
35	Garcia-Perez-de-Lema *et al.* (2017)	To investigate how contractual and relationship	A sample of 600 Spanish SMEs.	Structural equation modelling	Absorptive capacity (e.g., firm's capacity to carry out R&D, level of technological and scientific	1. Innovation performance (e.g., changes or improvement in existing products,	Absorptive capacity has a positive effect on both governance modes, innovation,

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
		governance modes has an impact on SMEs' innovation and performance when engaged in university-industry cooperation.			information, personnel education, skills to gather and use relevant information from markets).	commercialization, changes or improvement process, acquisition of new capital equipment). 2. Relational performance (e.g., increase in market share, profitability, productivity).	and performance. Engaging in contractual governance is positively influence by relational governance, resulting in increased innovation and performance.
36	Lin (2017)	To investigate the effects of collaboration with firms on academic innovation output.	A panel data of 110 top U.S. research universities.	Regression	Knowledge capacity (e.g., a 3-year stock of papers at a university level).	Academic innovation (e.g., total no. of citations received).	A number of cooperation with firms exhibits the inverted U-shaped relationship with academic innovation. This relationship is moderated by university contribution, collaboration breadth and knowledge capacity. Knowledge capacity weakens the relationship.
37	Qiu *et al.* (2017)	To investigate the spillovers effect of localised knowledge from domestic collaboration and distant knowledge from international collaboration with universities on firm innovation.	A panel data of 322 co-authored papers between university and firm during 1999–2012.	Regression	Regional absorptive capacity (AC) (e.g., R&D expenditures by firms in different provinces).	Innovation output of regional firms (e.g., the number of invention patent applications by firms).	For regions with higher AC, both domestic and inter-university collaborations show more significant positive relations to local firm's innovation. For regions with low AC, domestic collaboration has become positively related to local innovation whereas international collaboration is negatively associated with a firm's innovation.

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
38	Sengupta and Ray (2017)	To examine the dynamic interlinkages between the two pillars of ambidexterity in universities, research and knowledge transfer.	Secondary data from UK databases.	Regression	Research output (e.g., score from no. of articles published in the top-ranked journals).	Knowledge transfer (e.g., IP income, contract income, collaborative income, consulting income).	Research output has positive effects on all indicators of knowledge transfer performance. The marginal unit of research output has the highest likelihood of being transferred to practitioners through the contract research route followed by collaborations, commercialization, and consultancies.
39	Dezi *et al.* (2018)	To assess the impact of knowledge acquisition from university scientific research on a firm's innovation commercialisation.	A sample of 185 Italian knowledge-intensive firms.	Regression	Absorptive capacity (e.g., an average of R&D investment, internal knowledge creation and knowledge storage).	Innovation commercialisation (e.g., a ratio of sales from new or significantly improved products and services compared to total sales).	Firms benefit from research partnerships with and services from universities when they possess higher levels of internal absorptive capacity.
40	Kobarg *et al.* (2018)	To investigate the effects of innovation competencies and absorptive capacity on firm innovation performance when engaged in university-industry collaboration.	A sample of 2,061 manufacturing firms from the German Community Innovation Survey.	Regression	1. Absorptive capacity (e.g., R&D intensity, continuity of internal R&D, training, the share of employees holding university degrees). 2. Innovation competencies (innovation speed, entrepreneurial employees, product development, innovation competition and incentives, cooperation and collaboration).	1. Incremental innovation performance (e.g., the turnover share of new significantly improved products). 2. Radical innovation performance (e.g., turn over share of introduced product innovations new to the market).	Absorptive capacity presents a negative effect on incremental innovation but a positive effect on radical innovation competencies when firms are engaged in UIC. Innovation competencies only favour firms in enhancing radical innovation performance.

