OPEN INNOVATION AND FIRM PERFORMANCE IN HIGH-TECHNOLOGY INDUSTRIES

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Open Innovation and Firm Performance in High-Technology Industries

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

The rise of open innovation (OI) has recently received increasing attention from researchers and practitioners. It is widely believed that the implementation of OI would lead to better innovation performance and competitive advantage of a firm. However, anecdotal evidence shows that firms may encounter challenges in the implementation, such as unfavorable internal coordination and ineffective knowledge integration. This makes the performance of OI uncertain. The existing literature concerning the investigation of OI implementation is limited. The fundamental questions of whether and how firms can gain innovation benefits from OI are under-researched. Accordingly, we conducted two empirical studies to address these questions.

Our first study focuses on the impact of OI on firms' innovation performance (using number of patents as a proxy). Taking the knowledge-based view (KBV) of a firm, we argue that OI benefits firms by providing strategic knowledge for them to innovate. We collected data from 50 high-technology firms implementing OI between 2003 and 2016. Based on the collected data, we adopted an event study approach to examine the relationship between OI implementation and innovation performance. We find support that OI improves a firm's innovation performance.

To further investigate the underlying factors that may affect the impact of OI on innovation performance, our second study examines the contextual factors of knowledge absorptive capacity (KAC) (using R&D intensity as a proxy) and alliance portfolio size

(APS) (using the number of alliances as a proxy) in the relationship between OI implementation and innovation improvement. KAC and APS represent the ability to assimilate external knowledge and the availability of relevant knowledge and resources to help firms innovate, respectively. Given that the implementation of OI requires external knowledge acquisition and assimilation with internal knowledge for innovation, they act as facilitating factors for OI implementation. We also draw upon the KBV of a firm to postulate that KAC and APS have positive moderating effects on the relationship. A cross-sectional regression analysis based on the financial and alliance data of 37 high-technology firms is conducted. We find that higher KAC improves a firm's ability in knowledge integration when implementing OI, leading to higher innovation performance. Nevertheless, APS shows no moderating effect on the relationship between OI implementation and innovation improvement.

Overall, our two studies suggest that the implementation of OI is beneficial to high-technology industries and the impact of OI on innovation performance is strengthened by KAC. These findings have significant implications to both researchers and practitioners. From the theoretical perspective, this research contributes to a more comprehensive understanding of OI by examining its positive impact on innovation performance based on the KBV of a firm and identifying the observable characteristics of OI implementation in firms. This research also provides managerial implications to firms when making decision related to the implementation of OI. By understanding the innovation benefits imposed by OI and the contextual factor that can amplify the innovation benefits of OI, firms are able to obtain valuable insights from our study to employ OI for gaining competitive advantage.

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LIST OF ABBREVIATIONS

APS	Alliance Portfolio Size
GE	General Electric
IP	Intellectual Property
IT	Information Technology
KAC	Knowledge Absorptive Capacity
KBV	Knowledge-Based View
NIH	Not-Invented-Here
OI	Open Innovation
P&G	Procter & Gamble
R&D	Research and Development
USPTO	U.S. Patent and Trademark Office
WIPO	World Intellectual Property Organization
WSR	Wilcoxon Signed-Rank

CHAPTER ONE

INTRODUCTION

1.1 Research Background

Over the past two decades, firms have shifted the innovation model from closed to open. A closed innovation model follows a self-reliance philosophy that advocates individual research and development (R&D) (Benner and Tushman, 2015; Chesbrough, 2003). Strict control is given to a firm's product and process development and intellectual property (IP) to prevent internal knowledge from being revealed to the outside and imitated by others (Almirall and Casadesus-Masanell, 2010; Chesbrough, 2003, 2012a). Investments are made to hire experts into the business and keep their IP secret (Billington and Davidson, 2013; Chesbrough, 2003). It was mostly employed for gaining first mover advantages (Chesbrough, 2003; Chesbrough and Crowther, 2006). However, this model has been eroded by the changing external knowledge landscape (Chesbrough, 2003), the rise of information technology (Benner and Tushman, 2015; Billington and Davidson, 2013; Gómez et al., 2017; Yoo et al., 2012) and the dynamic market needs (Han et al., 2012). The growing availability of knowledge workers (e.g., university graduates, scholars, engineers and scientists) (Chesbrough, 2003; Gassmann et al., 2010; Lee and Schmidt, 2017) and rapid technological development (Baldwin and von Hippel, 2011; Billington and Davidson, 2013; Franke et al., 2013; Yoo et al., 2012) create an environment filled with abundant knowledge and information. Novel ideas and expertise are increasingly easy and quick to be found externally rather than invented inside a firm (Chesbrough, 2003). In order to innovate faster for the volatile market, firms are urged to open up their innovation process for external knowledge acquisition and assimilation (Fjeldstad et al., 2012; Garriga et al., 2013). The knowledge, including different domains of expertise, technologies and ideas, effectively stimulates inventions and facilitates new product and process development (Foss et al., 2013; Kornish and Hutchison-Krupat, 2017; Laursen and Salter, 2006; Ransbotham and Mitra, 2010). With the advent of the Internet, firms are even more able to reach diverse knowledge sources around the world (Baldwin and von Hippel, 2011; Billington and Davidson, 2013). As described by a R&D manager, "Before OI, the lab was our world; with OI, the world has now become our lab" (Chesbrough, 2017, p.38). The open model not only expands the access to numerous potential knowledge sources, but also saves time and cost in knowledge search and development for the firms' innovation activities. Thus, the closed innovation model is no longer the only promising way to succeed (Chesbrough and Crowther, 2006). Firms have progressively engaged in a larger and more diverse knowledge pool for greater innovation (Garriga et al., 2013). The open innovation model has begun gaining attention among industries (Boudreau, 2010; Du et al., 2014; Holgersson and Granstrand, 2017).

According to Chesbrough (2006), OI is defined as "the use of purposive knowledge inflows and outflows to accelerate internal innovation and expand the markets for external use of innovation, respectively" (p.1). It can be implemented through various forms such as online open forums or platforms (e.g., Open Innovation Drug Discovery Program from Eli Lilly), prize contests (e.g., Ecomagination from GE), occupying OI intermediaries (e.g., IdeaConnection and InnoCentive), IP exchange (e.g., technology licensing) and firms' co-development or collaborations (e.g., strategic alliance and joint ventures). These forms create a highly distributed innovation process connecting external parties across the firm's boundaries for knowledge exchange (Billington and Davidson, 2013; Chesbrough, 2017). Firms are able to obtain solutions and new ideas from the external crowd (Cassiman and Veugelers, 2006) while internal unused or underutilized know-how can be transferred to other potential businesses for further value generation (Chesbrough, 2007, 2012a; Parker and Van Alstyne, 2018). For instance, P&G launched the online open innovation platform (Connect and Develop), which shares their difficulties and technologies with the public. Interested parties (e.g., the "knowledge brokers" who have relevant knowledge) are invited to contribute new ideas or solutions to the platform for new product development and problem-solving. LEGO opens its software of a programmable robotics construction set (Mindstorms) to the public for idea generation in programming and design. A coding toolbox (Boost Creative Toolbox) was also launched with the software to confine and direct users to make feasible programs to the firm. Amazon shares its website infrastructure and provides online retailing services to outside retailers by charging them fees. This practice confers monetary benefits, magnifies the use of its own IT knowledge, and improves the website performance.

Anecdotal evidence indicates that OI is gaining popularity among industries. Chesbrough and Brunswicker (2014) found that 78 percent of 125 sample firms from low- to high-technology industries have implemented OI for five years or even longer. Continuous growth in management support and the use of OI are also acknowledged from the study. Moreover, about a 100 million of OI related articles have been published and increasing industry conferences have been held in recent years (Chesbrough, 2012a). The phenomenon implies that a widespread trend of OI implementation is fertilizing rapidly in both academic and industrial fields (Chesbrough, 2017; Chesbrough and Crowther, 2006; Gassmann et al., 2010).

Although previous studies show an emerging phenomenon of OI implementation, its innovation benefits and underlying challenges are still largely unexplored. Two cases are taken as typical examples in academia and industries to illustrate the benefits of OI implementation. First, P&G discovered about 45 percent of product development initiatives and more than 35 percent new product features externally through their OI platform, Connect and Develop (Huston and Sakkab, 2006). The external ideas helped the firm double up the innovation success rate to 70 percent after a six-year implementation of OI (Huston and Sakkab, 2006; Sakkab, 2007). Meanwhile, their R&D productivity increased by 60 percent with a 1.4 percent decrease in investment (Huston and Sakkab, 2006). Second, General Electric (GE) generated more than $200 billion in revenues from its OI platform, Ecomagination, from 2010 to 2015 (Chesbrough, 2017; Egan, 2015); $36 billion of the total revenue amount from cleaner-technology was generated with only a $2.3 billion R&D investment (Kumar, 2016). Apart from the cases, some scholars also discuss about the benefits of OI implementation. Billington and Davidson (2013) concur that using external ideas halves the times of a R&D project whereas Lakhani et al. (2006) reveal that a firm's R&D facilitated by an OI network is 20 times cheaper than a traditional closed innovation model.