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
41	Fudickar and Hottenrott (2019)	To investigate the impact of direct interactions with PRIs on NTBF's innovation success.	A survey of 2,879 German technology-based firms was established between 2001 and 2006.	Regression	1. Absorptive capacity (AC) (e.g., internal R&D). 2. Academic founder	Market novelty (introducing product innovation).	Non-academic start-ups benefit from continuous informal interactions with the presence of AC. For academic start-ups, continuous formal and informal interaction complement each other without AC.
42	Min *et al.* (2019)	To investigate the effects of factors on the commercialization in the university-public research institutes technology transfer.	A data of 669 technology transfer cases in Korea.	Regression	Absorptive capacity (e.g., quickly recognize target market changes, quickly responds to competitor's changes, regularly monitors environment changes, actively adopts successful best practice, quickly changes strategies based on customer feedback).	Successful commercialization of transferred technologies.	The intensity of market competition strengthens the positive effect of absorptive capacity on commercialization success.
43	Apa *et al.* (2020)	To examine the relationship between UICs and innovation performance of SMEs and the moderating roles of absorptive capacity on that relationship.	Italy	Regression	Absorptive capacity (e.g., the existence of the R&D department).	Innovation performance (e.g., a sum of product, process, organisational, and marketing innovation intensity).	Only informal UICs lead to an increase in SMEs' innovation performance. Absorptive capacity is a prerequisite for firms to benefit from formal and informal collaborations.
44	Leischnig and Geigenmuller (2020)	To investigate how academic alliance management capabilities affects the success of outward university technology transfer.	A sample of 85 professors, senior researchers, and researchers from German universities.	Partial least squares SEM, FsQCA	Alliance management capabilities (e.g., alliance proactiveness, alliance transformation, inter-organizational coordination, inter-organizational learning).	Technology transfer success (e.g., responsibilities and commitments, productive relationship, worthwhile time and effort, satisfying relationship).	Alliance management capability has a significant positive effect on technology transfer success. Different configurations of alliance management routines, reflecting alternative, consistently

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
							sufficient pathways to technology transfer success.
45	Petruzzelli and Murgia (2020)	To investigate how geographical proximity and acquisition of foreign knowledge for UIC affect international knowledge spillovers.	A sample of 772 joint patents developed by German and Italian universities in collaboration with a firm.	Regression	University specialisation (e.g., number of patents filed by university partner in five years before the publication of joint patents).	International spillovers (e.g., forward citations received by each joint patent filed by a university in collaboration with the company).	University specialization has a positive and significant moderating effect only on the relationship between the reuse of foreign knowledge and the international impact of the innovation developed.
46	**Tang *et al.* (2020)**	To examine the impact of the relationship between university proximity and research quality on product innovation performance when engaged in university-industry collaboration	A sample of 166 manufacturing firms in Guangdong, China.	Regression	University's research quality (e.g., high versus average quality based on the funding program).	1. Radical innovation performance. 2. Incremental innovation performance.	Collaboration with a university in the cross-regional region and high-quality universities has a positive effect on radical innovation while intra-regional average-quality university linkages are more associated with an increase in incremental innovations.
47	Tseng *et al.* (2020)	To investigate the relationship between UIC funding and university's technology innovation performance.	A sample of 145 Taiwanese universities.	Regression	UIC management mechanisms (e.g., no. of employees in charge with UIC affairs in the universities, no. of staff whose business is to establish links between university and industries).	University technology innovation performance (e.g., no. of research publications, no. of issued patents, amount of royalty income from technology licensing, no. of business incubations in the universities).	UIC management mechanisms positively influence UIC funding. UIC funding positively influences the university's technology innovation performance.
48	Guerrero and Urbano (2021)	To investigate the determinants and the impact of entrepreneurial	A sample of 514 Mexican firms from 2010 Mexican	Regression	1. Enterprise's innovation capabilities (e.g., innovation in products & processes, innovation in	Performance (a firm's profits increased during the last 3 years).	Enterprise and university's capabilities are determinants for developing entrepreneurial and innovation projects. Enterprise's

No.	Article	Research objective	Data	Method	Capability	Performance	Findings
		innovation projects within university-industry collaboration in an emerging economy.	Survey of Enterprise - University.		produce/services, innovation in processes). 2. University's capabilities (e.g., teaching, research, entrepreneurship).		innovation capabilities, knowledge of university's capabilities and access to state funds increase the profitability derived from the entrepreneurial innovation projects.
49	Melnychuk *et al.* (2021)	To investigate the impact of different dimensions of absorptive capacity on successful university knowledge transfer from subsidiaries to parents.	A panel data of 56 global pharmaceutical and biotech firms during1999 and 2016.	Regression	Absorptive capacity (AC) 1. Explorative external AC (e.g., research exploration intensity). 2. Transformative external AC (e.g., research diversity). 3. Transformative internal AC (e.g., a ratio of R&D expenditure to sales).	Parent firm's R&D performance (e.g., no. of drug candidates under development that entered clinical trials in phase 1).	A high diversity and R&D intensity levels strengthen the positive relationship between parents' UIC and R&D performance. A high exploration intensity level of the firm and high diversity in therapeutic activity help to transfer the knowledge from subsidiaries' preclinical research UIC to parents' innovation projects.

Appendix C Advantages and drawbacks of measures

Measures	Advantages	Drawbacks/concerns	Sources
R&D inputs	- Most commonly used - Human capital indicates the level of tacit knowledge and R&D orientation - Quantifiable output measure	- Only represents the commitment to R&D activities and short-term costs - Insufficient to link to performance	Cohen and Levinthal (1990), Koellinger (2008)
Patents	- Quantifiable output measure - Valuable and difficult to imitate according to RBV - Suitable for technology-intensive firms - Capture the research outputs as a result of technology transfer - Capture economic value of a focal patent because the subsequent citing patents are the result of costly innovation efforts undertaken by profit-seeking agents	- Not all inventions are patentable - Might not present actual innovativeness if being a result of patent-around strategy or funding purpose - Not suitable for low-patent-propensity industries including services - Unable to observe in some universities due to disclosure policy	Choonwoo *et al.* (2001), Grimaldi and Von Tunzelmann (2002), Lockett and Wright (2005), Coombs and Bierly (2006), Chen *et al.* (2016), Fabrizio (2009), Perkmann *et al.* (2011), Kleinknecht and Reinders (2012), Kafouros *et al.* (2015), Han and Kim (2016)
Publications	- Quantifiable output measure - Describe the early stage of technology and basic science	- Low degree of commercial and innovative values compared with patents - Quality varies among research fields and disciplinary - Being judged by specific standards (such as a quality list)	Grimaldi and Von Tunzelmann, 2002, Coombs and Bierly (2006), Kleinknecht and Reinders (2012), Seppo and Lilles (2012), Sengupta and Ray (2017)
Number of new products	- Represent a final output of the innovation process - Present a degree of innovativeness and technological capability	- Create bias due to different degrees of newness among products	Choonwoo *et al.* (2001), Coombs and Bierly (2006)
Sales of new products	- Commonly used for capturing innovation performance	- Difficult to link to the UIC outcomes - Vary by the degree of novelty (e.g., radical vs incremental). - Difficult to accurately observe - Maybe confounded with other factors - Not suitable for startups	Choonwoo *et al.* (2001), Kobarg *et al.* (2018)
Citations	- Quantifiable output measure - Indicate technological development and invention's usefulness - Indicate innovation speed if measuring time lag between cited and citing patents/publications - Powerful than publications or patents	- Less commercial value (publication citations) - Might be influenced by a patent-around strategy - Many patent citations may be added by a patent examiner	Trajtenberg (1990), Grimaldi and Von Tunzelmann (2002),Hagedoorn and Cloodt (2003), Coombs and Bierly (2006), Ambos *et al.* (2008), Fabrizio (2009)
Perceptual measures	- Offer a more accurate estimation of complex constructs of such variables	- Concern about the preservation of objectivity - Associated with variations and self-evaluation bias	Grant (1991), Henttonen *et al.* (2016), Camison and Fores (2010)