However, despite OI benefits are observed to be gained in firms, scholars also point out three major challenges when implementing OI (Billington and Davidson, 2013; Boudreau, 2010; Brokaw, 2011; King and Lakhani, 2013; Laursen and Salter, 2006; Parker and Van Alstyne, 2018; Von Krogh et al., 2018). First, insufficient knowledge absorptive capacity (KAC) is mostly discussed (Billington and Davidson, 2013; Chesbrough, 2012a, 2017; Chesbrough and Crowther, 2006; Foss et al., 2011; King and Lakhani, 2013; Laursen and Salter, 2006; Lichtenthaler, 2008; Von Krogh et al., 2018). Caused by the lack of accumulated internal knowledge, incompatible internal cooperation and inappropriate use of existing know-how, a low capacity of knowledge absorption cannot provide adequate support to process and assimilate external knowledge. It may impede the integration and use of external and internal knowledge on innovation activities. Second, different costs are required to implement OI (Billington and Davidson, 2013), such as technological alignment cost, coordination cost (Almirall and Casadesus-Masanell, 2010), transaction cost (King and Lakhani, 2013; Terwiesch and Xu, 2008), communication cost and knowledge processing cost (Chesbrough, 2012a). These costs may create heavy financial burden on R&D activities, affecting the innovation. Third, a high level of IP protection (Alexy et al., 2009; Chesbrough, 2012a; Parker and Van Alstyne, 2018; Wadhwa et al., 2017). Given that some firms want to restrict the external use and exposure of their internal IP in the process of knowledge sharing under OI, over patenting and governance may be taken. These practices possibly prevent collaborations with other businesses which inhibit internal knowledge exploitation and external ideas exploration. Therefore, limited external knowledge contribution can be obtained for a firm’s process and product advancements.

A practical case of failed OI implementation is given. Quirky produces products invented by the public. It went bankrupt in 2015 with an overall expense of $150 million and net loss of $120 million although the OI platform was employed (Fixson and Marion, 2016). Possible major reasons are deficient KAC and unbearable OI operational costs. Being unable to identify and assimilate suitable knowledge matched with the business (Lee and Schmidt, 2017), the influx of external ideas drove the firm losing its primary focus on products and coherence in multiple product categories. Meanwhile, decreasing sales, due to the shifted resources put in the many changes and developments of over twenty-six product categories, could not support the firm's R&D activities and the business. Hence, the firm failed in OI implementation.

The above cases and literature have shown both benefits and challenges of OI, setting a paradoxical choice for firms to decide an actual implementation. Yet existing studies are limited for both researchers and practitioners to refer to. Continuous debate in OI implementation urges us to investigate further on the issues. In this research, we argue that OI contributes to internal and external knowledge use through effective knowledge flows between a firm and external parties for increasing innovation performance.

1.2 Literature on Open Innovation and Research Motivation

OI implementation has been more prevalent in recent years that receives much attention from different research disciplines (Chesbrough and Brunswicker, 2014; Lee and

Schmidt, 2017). Relevant studies and literature mostly come from the fields of technology and innovation management, strategic management and organizational behavior and learning (Garriga et al., 2013; Gassmann et al., 2010; West and Bogers, 2014). Yet the knowledge gained from these fields has not specifically shed light on the impact of OI on innovation performance and the determinants of successful OI implementation (Chesbrough, 2012a; Gassmann et al., 2010; Levine and Prietula, 2014). Most of the existing research focuses on the practical implementation process of OI (Billington and Davidson, 2013; King and Lakhani, 2013; Lee and Schmidt, 2017; Terwiesch and Xu, 2008), incentives or reward systems to knowledge contributors in OI (Fleming and Waguespack, 2007; Franke et al., 2013), comparisons between closed and open innovation models (Alexy et al., 2009; Almirall and Casadesus-Masanell, 2010; Baldwin and von Hippel, 2011; Litchtenthaler, 2008), IP management (Brem et al., 2017), drivers of OI implementation (Belenzon and Schankerman, 2015; Bhaskarabhatla and Hegde, 2014), the implementation challenges (Almirall and Casadesus-Masanell, 2010; Boudreau, 2010; Brokaw, 2011; King and Lakhani, 2013; Von Krogh et al., 2018; Litchtenthaler et al., 2011) and its applications (Benner and Tushman, 2015; King and Lakhani, 2013). Some researchers have studied the relationship between OI and innovation performance (Caputo et al., 2016; Cheng and Huizingh, 2014; Laursen and Salter, 2006). However, they lack clear measurement of OI to identify the samples and mostly rely on qualitative research methods. Moreover, different interpretations of innovation in those studies with conflicting results may generate inconsistent implications that are not applicable to the general context of OI. For instance, Laursen and Salter (2006) revealed that external knowledge search through OI and innovation performance are curvilinearly related (taking an inverted U-shape), based on the secondary data from a U.K. innovation survey; Cheng and Huizingh (2014) assessed the positive relationship between OI and innovation performance by conducting interviews with Taiwanese service companies; Caputo et al. (2016) demonstrated that there is no significant effect of OI on innovation performance by analyzing the secondary data of biopharmaceutical firms; Bayona-Saez et al. (2017) examined an inverted U-shape relationship between OI and innovation performance in the Spanish food and beverage based through surveys. The indicators of innovation performance in these studies include new product or service innovativeness, customer performance, financial performance, R&D productivity, and patent marketability and growth. Limited understanding can be obtained from the scant literature. This lack of research may account for the difficulties in sample identification and data collection, considering that OI is a relatively new concept and less understood in academia. Hence, a great deal of knowledge and empirical studies on OI implementation is needed (Chesbrough and Brunswicker, 2014; Parker and Van Alstyne, 2018).

In addition, determinants of a successful OI implementation for business improvements are not well explored (Billington and Davidson, 2013; Wooten and Ulrich, 2017). While much effort has been put into the external knowledge search and transfer (Laursen and Salter, 2006; Lee and Schmidt, 2017; Terwiesch and Xu, 2008), investigation and explanation on external knowledge integration for internal use under OI is limited. The related issues are essential, considering that OI provides strategic innovation benefits through effective external knowledge integration and exploitation (Chesbrough, 2017;

Kornish and Hutchison-Krupat, 2017; Litchtenthaler, 2008). Possible determinants are KAC and APS. KAC determines a firm's ability to process appropriate external knowledge for internal innovation (Foss et al., 2013; Wagner and Bode, 2014), which affects knowledge assimilation and its use in OI (Billington and Davidson, 2013; Laursen and Salter, 2006). Meanwhile, APS represents the availability of complementary resources and knowledge retrieved from alliances. It influences the creation of useful knowledge under OI for innovation purposes (Gassmann et al., 2010; Han et al., 2012). In order to implement OI successfully, we attempt to uncover and assess the underlying factors altering the effect of OI implementation on innovation performance.

Moreover, scant research investigated OI as a whole concept including both inbound and outbound OI (Chesbrough and Crowther, 2006). Referring to the definition given by Chesbrough (2006, p.1), OI uses both knowledge inflows (inbound OI) and outflows (outbound OI) to create advantages on innovation. Dyadic knowledge flows are established between the firm and external parties (Billington and Davidson, 2013; Chesbrough, 2011). While knowledge inflows acquire external knowledge for idea generation and problem-solving (Chesbrough, 2003, 2011, 2012a, 2017; Chesbrough and Crowther, 2006; Lichtenthaler et al., 2011), knowledge outflows share internal unused and underutilized knowledge to the outside parties for ideas and value exploration (Chesbrough, 2012a, 2017; Chesbrough and Crowther, 2006; Lichtenthaler et al., 2011). The practice can be understood as a reciprocal process that every outbound effort generates an inbound effort from the others, vice versa (Chesbrough and Crowther, 2006). Two kinds of OI activities simultaneously occur under the implementation of OI and they are mutually complemented (Gassmann et al., 2010). The use of both flows encourages knowledge exchange and shared R&D effort with different outside parties (Billington and Davidson, 2013; Chesbrough, 2017). However, most of the existing research only focuses on the inbound OI which overlooks the other part of OI. For instance, Laursen and Salter (2006) and Bayona-Saez et al. (2017) only considered the effect of inbound OI on innovation performance. In order to generate a more comprehensive view on OI investigation, we put stress on the whole concept of OI which involves both inbound and outbound OI to analyze its impact on innovation performance.

Additionally, different from a system or a set of principles (e.g., business intelligence system or ISO 9001) that firms can install or follow, OI is a strategy originating from a concept applied to the whole business model. It associates with all the things in a firm from employees' attitude to the organizational culture, from manufacturing processes to product distribution, and from knowledge to operations management. Researchers and practitioners cannot easily recognize the actual implementation of OI in firms. Although definitions are given by different scholars (Almirall and Casadesus-Masanel, 2010; Chesbrough, 2003, 2017; Terwiesch and Xu, 2008), they do not provide specific and observable characteristics of OI implementation. Most studies follow the definition given by Chesbrough (2006) which is mentioned before. However, because of the conceptual nature of the open model, qualitative research methods (e.g., surveys and interviews) (Chesbrough and Brunswicker, 2014; Gómez et al., 2017; Litchtenthaler, 2008) or simulations (Almirall and Casadesus-Masanell, 2010; Parker and Van Alstyne, 2018; Terwiesch and Xu, 2008) have been employed to investigate OI. For instance, Gómez et al. (2017) use data from the Survey on Business Strategies database to address the relationship between OI, IT and innovation performance; Parker and Van Alstyne (2018) developed a sequential innovation model to analyze the optimal level of openness of an OI platform for better innovation. Limited insights are drawn from the research. In light of the continuous trend of OI implementation, a research focus on the practical measurement of OI is fundamental and crucial to contribute in empirical studies and OI development. We aim to identify the observable characteristics and provide a more explicit measurement of OI implementation to help achieve a deeper OI investigation.