Appendix D Measurement items of innovation capabilities

Capability	Item	Question from CIS
Product innovation capability	1	Did your enterprise produce inventions? (Yes/No)
	2	Did your enterprise produce prototypes? (Yes/No)
	3	Did your enterprise produce pilot plants? (Yes/No)
Process innovation capability	4	Does your enterprise introduce new or significantly improved processes of producing goods? (Yes/No)
	5	Does your enterprise introduce new or significantly improved processes of producing service? (Yes/No)
	6	Did your enterprise introduce new or significantly improved logistics, delivery, or distribution methods for your inputs, goods or services? (Yes/No)
	7	Did your enterprise introduce new or significantly improved supporting activities for your processes, such as maintenance systems or operations for purchasing, accounting, or computing? (Yes/No)
Organisational innovation capability	8	Did your enterprise implement a new or significantly changed corporate strategy? (Yes/No)
	9	Did your enterprise implement new management techniques within the business e.g., Six Sigma, Just in Time, Total Quality Management? (Yes/No)
	10	Did your enterprise receive externally certified standards such as ISO 9000 or ISO 14000? (Yes/No)
	11	Did your enterprise implement major changes to your organisation structure e.g., organisational restructuring and introduction of a team working? (Yes/No)
Marketing innovation capability	12	Did your enterprise implement changes in existing product design or packaging (Excluding new products)? (Yes/No)
	13	Did your enterprise use new media or techniques for promotion such as social media, loyalty card, etc.? (Yes/No)
	14	Did your enterprise use new sales channels such as Franchise, direct sales, etc.? (Yes/No)
	15	Did your enterprise use a new pricing system such as a demand-side price system? (Yes/No)

Appendix E Additional analysis for Paper 3

E.1 Estimates of the logistic models on the breadth of contractual and relational channels

Variables	Breadth of UIC	
	Model 1 (Contractual channels)	**Model 2 (Relational channels)**
App	0.216*	0.092**
	(0.114)	(0.036)
App^2	-0.006	-0.002
	(0.010)	(0.003)
Product innovator	0.007	-0.015
	(0.200)	(0.070)
Process innovator	1.040***	0.485***
	(0.237)	(0.099)
Interaction effects		
App x Product innovator	0.119	0.065
	(0.131)	(0.053)
App^2 x Product innovator	-0.016	-0.010**
	(0.010)	(0.005)
App x Process innovator	-0.334**	-0.122*
	(0.137)	(0.070)
App^2 x Process innovator	0.024**	0.007
	(0.011)	(0.006)
Control variables		
Firm size	0.155***	0.248***
	(0.038)	(0.012)
Firm age	0.010**	-0.000
	(0.004)	(0.001)
MNC	-0.443**	0.052
	(0.175)	(0.046)
R&D unit	0.572***	0.392***
	(0.114)	(0.036)
R&D intensity	0.146	-0.026
	(0.142)	(0.079)
OBM	0.159	0.183***
	(0.105)	(0.035)
Grant	1.257***	0.625***
	(0.133)	(0.058)
Uni Imp	0.430***	0.167***
	(0.033)	(0.021)
Knowledge intensity	0.042	-0.089**
	(0.117)	(0.037)
Year 2017	-0.989***	-0.042
	(0.132)	(0.035)
Year 2018	-0.444***	-0.035
	(0.112)	(0.039)
Constant	-5.928***	-3.118***
	(0.268)	(0.083)
QIC	1485	10097
Wald Chi^2	858.9***	1301***
No. of observations	10,800	10,800

Standard errors are reported in parentheses;
* significant at $p < 0.1$, ** significant at $p < 0.05$, *** significant at $p < 0.01$

E.2 Estimates of the logistic models on a firm's propensity to collaborate with customers and suppliers

Variables	Collaboration with customers				Collaboration with suppliers			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
App	0.037	0.093	0.061	0.107	0.025	0.235***	0.114**	0.407***
	(0.035)	(0.089)	(0.050)	(0.126)	(0.036)	(0.090)	(0.052)	(0.120)
App^2		-0.007		-0.005		-0.022**		-0.032***
		(0.009)		(0.013)		(0.009)		(0.011)
Product inno.	-0.306***	-0.309***	-0.203	-0.194	-0.149	-0.173	0.134	0.325
	(0.105)	(0.106)	(0.147)	(0.217)	(0.112)	(0.112)	(0.150)	(0.222)
Process inno.	0.269*	0.262*	0.161	0.023	0.006	-0.020	-0.076	-0.166
	(0.142)	(0.142)	(0.215)	(0.301)	(0.152)	(0.153)	(0.215)	(0.322)
Interaction effects								
App x Product innovator			-0.073	-0.087			-0.197***	-0.414**
			(0.072)	(0.178)			(0.071)	(0.178)
App^2 x Product innovator				0.002				0.025
				(0.019)				(0.018)
App x Process innovator			0.070	0.212			0.037	0.117
			(0.104)	(0.241)			(0.091)	(0.259)
App^2 x Process innovator				-0.019				-0.013
				(0.026)				(0.029)
Control variables								
Firm size	0.201**	0.203**	0.197**	0.198**	0.187**	0.191**	0.176*	0.175*
	(0.082)	(0.082)	(0.082)	(0.082)	(0.092)	(0.092)	(0.092)	(0.092)
Firm age	-0.031**	-0.031**	-0.031**	-0.031**	-0.035*	-0.034*	-0.034*	-0.034*
	(0.015)	(0.015)	(0.015)	(0.015)	(0.020)	(0.020)	(0.020)	(0.020)
MNC	0.773***	0.773***	0.772***	0.771***	0.203	0.193	0.203	0.192