Further, little research assesses the impact of OI in high-technology industries. Forefront knowledge in this segment is of particular importance, considering that the industries are the pioneering implementers of OI who play a pivotal role in OI development (Chesbrough and Crowther, 2006). Anecdotal evidence indicates that other industries follow the OI practices implemented in high-technology industries after witnessing its positive impact (Chesbrough, 2003). However, scant studies have been conducted to examine and verify whether actual OI benefits are obtained by the firms in high-technology industries. Existing literature only focuses on different OI impact on the firms with various sizes (Brem et al., 2017; Foss et al., 2011; Lichtenthaler; 2008), specific product categories such as handheld computer service (Boudreau, 2010) and in the service industry (Cheng and Huizingh, 2014), which cannot represent the general performance of OI implementation in high-technology industries. Hence, we attempt to provide evidence on this issue to consolidate the understanding of OI.

1.3 Research Aim and Objectives

The aim of this study is to investigate whether and how OI affects firms' innovation performance. To achieve this aim, we set two objectives listed below.

1. To examine the effect of OI on firm performance, in terms of the innovation performance.
2. To explore the moderating effects of knowledge absorptive capacity and alliance portfolio size on the relationship between OI and innovation performance.

1.4 Scope of This Research

This research is conducted in high-technology industries. The industries are characterized by short product life cycles, rapid product and process development, high environmental uncertainties, and a high level of ambiguous information (Chandrasekaran et al., 2012; Jayanthi and Sinha, 1998). To fulfill ever-changing market needs, they need efficient and effective innovation activities (Jayanthi and Sinha, 1998). Given that OI provides a timely access to different domains of knowledge and environmental information, it particularly benefits firms in the high-technology industries to tap into updated and diverse knowledge. The knowledge and information help create a competitive and dynamic innovation process aligned with the volatile market. Meanwhile, a higher degree of openness of the innovation process is pursued by the industries than low-technology industries (Lichtenthaler, 2008). Regarding the characteristics of high-technology industries, we consider that OI contributes to the high-technology industries' innovation performance in our study.

In addition, we focus on the listed high-technology firms in the U.S. stock market. We believe that the firms possess with adequate financial resources to implement OI while they confront with more innovation activities to sustain their market positions. Hence, we also consider this scope in our research.

1.5 Research Approaches and Findings

To achieve our research objectives, we conduct two studies of OI implementation. Our first study investigates the impact of OI on innovation performance, using the number of patents as a proxy. Based on the data collected from 50 high-technology firms between 2003 and 2016, we adopted the event study methodology to test our argument. The methodology was first adopted by the field of financial economics to measure the reactions of firms' stock prices to a sudden corporate or public issue (Hendricks and Singhal, 2005; Kothari and Warner, 2007). We apply this method to measure the impact of OI implementation, overcoming the difficulties in quantifying the abnormal performance of innovation in firms. Results show that OI leads to higher innovation performance, in terms of an increased number of patents, three years after the implementation.

Our second study examines the moderating effects of KAC and APS in the relationship between OI and innovation performance, R&D intensity and number of alliances are used as the proxies respectively. Based on the data collected from 37 firms, we conducted a cross-sectional regression analysis to evaluate how the moderating variables influence the innovation performance over the five-year period (from year -2 to year +3). Results show that superior KAC amplifies the impact of OI on innovation performance three years after its implementation; whereas APS does not give a moderating effect to the relationship between OI and innovation performance.

This research provides empirical evidence that the implementation of OI enhances firms' innovation performance. In addition, higher KAC strengthens the positive impact of OI on innovation. However, the results reveal that APS does not have a moderating effect on OI in firms' innovation performance.

1.6 Research Significance

While the debate over the business value of OI implementation continues among researchers and practitioners, scant empirical studies have been done to evaluate the innovation benefits of OI. Our research contributes insights to the understanding and development of OI. We examine whether and how OI affects firms' innovation performance, in terms of the number of patents. Performance changes under the moderating effects of KAC and APS are also assessed. The results provide empirical evidence to the research areas in operations management and support firms implementing OI for business purposes.

On the theoretical side, this research enriches the understanding of OI in operations management and innovation literature. It does not only confirm and document the positive impact of OI on innovation performance but also reveals the moderating factor that causes the impact to vary across firms, from the first and second study. We take the knowledge-based view (KBV) of a firm to develop the associations between OI, the moderating effects of KAC and APS, and innovation performance. Our empirical evidence shows that there is a positive relationship between OI and innovation performance. In addition, higher KAC facilitates OI to achieve better innovation performance in firms. The findings enable researchers to understand how OI improves innovation performance through the use of knowledge and how such positive impact varies under different levels of KAC. Moreover, we identify the characteristics of OI implementation in firms with a more concrete definition. It contributes to future empirical research in sample recognition, data collection and analysis in the related fields for OI investigation. Furthermore, we confirm the innovation benefits of OI in high-technology industries, assuring the pioneering and advantageous position of this segment in OI implementation. Overall, this research advances our knowledge in OI implementation and provides insights to future OI studies.

On the practical side, this research generate managerial insights to operations and innovation managers, particularly in high-technology firms. We document the innovation benefits of OI and explore the underlying factor that moderates the relationship between OI and innovation performance. Our first study reveals that it takes at least three years to realize the positive impact of OI on innovation after its implementation. It helps managers organize a better R&D plan consisting of different innovation activities and their expected returns from OI implementation. Meanwhile, we demonstrate that the innovation improvements can be amplified through higher KAC, in terms of R&D intensity. In other words, managers may consider putting more effort in R&D if greater innovation performance is aimed to achieve under OI. The above results provide empirical support and guidance for firms to implement OI for innovation purposes.

1.7 Organization of This Thesis

This thesis is organized in four chapters.

Chapter One introduces the research background, motivation, objectives, scope, approaches, main findings, and significance of this thesis. Chapter Two presents our first study from the literature review, hypothesis development, testing results, and the discussion and implications. It investigates the effect of OI on innovation performance. Chapter Three presents our second study also from the literature review, hypothesis development, testing results, and the discussion and implications. It examines the moderating effects of KAC and APS on the relationship between OI and innovation performance. Chapter Four concludes this thesis with a summary of the two studies and their general contributions. In addition, we discuss the limitations of this research and recommendations for future research.

CHAPTER TWO

STUDY 1: THE IMPACT OF OPEN INNOVATION ON INNOVATION PERFORMANCE

2.1 Theoretical Background and Hypotheses Development

2.1.1 Open Innovation

With reference to prior research (Benner and Tushman, 2015; Chesbrough, 2012a, 2017; Cheng and Huizingh, 2014; Fleming and Waguespack, 2007; Gassmann and Enkel, 2004; Terwiesch and Xu, 2008), we define OI as a strategy that purposively uses the communities formed by internet-based implementation practices connecting external individuals beyond the focal firm's boundaries and recognizes potential knowledge and commercialization paths to be exploited along the innovation process. It espouses the principle of openness and emphasizes dynamic knowledge flows and knowledge use (Billington and Davidson, 2013; Chesbrough, 2011) that relies on an online community.

Connecting to the community, dyadic knowledge flows occur between knowledge brokers and the firm for ideas and technologies exploitation and exploration. Three kinds of flows can be identified under OI to transfer knowledge. On one hand, knowledge inflows (also known as inbound OI) acquire external knowledge to internal innovation activities for idea generation and problem-solving (Chesbrough, 2003, 2011, 2012a, 2017;

Chesbrough and Crowther, 2006; Lichtenthaler et al., 2011). On the other hand, knowledge outflows (also known as outbound OI) share internal unused and underutilized knowledge to the outside parties for ideas and value exploration (Chesbrough, 2012a, 2017; Chesbrough and Crowther, 2006; Lichtenthaler et al., 2011). These two kinds of knowledge flows can be implemented together which is called coupled OI (Cheng and Huizingh, 2014; Gassmann and Enkel, 2004). It involves knowledge exchange between different parties and shared R&D effort through collaboration. These three kinds of knowledge flows in OI build ties with the outsiders and benefit firms in knowledge use for improved firm performance. In this research, we consider OI as a whole concept including all kinds of the knowledge flows to develop a more comprehensive understanding of its impact.

Thanks to the rapid development of IT, it simplifies and expedites the formation of communities for a firm to obtain knowledge flows in OI (Billington and Davidson, 2013; Bockstedt et al., 2015; Gómez et al., 2017). Advanced electronic products and the Internet facilitate firms to connect with the world freely by setting up online OI platforms, contests or forums. These practices create communities involving relevant knowledge brokers as participants to contribute to the firm. Without time and district restrictions, distant dispersed knowledge sources can be reached promptly and cheaply. The wider and more resourceful knowledge pool outside not only increases the chance to identify potential external knowledge for internal use, but also reduces external knowledge search cost (Boudreau, 2010; Chesbrough, 2003, 2012a; Gómez et al., 2017; Parker and Van Alstyne, 2018). Meanwhile, frequent direct communications with knowledge brokers can be established. Given that communication helps mitigate misunderstanding and confusion of new knowledge assimilation, a shared interpretation between parties and a more cohesive understanding among employees are achieved (Fugate et al., 2009). More effective knowledge transfer under OI is thus obtained. Hence, with the assistance of IT, there exists a growing popularity of firms to employ online practices in OI implementation (Gómez et al., 2017; Laursen and Salter, 2006). We focus on examining OI that uses the internet-based implementation practices, in view of the emerging adoption trend (Benner and Tushman, 2015).

2.1.2 Characteristics of Open Innovation Implementation in Firms

With reference to previous research work and observations on practical cases, we list three characteristics to identify OI implementation in firms. Firms who are found to have all these characteristics are regarded as the implementers.

1) The use of Internet-based implementation practices

   We focus on the emerging internet-based implementation practices of OI. The implemented firms should form the communities for creating knowledge flows via internet-based practices, such as online platforms, forums, websites, open source software and open programs. These practices provide firms accesses to the outside anytime and anywhere with low setup cost (Billington and Davidson, 2013; Gómez et al., 2017; Franke et al., 2013). Knowledge brokers with relevant expertise are gathered in the online community, giving ideas or solutions to the firm. For instance, GE invites participants to contribute solutions to the innovation issues on their online open platform, Geniuslink.

2) A community created through an open call

   A community is the core of OI (Benner and Tushman, 2015). OI was first understood and implemented as a series of collaboration between two parties that opened up their internal innovation processes (Chesbrough, 2012a). Over time, the open-up process that operates through an open call enables the firm to invite external parties in analogous, different, or same fields and form a community. A broader range of knowledge is provided for internal innovation and problem solving. It makes the fundamental difference between a traditional closed and an open innovation model (Baldwin and von Hippel, 2011; Chesbrough, 2003, 2012a; Laursen and Salter, 2006).

3) External parties' involvement for knowledge exchange

   Within the community, external parties should be involved for knowledge exchange with the firm (Kornish and Hutchison-Krupat, 2017). The external parties refer to all the organizations or individuals beyond the firm boundaries (Billington and Davidson, 2013; Chesbrough, 2003; Laursen and Salter, 2006). For instance, customers, suppliers, competitors, consultants, universities, research institutes or consortia, conference participants, and professional and industrial associations (Franke et al., 2013; Laursen and Salter, 2006; Wadhwa et al., 2017). Unless connections are built with them, knowledge can be exchanged to explore and identify new knowledge for internal innovation use (Lichtenthaler, 2008; Terwiesch and Xu, 2008). Common modes employed to exchange knowledge between firms are IP licensing, agreements of collaboration or co-development, strategic alliance, joint ventures crowdsourcing, and idea competitions and co-creation (Chesbrough and Brunswicker, 2014).

2.1.3 Examples of Open Innovation Implementation

Firms with the above mentioned three characteristics are regarded as the OI implementers. We provide some examples below to illustrate the practical OI implementation in high-technology industries.

For instance, in 2005 GE, one of the world's major companies in providing advanced technology, service, and finance, realized the increasing external threats to its related business fields (Chesbrough, 2012b; Egan, 2015). In order to cope with the environmental change, the company established a campaign called Ecomagination which used an online innovation platform to connect with universities and companies in service and medical industries. At first, the company used the platform to promote their commitment in clean technology and sustainable infrastructure development. However, it did not help much in meeting the dynamic market needs and competing with others. Later in 2010, it took the move to launch the first Ecomagination Challenge on the platform for collecting ideas of smart grid software technologies development (Chesbrough, 2012b). The public, including startups, universities, research institutes, governments, and other inventors, was asked openly to submit ideas or technologies in the competition. It created a community for the acquisition of smart grid software knowledge. Nearly 4,000 submissions were received from 1,600 organizations from 160 countries. Five winners were given $100,000 cash awards and fourteen participants were selected together to help develop and expand the business in the aspects of energy storage, utility security, energy management software and electric vehicle charging services (Chesbrough 2012b; Idelchik and Kogan, 2012; Mascioni, 2011). Their ideas and knowledge contributed to the company in different stages along the innovation process and reduced cost in R&D. Until now, GE is still employing the online platform and holding challenges of various business problems to seek knowledge from the outside.

Another online open platform of GE, GENIUSLINK ™, was also launched in 2013 to match internal resources or technologies with different industrial needs. It serves as an intermediary website for companies to post challenges on and to help them find solutions from both GE's internal expertise and the public. Knowledge exchange is allowed to occur between the focal firm and outsiders with relevant knowledge. This platform further facilitates GE to discover new opportunities for internal knowledge use and external knowledge exploration.

More examples of OI implementation drawn from the announcements from Factiva and other sources are presented in Table 2.1.

Table 2.1 Examples of OI Implementation

Company	Text extracted from data sources
AstraZeneca	To expand our problem-solving ecosystem, we are openly sharing key R&D challenges and looking for ways to collaborate with anyone willing to offer innovative solutions. We partner with open innovation pioneer InnoCentive® (an online OI intermediary) to crowdsource solutions. Rewarded solution submitters will be invited for R&D collaboration.
Siemens	Siemens launched Mobility IDEA (Improving Design and Engineering for All) Contest. Using the IDEA Contest website, powered by Mindjet's Spigit Engage platform (an online OI intermediary), members of the general public, including university students, will be asked to submit ideas for one of five scenarios that address a specific challenge faced by the traffic industry. Contest winners will be invited to participate in a product prototyping workshop with Siemens technology experts.
Cisco	Cisco I-Prize innovation contest was launched to help identify a business opportunity for Cisco. The company invited entrepreneurs from all over the world to join a collaborative online forum where they could brainstorm and comment on business and technology ideas, form teams, and draft business plans for a chance to join Cisco and help develop their business idea.
Toyota Motor	Since 2004, Toyota has been running a crowdsource design

Corporation	competition called the Toyota Dream Car Art Contest on the contest website. It is one of the largest global art contests for children in the world, and kids in several age categories are invited to draw pictures of their dream cars. The solutions provide ideas for car designs and functionality improvement.
Eli Lilly and Company	Eli Lilly and Company announced the launch of a new open innovation platform (titled "Open Innovation Drug Discovery ") designed to help build the company's pipeline of tomorrow and identify molecules that may have application for treating multi-drug resistant tuberculosis. The platform offers Lilly's proprietary computational and informatics tools to aid scientists in the world in the design and selection of molecules. Once a scientist submits a molecule to the website and it meets certain specified requirements, Lilly tests and evaluates it for its uniqueness and potential to be further optimized into a drug candidate of the firm.

2.1.4 Knowledge-Based View of a Firm

The knowledge-based view (KBV) of a firm posits that knowledge is the fundamental strategic resource from which firms create value and it leads to competitive advantage (Choo et al., 2015; Foss et al., 2013; Grant, 1996; Hult et al., 2006). The rationale behind this is that rare, unique, inimitable and idiosyncratic knowledge creates performance differences beyond rivals (Arend et al., 2014; Hult et al., 2006). The specific features are embedded in two types of knowledge in a firm: explicit and tacit knowledge. Explicit knowledge is the solid knowledge that can be codified and transferred through verbal communication or written documents, such as reports and records (Dutta and Weiss, 1997; Ranft and Lord, 2002). Employees can store and diffuse it in the firm through a precise way for internal organizational learning and exploitation. Tacit knowledge is the accumulated experience and intelligence of a firm which is hard to transfer and replicate, such as workers' skills and abilities, operational routines, and specialized expertise (Arend et al., 2014; Dutta and Weiss, 1997; Ranft and Lord, 2002). Other firms can only learn it by observing its actual application, creating a slow, costly and uncertain knowledge transfer beyond the firm's boundary (Grant, 1996).

A firm can attain the strategic knowledge to obtain knowledge-based advantage through internal knowledge accumulation and external knowledge integration (Arend et al., 2014; Choo et al., 2015; Ranft and Lord, 2002). The approaches create a heterogeneous knowledge base which reflects the intellectual capital of the firm, preventing easy imitation and transfer across firms (Choo et al., 2015). First, internal knowledge accumulation is achieved over time and cultivated in the firm-specific organizational, historical and social context, developing distinctive knowledge of the firm (Nag and Gioia, 2012; Ranft and Lord, 2002). Under a particular environment with the firm's features, unique and tacit knowledge such as technological know-how, specialized manufacturing methods and human capital are generated. It serves as the primary element to support the business and create value for the firm. Apart from the internal knowledge accumulation, external knowledge integration also produces strategic knowledge which benefits firm performance. Previous research indicates that external knowledge integration helps create uniqueness and sustainable value on product and process development (Grant, 1996; Nickerson and Zenger, 2004). Consisting of new ideas and information from different domains, external knowledge provokes knowledge attacks to the internal environment. The knowledge attacks challenge the firm's existing business practices, rules and traditional perspectives of product and process development, bringing new views and helping brainstorm ideas and solutions to the firm (Fang, 2011). Firms who are able to learn and nurture the external knowledge as the complementary input for internal use can obtain a critical source of competitive advantage (Arend et al., 2014; Choo et al., 2015; Ranft and Lord, 2002). Knowledge advancement can be achieved with the influx of external dynamic and updated knowledge. In this regard, the KBV of a firm further emphasizes that the formation of a firm's strategic knowledge relies on external knowledge integration to generate knowledge-based advantage such as innovation improvement (Grant, 1996; Nickerson and Zenger, 2004; Ranft and Lord, 2002).

2.1.5 Open Innovation and Innovation Performance

Innovation is the center of a firm's success. It is defined as the generation of an idea or behavior new to the adopting entity (Damanpour, 1996; Zhou and Wu, 2010). Firms generally set two innovation objectives to achieve. First, product innovation objectives include new product and service development and existing product and service improvement such as advanced functions or quality (Leiponen and Helfat, 2010). Second, process innovation objectives include cost reduction and improved manufacturing flexibility (Leiponen and Helfat, 2010). These objectives direct firms to innovate for specific value creation (Adner and Kapoor, 2010; Makri et al., 2006; Rindova and Petkova, 2007). Different types of innovation enhance a firm's competitiveness while offering opportunities to enter new markets (Damanpour, 1996). For instance, the adoption of improved or new organizational structures, administrative systems, manufacturing plans or programs increases the efficiency of internal operations; the introduction of advanced or new products or services and technologies helps satisfy diverse customer needs and expand the markets. They are considered as responses to the changes of or as actions to influence the environment (Adner and Kapoor, 2010; Damanpour, 1996; Sood and Tellis 2009). They help cope with both internal and external changes over time, such as advancements in business growth, changing industrial structure and environmental needs (Rindova and Petkova, 2007; Smith and Tushman, 2005; Sood and Tellis, 2009; Strebel, 1987). Hence, firms with better innovation performance are perceived to have higher adaptability to the volatile market and eventually to achieve a more competitive status (Zhou and Wu, 2010), especially in high-technology firms (Makri et al., 2006).