Variables	Collaboration with customers				Collaboration with suppliers			
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
	(0.179)	(0.179)	(0.179)	(0.179)	(0.188)	(0.188)	(0.189)	(0.189)
R&D unit	0.564***	0.567***	0.569***	0.574***	0.346**	0.340*	0.339*	0.336*
	(0.171)	(0.171)	(0.172)	(0.172)	(0.177)	(0.177)	(0.178)	(0.178)
R&D intensity	-0.134	-0.130	-0.137	-0.130	-0.226	-0.218	-0.250	-0.229
	(0.195)	(0.194)	(0.198)	(0.196)	(0.245)	(0.240)	(0.273)	(0.255)
OBM	0.196	0.198*	0.196	0.199*	0.331**	0.341**	0.340**	0.350**
	(0.119)	(0.119)	(0.119)	(0.119)	(0.135)	(0.135)	(0.135)	(0.136)
Grant	0.641***	0.634***	0.632***	0.625***	0.516***	0.517***	0.511***	0.523***
	(0.172)	(0.173)	(0.173)	(0.173)	(0.175)	(0.176)	(0.176)	(0.178)
Knowledge intensity	0.094	0.097	0.078	0.084	0.273	0.254	0.278	0.246
	(0.293)	(0.293)	(0.294)	(0.294)	(0.326)	(0.327)	(0.329)	(0.329)
Source of inno[a]	0.395***	0.394***	0.394***	0.394***	1.012***	1.006***	1.012***	1.007***
	(0.026)	(0.026)	(0.026)	(0.026)	(0.066)	(0.066)	(0.067)	(0.067)
Year 2017	-1.638***	-1.642***	-1.636***	-1.641***	0.087	0.055	0.083	0.048
	(0.103)	(0.103)	(0.103)	(0.103)	(0.098)	(0.099)	(0.099)	(0.100)
Year 2018	-0.488***	-0.491***	-0.489***	-0.493***	0.279***	0.270***	0.278***	0.264***
	(0.091)	(0.091)	(0.091)	(0.091)	(0.095)	(0.095)	(0.095)	(0.095)
Wald Chi^2	718.6***	719.1***	719.9***	720.7***	602.6***	609.5***	610.6***	619.0***
Pseudo R^2	0.262	0.262	0.263	0.263	0.255	0.258	0.258	0.262
Log likelihood	-1011	-1011	-1011	-1010	-880.3	-876.9	-876.3	-872.2
No. of observations	3,815	3,815	3,815	3,815	3,285	3,285	3,285	3,285

Standard errors are reported in parentheses, [a] importance of each partner associated with the dependent variable as a source of innovation
* significant at $p < 0.1$, ** significant at $p < 0.05$, *** significant at $p < 0.01$

E.3 Estimates of the logistic models on a firm's propensity to collaborate with companies and PRIs