Successful and sustainable innovation requires a diversified knowledge pool and external knowledge assimilation. Previous literature indicates that different challenges exist along the innovation process (Adner and Kapoor, 2010), from the stages of ideation, concept evaluation, design, and development to testing and commercialization (Lee and Schmidt, 2017). Some typical challenges are a lack of ideas, failed integration of external components into business, lagged technological development, poor technological capability, and slack internal resources and knowledge, which constrain a firm to innovate (Adner and Kapoor, 2010; Rindova and Petkova, 2007; Smith and Tushman, 2005; Zhou and Wu, 2010). To overcome these challenges and achieve better innovation, external search and associations with diversified external parties are the keys (Freeman, 1991; Leiponen and Helfat, 2010; Lind and Zmud, 1991). The rationale behind this is the knowledge and information exchange and combination between the focal firm and outsiders (Cassiman and Veugelers, 2006; Lahiri and Narayanan, 2013; Lind and Zmud, 1991). Given that external knowledge encompasses various technological or industrial domains, firms are able to expose themselves in unfamiliar fields and absorb different expertise and technological know-how. It triggers breakthroughs and solutions for innovation problems (Adner and Kapoor, 2010; Damanpour, 1996; Leiponen and Helfat, 2010; Zhou and Li, 2012). Fang (2011) also explains that different knowledge sources challenge traditional practices which help brainstorm and discover new product or process developments. Meanwhile, the external expertise, skills, technologies, methods or systems can be learned and applied to internal R&D for augmentation (Cassiman and Veugelers, 2006; Lichtenthaler and Ernst, 2012; Zhou and Li, 2012). Hence, diversified aspects of external knowledge are crucial for a firm to enhance its internal knowledge for achieving successful innovation.

OI is likely to enhance the innovation performance of a firm (Gómez et al., 2017). The relationship can be understood through the KBV of a firm. By adopting different implementation practices such as online open platforms and contests, OI implementers are able to establish purposive knowledge flows with globally dispersed knowledge sources. The flows allow particular and relevant knowledge which is suitable for internal use to be obtained from the outside. The external knowledge can be integrated and nurtured under the firm-specific context, becoming the heterogeneous and tacit knowledge for the firms to make use of while preventing rivals to replicate. It also serves as an inspiring, new and complementary input to internal knowledge base for idea generation and problem-solving (Andriani et al., 2017). On one hand, new knowledge from uncharted domains provokes knowledge attacks to internal environment. It initiates breakthroughs and introduces different views of product or process development to a firm (Fang, 2011). Meanwhile, innovation opportunities may be explored during the process of knowledge exchange with external parties (Chesbrough 2003, 2012a, 2017). Potential product advancements or other innovation initiates are possibly discovered (Chesbrough, 2003, 2012a). For instance, technological or product combinations may be explored to add auxiliary features or advanced functions in existing products. On the other hand, the firms may learn new knowledge or skills to solve internal innovation problems by seeking required techniques and solutions from the outside knowledge brokers. Previous researchers also concur that OI enhances new product and service innovativeness and helps tackle innovation problems (Bayona-Saez et al., 2017; Cheng and Huizingh, 2014). Hence, OI is likely to improve a firm's innovation performance by granting the strategic knowledge for internal use. We hypothesize that:

Hypothesis 1 (H1). *Open innovation improves the implemented firm's innovation performance.*

2.2 Methodology

2.2.1 Sample and Data Collection

We focus on the U.S. listed high-technology industries in this study for several reasons. First, there is a close association between OI and high-technology industries. The industries are characterized by rapid innovation cycles and simultaneously a high level of environmental uncertainties and ambiguous information which pose difficulties in innovation activities (Chandrasekaran et al., 2012; Jayanthi and Sinha, 1998). OI enables updated and diverse knowledge flowing into the firm that helps understand the enigmatic market while finding potential solutions and ideas to innovate (Billington and Davidson, 2013). Previous studies also indicate that a higher level of external knowledge search is undertaken by high-technology than low-technology industries (Laursen and Salter, 2006). Moreover, they are considered as the pioneers of OI implementation (Chesbrough and Crowther, 2006). Therefore, we believe that OI is especially pertinent to and benefits the highly competitive and dynamic high-technology industries. Meanwhile, listed firms in the U.S. stock market allow us to obtain available data and public announcements from different sources for analysis. Thus, we collect samples in this sector. With reference to prior studies (Beckman and Sinha, 2005; Rosenzweig and Roth, 2004), we recognize high-technology firms in the following sectors as our sample:

1) high-technological product manufacturing;

   e.g., computers and office equipment, consumer electronics, communications equipment, electronic components and accessories, semiconductors and related devices, industrial electronic, photonics, chemicals, defense electronics, radiotelephone, and telephone

2) high-technological services;

   e.g., 3D/4D printing, artificial intelligence, autonomous driving technologies, online services, virtual reality technologies, telegraph communications, cable and television services, software and computer-related services

3) health science;

   e.g., biotechnology, medical equipment or supplies, pharmaceuticals

4) energy;

   e.g., electric power generation and natural gas processing

We selected the corresponding sectors or used keywords of the above relevant industry or product or service names to identify the sample firms in Factiva or web search. Only firms listed in the U.S. stock market are included. A few examples of the identified firms are Eli Lilly (pharmaceutical), Apple (consumer electronics), Amazon (electronic service), IBM and Intel (computer software and hardware), Cisco (telecommunication) and Ford (high-technology product manufacturing).

Open Innovation

Before collecting performance data, we conducted a comprehensive announcement search of OI covering various sources. First, we obtained announcements related to OI implementation from Factiva. Factiva consists of a large number of news articles from hundreds of top and diverse media such as *The New York Times* and *The Wall Street*

Journal (Lam et al., 2016). Given wider coverage of announcements, the database allows us to search high-technology firms by selecting specific industrial sectors. We searched the OI announcements with a combination of the following key words: (open innovation or open innovation contests or open innovation tournaments or open innovation challenges or open platform or open source or open community or open network or other relevant keywords of OI such as the names of OI intermediaries and OI challenges) and (names of high-technology firms or relevant keywords of high technology firms such as high technology and computer products). We read through all the news articles and filtered out those with explicit mention of the OI implementation year and process. Repeated announcements from different sources were deleted.

As examples, two news articles extracted from Factiva reporting the implementation of OI in Eli Lilly and Intuit for the enhancement of mobile technology and drug development are shown in APPENDIX A. Second, we studied the cases of OI implementation on OI intermediaries' websites (e.g., InnoCentive, ideaConnection, NineSigma, Brightidea, Imaginatik), open contest platform (e.g., Kaggle) and the Internet by using the keywords employed in Factiva. For instance, about 500 OI implementation cases on IdeaConnection were reviewed. We extracted two examples from the website reporting the implementation of OI in Intel and Verizon Communications for technological development and mobile app development respectively, which are shown in APPENDIX B.

We further verified the firms that actually implemented OI and determined the implementation year on firms' official websites and news from other online public sources. The implementation year is identified when the firm formed an online community through adopting an internet-based implementation practice (see section 2.1.2). For instance, the OI implementation year of Eli Lilly and Company is 2011 (see APPENDIX A) when its OI platform was launched. Exclusions were made concerning that OI was not practically implemented (e.g., without the adoption of internet-based implementation practices), the firms are not in high-technology industries, and not publicly listed in the U.S. stock market. As the concept of OI was first introduced by Chesbrough in 2003, we searched OI implementation announcements from 2003 to 2016.

We collected 74 high-technology firms for our research. Table 2.2 presents the distribution of sample firms based on 2-digit SIC codes. The sample contains firms from twelve unique 2-digit SIC codes. The majority of firm are accounted for the industry in Chemicals and Allied Products (22%), Business Services (16%) and Electronic, Electrical Equipment and Components (15%). Table 2.3 presents the distribution of the sample firms based on the implementation year of OI. During the sample period, most firms implemented OI in 2009. We note the growth in OI implementation in our sample from 2003 to 2009 and the trend remained relatively stable afterward. Given the increasing interest and more successful cases of OI implementation raised among academia and industries, we suspect that the stable growth is indicative of the continuous trend.