Variables	Collaboration with companies				Collaboration with PRIs			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
App	0.014	0.051	0.061	0.010	0.047	0.072	0.045	0.088
	(0.048)	(0.109)	(0.067)	(0.171)	(0.043)	(0.101)	(0.056)	(0.140)
App^2		-0.004		0.006		-0.003		-0.007
		(0.011)		(0.020)		(0.010)		(0.014)
Product inno.	-0.370**	-0.373**	-0.176	-0.289	-0.493***	-0.495***	-0.512***	-0.039
	(0.147)	(0.147)	(0.206)	(0.310)	(0.145)	(0.145)	(0.191)	(0.350)
Process inno.	0.474***	0.467**	0.300	0.194	0.333*	0.333*	0.376	-0.334
	(0.183)	(0.184)	(0.278)	(0.379)	(0.185)	(0.185)	(0.257)	(0.420)
Interaction effects								
App x Product innovator			-0.128	-0.016			0.013	-0.490
			(0.097)	(0.257)			(0.084)	(0.319)
App^2 x Product innovator				-0.013				0.070
				(0.032)				(0.043)
App x Process innovator			0.103	0.204			-0.025	0.692**
			(0.136)	(0.300)			(0.103)	(0.349)
App^2 x Process innovator				-0.011				-0.087**
				(0.033)				(0.044)
Control variables								
Firm size	0.241**	0.242**	0.239**	0.241**	0.302***	0.304***	0.302***	0.317***
	(0.101)	(0.101)	(0.101)	(0.101)	(0.107)	(0.107)	(0.107)	(0.108)
Firm age	-0.008	-0.008	-0.008	-0.008	0.008	0.008	0.008	0.008
	(0.019)	(0.019)	(0.019)	(0.019)	(0.022)	(0.022)	(0.022)	(0.022)
MNC	0.640***	0.640***	0.635***	0.631***	0.173	0.177	0.173	0.147
	(0.210)	(0.210)	(0.212)	(0.212)	(0.244)	(0.245)	(0.244)	(0.246)
R&D unit	0.810***	0.812***	0.795***	0.802***	0.207	0.203	0.206	0.184

Variables	Collaboration with companies				Collaboration with PRIs			
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
	(0.227)	(0.227)	(0.227)	(0.227)	(0.227)	(0.228)	(0.228)	(0.228)
R&D intensity	-0.151	-0.175	-0.174	-0.169	0.335	0.341	0.335	0.447
	(1.341)	(1.346)	(1.357)	(1.351)	(0.784)	(0.782)	(0.787)	(0.783)
OBM	-0.042	-0.037	-0.034	-0.030	-0.124	-0.123	-0.126	-0.133
	(0.150)	(0.151)	(0.151)	(0.151)	(0.148)	(0.148)	(0.148)	(0.149)
Grant	0.790***	0.789***	0.769***	0.759***	0.533**	0.532**	0.532**	0.537**
	(0.236)	(0.236)	(0.237)	(0.237)	(0.213)	(0.213)	(0.213)	(0.214)
Knowledge intensity	-0.247	-0.250	-0.249	-0.256	-0.492	-0.493	-0.494	-0.496
	(0.448)	(0.448)	(0.445)	(0.447)	(0.376)	(0.376)	(0.376)	(0.378)
Source of inno[a]	0.928***	0.928***	0.931***	0.933***	0.540***	0.540***	0.540***	0.553***
	(0.076)	(0.076)	(0.076)	(0.076)	(0.073)	(0.073)	(0.073)	(0.074)
Year 2017	-0.260**	-0.263**	-0.261**	-0.261**	-0.831***	-0.834***	-0.832***	-0.827***
	(0.120)	(0.121)	(0.120)	(0.121)	(0.116)	(0.116)	(0.116)	(0.117)
Year 2018	0.789***	0.789***	0.789***	0.789***	-0.454***	-0.455***	-0.455***	-0.456***
	(0.111)	(0.111)	(0.111)	(0.112)	(0.109)	(0.109)	(0.109)	(0.110)
Wald Chi^2	589.9***	590.0***	592.1***	592.7***	215.8***	215.9***	215.9***	222.5***
Pseudo R^2	0.332	0.332	0.333	0.333	0.159	0.159	0.159	0.164
Log likelihood	-594.0	-593.9	-592.8	-592.6	-571.0	-571.0	-571.0	-567.7
No. of observations	2,486	2,486	2,486	2,486	1,887	1,887	1,887	1,887

Standard errors are reported in parentheses, [a] importance of each partner associated with the dependent variable as a source of innovation
* significant at $p < 0.1$, ** significant at $p < 0.05$, *** significant at $p < 0.01$

E.4 Estimates of the logistic models on a firm's propensity to collaborate with consultants and competitors