Table 2.2 The Distribution of Sample Firms with OI Implementation across Industries

SIC Code	Industry	Number of Firms	Percentage
28	Chemicals and Allied Products	16	22%
73	Business Services	12	16%
36	Electronic, Electrical Equipment and Components	11	15%
37	Transportation Equipment	10	13%
48	Communications	8	11%
35	Industrial and Commercial Machinery and Computer Equipment	5	7%
45	Transportation by Air	3	4%
99	Public Administration	3	4%
26	Paper and Allied Products	2	3%
49	Electric, Gas and Sanitary Services	2	3%
20	Food and Kindred Products	1	1%
30	Rubber and Miscellaneous Plastic Products	1	1%
Total		74	100%

Table 2.3 The Distribution of Sample Firms with OI Implementation by Implementation Year

Year	Number of Firms	Percentage
2003	1	1%
2004	3	4%
2005	3	4%
2006	3	4%
2007	6	8%
2008	4	5%
2009	9	12%
2010	5	7%
2011	8	11%
2012	6	8%
2013	8	11%
2014	6	8%
2015	7	10%
2016	5	7%
Total	74	100%

2.2.2 Measurements

Innovation Performance

To examine the impact of OI on innovation performance, we use the number of patents as an indicator of a firm's innovation performance (Bellamy et al., 2014; Joshi and Nerkar, 2011; Lahiri and Narayanan, 2013; Rothaermel and Alexandre, 2009). Patents serve as a useful measure of innovation that represents the validated advancements of existing outputs and new products or technologies (Bellamy et al., 2014; Joshi and Nerkar, 2011). We obtained patent data of our sample firms from the U.S. Patent and Trademark Office (USPTO) (Leone and Reichstein, 2012) and World Intellectual Property Organization (WIPO) (Zhou and Li, 2012). USPTO mainly provides data of firms in the U.S. whereas WIPO contains patent data of firms around the world. We verified and crosschecked the patent data of each firm by searching them in both databases. For the firms with different patent data, we relied on the ones with larger number of patents to include all the patents granted to the firms. If we could not find the patent data of a firm in one database, we searched the other one. As our analysis requires data at least two year before OI implementation, we obtained the data covering the period from 2001 to 2016. After the search, the sample firms with available patent data that can be used for analysis dropped from 74 to 63. The financial and accounting data for these firms were then retrieved from Compustat and their annual reports. Table 2.4 summarizes all the variables and the data sources used in the study.

Table 2.4 Variable Descriptions

Variable	Description	Measurement	Data Source	Reference
Open Innovation	OI implementation	Announcements of OI implementation	Factiva, OI intermediaries' websites, firms' official websites and other public web sources	/
Innovation performance	Innovation output prior to and during OI implementation	Number of patents	USPTO and WIPO	Bellamy et al.,2014; Joshi and Nerkar, 2011; Lahiri and Narayanan, 2013; Rothaermel and Alexandre, 2009; Zhou and Li, 2012
Firm size	Size of a firm prior to OI implementation	Total assets	Compustat and firms' annual reports	Kortmann et al., 2014; Lavie and Miller,

	2008; Patel et al., 2012

2.2.3 Event Study Methodology

To examine the abnormal innovation performance of OI implementation (H1), we employed the event study methodology. The methodology has been widely used in various research fields such as in finance, accounting, strategic management and marketing (Ba et al., 2013). In the field of operations management, it has also become a useful tool to assess the associations between economic events and firm performance (Corbett et al., 2005; Lo et al., 2012; Swink and Jacobs, 2012). It is a well-accepted and rigorous approach to investigate the abnormal returns associated with specific events (Ba et al., 2013; Jacobs and Singhal, 2014). An "abnormal return" is defined as the difference between the actual return and the normal return without the effect of an event (Brandon-Jones et al., 2017). In this study, we employed this methodology to assess the impact of OI on abnormal innovation performance in high-technology firms, using the number of patents as a proxy.

We investigate the abnormal changes for a six-year period. The implementation year of OI is defined as year 0 (t). The year immediately prior and after the implementation are defined as year -1 and +1, respectively. We consider two years preceding the OI implementation (year -2) as the base year as it is free from the impact of OI to determine the control firms. Changes over the next six years from year -1 to year +4 are measured.

With reference to prior studies (Barber and Lyon, 1996; Lo et al., 2014; Corbett et al., 2005; Hendricks and Singhal, 2005; Swink and Jacobs, 2012), we estimate the abnormal changes in innovation performance by comparing the actual performance with the expected performance of the sample firms. We firstly matched each sample firm with a control firm for the calculation of changes. The use of control firms provides a performance benchmark for the sample to be compared and control any industrial or economic confounding factors on firms' performance (Barber and Lyon, 1996; Tang et al., 2016; Zhang et al., 2014). The selection of control firms was based on a combination of three criteria: pre-event performance, industry and firm size (Barber and Lyon, 1996; Corbett et al., 2005; Tang et al., 2016). Pre-event performance controls the endogeneity caused by different managerial capability and other underlying financial forces; firm size measured by total assets provides the similar control on firms' resources. We match the control firms to each sample firm within 90-110% of pre-event performance and 50-200% of the total assets. Industry using the same 2-digit SIC code to match with the sample firms controls the industrial and environmental factors across firms. We developed the sample-control pairs following the steps below with reference to previous research (Barber and Lyon, 1996; Lo et al., 2014; Tang et al., 2016):

1) We matched control firms with the same 2-digit SIC code; 50-200% total assets of the sample firm; and within 90-110% pre-event performance of the sample firm.

2) We matched control firms with the same 1-digit SIC code; 50-200% total assets of the sample firm; and within 90-110% pre-event performance of the sample firm.
3) We matched control firms with 50-200% total assets of the sample firm; and the pre-event performance was within 90-110% of the sample firm.
4) We matched control firms with 90-110% pre-event performance of the sample firm.

For the sample firm matched with multiple control firms, we selected the one with the closest pre-event performance to the sample firm considering that it is the most crucial factor in the matching. It provides well specified test statistics for the analysis in the study (Barber and Lyon, 1996; Lo et al., 2012). The sample firms failed to match with any control firm or without financial data in year -2 were dropped. We obtained 52 sample-control pairs for analysis after matching. The number of pairs gradually decreases from year t-1 to year t+4 because of the lack of patent data in either sample or control firms.

Following Barber and Lyon (1996), we calculate the abnormal performance as the difference between actual performance and expected performance of the sample firm. Equations (2.1) and (2.2) used for the calculation are as follows:

$$AP_{i,t+k} = P_{i,t+k} - E\left(P_{i,t+k}\right) \tag{2.1}$$

$$E\left(P_{i,t+k}\right) = P_{i,t+j} + (PC_{i,t+k} - PC_{i,t+j}) \tag{2.2}$$

where, $AP_{i,t+k}$ is the abnormal performance of a sample firm *i* in any period t+k, k as the ending year of comparison (k= -1, 0, +1, +2, +3, +4). $E\left(P_{i,t+k}\right)$ is the expected performance of a sample firm i in any period $t+k$. $PC_{i,t+k}$ is the performance of a control firm i in period $t+k$. j is the base year which is also the starting year of comparison (j=-2).

After calculating the abnormal performance of the sample firms, we trimmed the data by removing the outliers at 2.5% level at each tail of the abnormal performance (Corbett et al., 2005). The final sample of our study reduced to 50 pairs for abnormal innovation performance.

Consistent with prior studies (Ba et al., 2013; Barber and Lyon, 1996; Lo et al., 2012), we conducted non-parametric and parametric tests on the significance of the abnormal innovation performance. Considering that outliers may still exist to affect the analysis after trimming (Tang et al., 2016), we focus on the more powerful non-parametric tests than the parametric tests (Barber and Lyon, 1996). We applied the non-parametric Wilcoxon-signed rank (WSR) test to examine the median abnormal performance and binominal Sign test for the percentage of abnormal performance significantly higher than 50%. A parametric one-sample t-test was also applied to examine the mean abnormal performance for more robust test results. The null hypothesis in our study is that the abnormal innovation performance is equal to zero. Test results are reported on the basis of one-tailed tests.

2.3 Results

Before we conducted the hypothesis testing, we compared the means of the innovation performance of sample and control firms. Table 2.5 presents the descriptive statistics of the comparison. For the sample firms, the median and mean innovation performance are 150 and 420 patents, respectively. For the control firms, the median and mean innovation performance are 143 and 393 patents, respectively. We conducted a paired-sample t-test and the statistical results show that the means of innovation performance of sample firms and control firms are not significantly different from zero ($p > 0.1$). It implies that there is a good match between the sample and control firms for examining the abnormal innovation performance.

Table 2.5 Descriptive Statistics of Pre-Event Data

		Innovation performance (t-2)				
	N	Mean	Median	Std. dev	Min.	Max.
Sample firms	52	420.039	150.5	813.344	1	4554
Control firms	52	393.058	143.5	767.794	1	4278

We examine the hypothesis that the innovation performance of a firm significantly increases due to OI implementation both on a year-to-year basis and for multiple-year periods. Table 2.6 presents the test results of abnormal performance changes. The base year is year -2, and the year of OI implementation is year t. N is the sample size of each time phase which decreases progressively as the unavailable patents or financial data collected. Panel A shows the results of abnormal performance annually, six annual changes beginning with the change from year -2 to year -1 (e.g., t-2 to t-1) to the change from year +3 to year +4 (e.g., t+3 to t+4). Panel B shows the results of five multiple period changes from year -2 to year 0 (e.g., t-2 to t) to year -2 to year +4 (e.g., t-2 to t+4). Investigating and comparing the results between or across years, we are able to see the pattern of abnormal changes. For instance, the immediate, lagged or persistent impact of OI implementation on innovation performance.

We start with the results of annual abnormal innovation performance of OI implementation. From panel A, the results show that significant impact of OI on innovation performance started in the year +2 to year +3 period (e.g., t+2 to t+3). The annual abnormal changes in the periods before year +3 are not significant ($p>0.1$ for both the t-test and WSR test). In the period from year +2 to +3 (e.g., t+2 to t+3), the median (mean) change is 7.5 (41.45) patent counts, which is significant at the 10% (10%) level. The percentage of sample firms with positive changes (60%) is greater than 50% but it is not significant. Since we rely on the results of WSR test mainly, we still consider that Hypothesis 1 is supported. Meanwhile, the cumulative results in panel B indicate that the cumulative abnormal increase of innovation performance is significant, from the base year to three years after OI implementation (e.g., t-2 to t+3). The median (mean) change is 9.5 (153.238) patent counts which is significant at the 5% (10%) level. More than half of the sample firms (62%) attained positive changes, which is significant at a 10% level.

The positive cumulative abnormal performance continues for the period from year -2 to year +4 (e.g., t-2 to t+4). The median (mean) change is 10 (126.838) patent counts which is significant at the 5% (10%) level. 62% of sample firms experience positive changes, significantly greater than 50% at the 10% level. The results give further evidence and support to Hypothesis 1. Hence, based on our results, OI provides significant and positive abnormal innovation performance to firms three years after the implementation.

Table 2.6 Test Results of Sample Firms' Abnormal Innovation Performance

Year	N	Median (Z- statistic)	% Positive (Z statistic)	Mean (t-statistic)
Panel A: Abnormal Returns (ARs)				
t-2 to t-1	50	10.500 (.109)	62% (.990)	53.260 (.405)
t-1 to t	50	-3.500 (.363)	34% (.147)	-6.960 (-.217)
t to t+1	50	-.500 (.950)	48% (.791)	19.020 (.405)
t+1 to t+2	46	1.000 (1.169)	54% (.833)	3.391 (.106)
t+2 to t+3	42	7.500 (1.318) *	60% (.676)	41.45 (1.599) *
t+3 to t+4	37	1.000 (.950)	51% (.737)	-56.73 (-1.117)
Panel B: Cumulative Abnormal Returns (CARs)				
t-2 to t	50	2.000 (.903)	56% (1.080)	46.300 (1.167)
t-2 to t+1	50	-.500 (.158)	48% (.986)	65.320 (1.330) *
t-2 to t+2	46	9.500 (1.312) *	61% (1.407) *	79.391 (1.050)
t-2 to t+3	42	9.500 (2.000) **	62% (1.556) *	153.238 (1.642) *
t-2 to t+4	37	10.000 (1.850) **	62% (1.531) *	126.838 (1.491) *

Notes:

Z-statistics for medians and % positive were obtained by Wilcoxon signed-rank test and binominal sign test respectively, t-statistics was obtained by t-test.

% Positive indicates the percentage of firms achieving positive abnormal innovation performance changes.

All samples trimmed at 2.5% each tail; * $p<0.1$; ** $p<0.05$; *** $p<0.01$ (one-tailed tests).

Null hypothesis is no abnormal innovation performance, using the Wilcoxon signed-rank test, Sign test, and t-test, respectively.

2.4 Discussion and Conclusion

In this study, we investigate and provide empirical evidence of the impact of OI on firms' innovation performance in high-technology industries by conducting an event study. Based on the sample of 50 high-technology firms, we find that OI has a positive impact on innovation performance significantly, in terms of number of patents. For the annual median (mean) abnormal innovation performance changes, 60% sample firms obtained about 7.5 (41.45) increased number of patents three years after the implementation significantly (shown in Panel A in Table 2.6). At the same time, the cumulative median (mean) abnormal changes also show that significant improvement of innovation performance occurred three years after OI implementation from the base year (e.g., t-2 to t+3; shown in Panel B in Table 2.6). The cumulative median (mean) improvement continued in the fourth year (e.g., t-2 to t+4) and increased from 9.5 (153.238) to 10 (126.838) patents. It reflects that there is a gradually inclining positive impact of OI on the firms' innovation performance, which starts in the third year after the implementation.

Our results are consistent with the findings of foregoing research and practical cases, suggesting that firms achieve better innovation performance under OI. Previous research found that there is a positive relationship between OI and innovation performance (Cheng and Huizingh, 2014). Our results are aligned with them and further reveal when the innovation benefits will realize. For instance, three years after the OI implementation (t+3). In addition, our results showing improved innovation performance under OI implementation also conform to the practical cases in industries. For instance, P&G launched more than a hundred innovative products after implementing its online OI platform, Connect and Develop, for four years (Huston and Sakkab, 2006). Its innovation success rate also doubled from 35% up to 70% in the fifth year of implementation (Huston and Sakkab, 2006). P&G thus took at least four years to reap the innovation benefits from OI. Our results match with the time that firms need to take before innovation benefits to be realized. Idelchik and Kogan (2012) also illustrate that a new technology normally takes from five to ten years to develop for core business use. Hence, this study provides relevant and solid evidence to advance the understanding of the positive impact of OI on innovation performance in high-technology industries. We discuss the implications of our study for both practice and research below.

2.4.1 Theoretical Implications

With a view to the increasing popularity and importance of OI implementation, yet studies in the field are scarce, our study addresses the interface between OI and innovation performance. Based on the KBV of a firm, we investigate that OI uses internet-based implementation practices to generate useful and strategic knowledge for innovation improvement in high-technology industries. The results show that significant innovation improvement is obtained, strengthening the evidence that OI is positively associated with innovation performance. It is consistent with the literature that OI is a crucial means for organizations to enhance their innovation performance (Billington and Davidson, 2013; Gómez et al., 2017). The KBV of a firm provides a theoretical basis for researchers to understand that OI implementers possessing with strategic knowledge are able to obtain knowledge-based advantage of innovation improvement. Through the use of purposive knowledge flows, OI provides an access to various fields of knowledge, expertise, information and organizational practices which can be acquired, learned and exploited by the firm. The knowledge containing globally dispersed knowledge is integrated with the internal environment and developed as a fundamental resource for a firm to innovate. It helps spur breakthroughs and solve innovation problems. Further, innovation opportunities may be explored to develop advanced functions for existing products or new products. Hence, the use of strategic knowledge under OI benefits innovation performance. Our findings verify that OI has a positive impact on innovation performance and provide a theoretical basis for future studies in OI investigation.

In addition, our findings contribute to identifying when the innovation improvement from OI implementation will realize. Some researchers examined the impact of OI on innovation performance but they overlooked the time for firms to obtain positive returns from OI. We investigate the innovation impact of OI and find that there is a waiting time before significant benefits to be received. For instance, three to four years after the implementation. This contributes to the understanding of OI impact and suggests other researchers might investigate a longer period to explore whether the benefits will continue in the next few years.

Also, our research identifies and illustrates the observable characteristics of OI implementation in firms. Most of the anecdotal research conducted survey to examine OI (Cheng and Huizingh, 2014; Chesbrough and Brunswicker, 2014) but they lack explicitness to identify firms who are implementing OI. It may be one of the major difficulties in OI investigation. We contribute to future research by revealing the observable characteristics of OI implementation in firms. For instance, the use of Internet-based implementation practices and the involvement of external parties in the OI community. The characteristics facilitate sample identification and data collection in future studies. Considering the implications mentioned above, our research is important to current and future research in OI.

2.4.2 Managerial Implications

Firms have struggled to decide whether OI is beneficial for them to implement, since little research has investigated its consequences while both successful and failed cases exist among industries. Our study provides empirical evidence of the positive impact of OI on innovation performance and contributes practical implications to managers. Our findings are important as innovation is the most crucial element in a firm that creates value and competitive advantage to succeed (Adner and Kapoor, 2010). It is related to the profitability and sustainability of the business. This research enables firms to recognize the important role of OI in achieving innovation improvement through the use of strategic knowledge. Firms are suggested to implement OI if they aim to improve innovation performance.

Further, our findings reveal when the innovation improvement from OI implementation will be realized in firms. For instance, three years after the implementation. Although there is a waiting time period, the benefits are likely to be continuous because significant cumulative improvement is found in the next year (t+4). It implies that OI probably provides consistent innovation benefits to high-technology firms after the waiting time period. Thus, our research suggests that OI is a strategic approach for firms to obtain long-term innovation improvement. At the same time, our results help firms to plan a more organized R&D schedule with different innovation activities and their expected returns under OI. Previous studies demonstrate that there is a curvilinear relationship between OI and innovation performance, where diminished return lies after a certain period of implementation time (Garriga et al., 2013; Laursen and Salter, 2006). However, none of them assesses the duration of the specific time period. In light of the time uncertainties of the decreasing benefits to appear, our finding suggests that four years may be an optimal or a relatively promising period for firms to receive the positive impact of OI on innovation performance before the returns drop. Firms are able to design a more sufficient R&D schedule with adequate resource arrangement under the implementation of OI. Thus, expected innovation improvement can be obtained through effective knowledge use.

2.4.3 Conclusion

In conclusion, we contribute to the understanding of the impact of OI on innovation performance in high-technology industries, based on the KBV of a firm. Employing the event study methodology, we find further evidence supporting the argument that OI and innovation performance are positively associated. Also, we reveal the specific time that OI benefits will realize. The findings suggest that significant innovation improvement occurs at least three years after the implementation of OI. The results also indicate that the cumulative improvement continues in the next year (t+4) which implies a stable OI impact on innovation performance can be obtained. Firms are able to benefit from OI in that period. The findings provide a reference to firms for making decisions regarding to OI implementation. Meanwhile, we illustrate three observable characteristics of OI implementation. It helps researchers identify the implemented firms and extend the investigation of OI in the future.