Variables	Collaboration with consultants				Collaboration with competitors			
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
App	0.247**	0.556**	0.104	0.473	0.172*	0.354	0.171	0.451
	(0.102)	(0.237)	(0.149)	(0.426)	(0.095)	(0.237)	(0.119)	(0.359)
App^2		-0.041		-0.050		-0.017		-0.022
		(0.026)		(0.054)		(0.020)		(0.027)
Product inno.	0.002	-0.027	-0.369	-0.667	-1.101***	-1.156***	-1.093**	-2.174**
	(0.270)	(0.272)	(0.373)	(0.635)	(0.400)	(0.409)	(0.522)	(0.882)
Process inno.	0.339	0.279	0.345	0.486	0.855*	0.843*	0.810	2.089*
	(0.296)	(0.299)	(0.485)	(0.661)	(0.508)	(0.512)	(0.749)	(1.128)
Interaction effects								
App x Product innovator			0.253	0.494			-0.005	1.174
			(0.180)	(0.563)			(0.201)	(0.752)
App^2 x Product innovator				-0.027				-0.188*
				(0.073)				(0.098)
App x Process innovator			-0.010	-0.243			0.025	-1.398
			(0.209)	(0.505)			(0.311)	(0.897)
App^2 x Process innovator				0.032				0.202*
				(0.063)				(0.111)
Control variables								
Firm size	0.004	0.009	0.007	0.015	0.269	0.292	0.269	0.295
	(0.185)	(0.185)	(0.184)	(0.185)	(0.309)	(0.315)	(0.310)	(0.326)
Firm age	0.058	0.061	0.058	0.062	0.089	0.084	0.089	0.094
	(0.055)	(0.056)	(0.055)	(0.055)	(0.080)	(0.080)	(0.080)	(0.083)
MNC	0.925*	0.929*	0.908*	0.904*	0.145	0.168	0.144	0.204
	(0.498)	(0.505)	(0.499)	(0.510)	(0.722)	(0.723)	(0.722)	(0.740)
R&D unit	0.653	0.616	0.615	0.536	-0.024	0.049	-0.024	0.174

Variables	Collaboration with consultants				Collaboration with competitors			
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
	(0.457)	(0.457)	(0.463)	(0.467)	(0.552)	(0.562)	(0.553)	(0.577)
R&D intensity	-6.635*	-5.674	-5.344	-4.864	0.873	0.724	0.876	0.714
	(3.866)	(3.866)	(4.334)	(4.792)	(2.112)	(2.184)	(2.113)	(2.174)
OBM	0.072	0.056	0.079	0.048	0.501	0.523	0.501	0.552
	(0.257)	(0.258)	(0.258)	(0.262)	(0.354)	(0.356)	(0.356)	(0.358)
Grant	0.668*	0.643	0.702*	0.666	0.937	1.036	0.936	1.005
	(0.397)	(0.396)	(0.408)	(0.409)	(0.611)	(0.638)	(0.620)	(0.642)
Knowledge intensity	-0.414	-0.359	-0.367	-0.245	-1.593**	-1.617**	-1.591**	-1.654**
	(0.970)	(0.972)	(0.957)	(0.975)	(0.728)	(0.745)	(0.728)	(0.751)
Source of inno[a]	1.123***	1.146***	1.126***	1.152***	0.399***	0.396***	0.399***	0.406***
	(0.176)	(0.180)	(0.177)	(0.182)	(0.090)	(0.090)	(0.092)	(0.093)
Year 2017	-0.393	-0.406	-0.369	-0.377	-2.158***	-2.153***	-2.158***	-2.240***
	(0.252)	(0.253)	(0.255)	(0.257)	(0.384)	(0.383)	(0.386)	(0.400)
Year 2018	1.686***	1.698***	1.706***	1.731***	0.794***	0.809***	0.793***	0.891***
	(0.211)	(0.212)	(0.215)	(0.218)	(0.256)	(0.259)	(0.257)	(0.267)
Wald Chi^2	373.4***	374.9***	375.8***	378.5***	238.5***	239.2***	238.5***	242.9***
Pseudo R^2	0.518	0.521	0.522	0.526	0.565	0.567	0.565	0.576
Log likelihood	-173.4	-172.6	-172.2	-170.9	-91.76	-91.41	-91.76	-89.53
No. of observations	1,009	1,009	1,009	1,009	593	593	593	593

Standard errors are reported in parentheses, [a] importance of each partner associated with the dependent variable as a source of innovation
* significant at $p < 0.1$, ** significant at $p < 0.05$, *** significant at $p < 0.01$

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