CHAPTER THREE

STUDY 2: THE MODERATING EFFECTS ON THE RELATIONSHIPS BETWEEN OPEN INNOVATION AND INNOVATION PERFORMANCE

3.1 Theoretical Background and Hypotheses Development

3.1.1 The Knowledge-Based View of a Firm

We also apply the KBV of a firm in this study since it provides a theoretical lens through which we understand that the impact of OI on innovation performance may vary under the moderating factors affecting strategic knowledge creation and development in OI. As mentioned in study 1, the KBV of a firm posits that knowledge is the fundamental strategic resource from which firms create value and it leads to competitive advantage (Choo et al., 2015; Foss et al., 2013; Grant, 1996; Hult et al., 2006). The strategic knowledge can be created through internal knowledge accumulation and external knowledge integration (Arend et al., 2014; Choo et al., 2015; Ranft and Lord, 2002). Along the process of OI implementation, dyadic knowledge flows between the firm and outside parties are established to acquire particular knowledge from the external for internal innovation use. For instance, idea generation, problem-solving or product and process development. The external knowledge is allowed to flow into the firm and integrate with internal knowledge base, developing as the strategic knowledge for obtaining the knowledge-based advantage of innovation improvement. However, the creation and development of strategic knowledge largely depend on the capacity of external knowledge absorption and the availability of external knowledge sources. On one hand, external knowledge input requires a series of conversion and assimilation activities to transfer it into applicable knowledge for internal use (Adner and Kapoor, 2010; Freeman, 1991; Grant, 1996; Nickerson and Zenger, 2004; Ranft and Lord, 2002). The capacity to process external knowledge becomes pivotal in determining the knowledge applicability and usefulness in a firm (Cohen and Levinthal, 1990). Thus, we consider knowledge absorptive capacity (KAC) as the hypothesized moderator in the relationship between OI and innovation performance in this study. On the other hand, the number of available knowledge sources to which the firm can reach determine the extent of external knowledge input (Hoffmann, 2007; Wassmer et al., 2017). It affects the scale and scope of complementary knowledge to augment the internal knowledge base. Hence, we also consider the moderating role of alliance portfolio size (APS) in the relationship between OI and innovation performance. Based on the KBV of a firm, this study examines the underlying factors that potentially influence strategic knowledge creation and development for innovation use under OI.

3.1.2 The Moderating Role of Knowledge Absorptive Capacity

KAC is defined as "the ability of a firm to recognize the value of new, external knowledge, assimilate and apply it to commercial ends, based on the level of existing internal knowledge base" (Cohen and Levinthal, 1990, p.128). It is also seen as the organizational learning capability affecting the efficacy of internal learning (Cohen and Levinthal, 1990). The capacity is developed by three elements: an accumulated prior knowledge base, a communication network and a communication climate (Cohen and Levinthal, 1990; Tu et al., 2006; Volberda et al., 2010). First, an accumulated prior knowledge base includes the basic skills and intelligence of a firm, a shared language built among employees, and the scientific or technological development in specific fields (Cohen and Levinthal, 1990). It confers a foundation with former experience and a language for organizational communication to new knowledge learning and assimilation (Volberda et al., 2010). The firm is able to disentangle and understand new knowledge for internal diffusion. Cohen and Levinthal (1990) also explain that prior knowledge enhances the ability to memorize, recall and employ new knowledge in a firm, reducing the difficulties in new knowledge processing. Second, a communication network connecting the firm's internal units and with outside parties influences knowledge absorption. The structural connections in the network bind different organizational units together, which favors frequent communications and interactions in between. It helps solve misunderstandings and confusion of new knowledge learning, ensuring explicit and accurate information is transferred properly from the external to every internal unit (Tu et al., 2006). Hence, a communication network facilitates the assimilation of external knowledge (Fugate et al., 2009). Third, a communication climate also affects knowledge absorption. It is defined as the internal atmosphere that encourages accepted behavior for new knowledge input or operational changes (Tu et al., 2006). A healthy and open climate enhances employees' motivations and learning ability to understand the external knowledge for internal use (Tu et al., 2006). In sum, these three factors develop a firm's KAC, contributing to external and internal knowledge integration for innovation.

According to the KBV of a firm, strategic knowledge can be developed by external knowledge integration that leads to knowledge-based advantage of innovation improvement. We postulate that firms with higher KAC are more able to integrate suitable external knowledge to create strategic knowledge under OI for improved innovation performance. We explain the postulation based on the above mentioned three factors that assemble KAC. First, a higher KAC consists of a stronger accumulated prior knowledge base. It increases the commonalities between internal and external knowledge, alleviating the process of knowledge codification and assimilation (Patel et al., 2012; Ferdows, 2006; Tu et al., 2006; Volberda et al., 2010). Useful relevant knowledge can be more easily identified, understood, and blended into the firm. Second, the more mature communication network creates an advantageous structure for more accurate knowledge diffusion in the firm, tacit knowledge in particular (Tu et al., 2006). Different organizational units are grouped together with closer and more inextricable interactions, enabling their expertise to be used mutually. It solves the complexities and misunderstandings in knowledge learning (Aletan, 1991) so more precise and proper knowledge can be ensured to transfer from the external to internal. Third, a favorable communication climate enhances employees' ability to learn and adapt to changes (Tu et al., 2006). It builds an open culture to embrace new knowledge input. More diverse knowledge is allowed to flow into the organization. Hence, firms with higher KAC are more likely to integrate external knowledge effectively for innovation activities (Liu et al.,

2014) under OI. On the contrary, firms with lower KAC may only be able to integrate elementary or less knowledge in OI. As insufficient accumulated prior knowledge resides, limited commonalities can be found between internal and external knowledge for reducing difficulties in knowledge codification. It directly affects and restricts potential knowledge learning and its use in the firm. Meanwhile, a loosely connected communication network with weak interactions among involved parties is created. Given that misunderstanding or misinterpretation may exist, ambiguous or improper knowledge is possibly transferred. Moreover, a hostile or conservative communication climate may be provided that further hinders external knowledge integration. Employees tend to remain at the current situation and refuse to change and accept new knowledge input, thus discouraging knowledge absorption. Therefore, higher KAC is more likely to facilitate external knowledge integration under OI to create strategic knowledge for innovation use. Accordingly, we posit a contingency factor of KAC in the relationship between OI and a firm's innovation performance as follows:

Hypothesis 2a (H2a). *Knowledge absorptive capacity positively moderates the relationship between open innovation and innovation performance.*

3.1.3 The Moderating Role of Alliance Portfolio Size

Alliance portfolio size (APS) is defined as the number of alliances where a focal firm access external resources and knowledge from, aiming at resource combinations or knowledge complementarity (Lahiri and Narayanan, 2013; Wassmer et al., 2017). The alliances link the focal firm to selected alliance partners for knowledge or resources exchange, sharing or codevelopment (Lahiri and Narayanan, 2013). They assemble as a portfolio that provides expanded access to preferential or additional resources and knowledge owned by the alliance partners (Dyer and Singh, 1998; Joshi and Nerkar, 2011; Wassmer and Dussauge, 2012). Joint ventures, technology exchange, research consortia, agreements on collaborative R&D, production, marketing, and distribution are the common practices adopted by the focal firm to form the alliances (Lahiri and Narayanan, 2013; Lavie and Miller, 2008). Fang (2011) indicates that advantageous complementarity and combinations occur when two firms have nonoverlapping or different resources or knowledge in relevant fields. However, extreme differences and dissimilarity provide less facilitation because little connection is made to join two parties together for mutual gains. Therefore, partners of the alliances in the portfolio should be selected with the aim to create synergistic value and benefits. They have to align with the firm's strategy and match with the internal resource endowment and external environmental conditions (Hoffman, 2007). On one hand, their resources and knowledge should be compatible with the use of the internal knowledge base for the business development. On the other hand, the alliances' input can introduce new ideas and information that help the focal firm to cope with external environmental changes. Hence, a useful alliance portfolio should be carefully formed according to different firm strategies, creating particular joint value and high resource and knowledge complementarity. APS is often employed in high-technology firms for innovation improvement because of the granted hybrid synergy and resource flexibility that help cope with the high demand velocity and environmental uncertainties (Hoffmann, 2007; Joshi and Nerkar, 2011; Lahiri and Narayanan, 2013).

Based on the KBV of a firm, we postulate that APS is likely to positively moderate the relationship between OI and innovation performance. A larger APS is able to provide more sources of complementary knowledge to consolidate and augment the existing internal knowledge base (Fang, 2011; Lahiri and Narayanan, 2013) for innovation use under OI. Consisting of more diverse or deeper technological know-how, expertise and environmental information, the knowledge contribution from a larger portfolio does not only advances the current knowledge level of the focal firm but also helps spur more breakthroughs (Hoffmann, 2007; Lavie, 2007; Lahiri and Narayanan, 2013; Phelps, 2010). The focal firm can learn better organizational practices and skills from numerous alliance partners while exploring new perspectives for new product or process development (Dahlander and Frederiksen, 2012; Fang, 2011; Hess and Rothaermel, 2011). Further, more auxiliary product or process components and ready-made solutions can be retrieved from various alliances to create incremental innovations and tackle different innovation problems (Leone and Reichstein, 2012; Phelps, 2010). For instance, adding new features or functions in existing products or adopting solutions experienced by alliance partners previously to help overcome similar innovation problems. The alliances' knowledge input saves time in idea generation and problem-solving, accelerating the focal firm's innovation process (Leone and Reichstein, 2012; Phelps, 2010). Previous studies also concur that alliances enhance innovativeness and expedite the innovation process through providing complementary knowledge, resources and ready-made solutions to the focal firm (Hess and Rothaermel, 2011; Lahiri and Narayanan, 2013; Leone and Reichstein, 2012; Phelps, 2010; Wassmer et al., 2017). Hence, firms with a larger APS are more likely to obtain useful strategic knowledge for innovation use under OI (Gassmann et al., 2010; Han et al., 2012). Contrarily, a smaller APS provides less facilitation in strategic knowledge creation and development for innovation purposes under OI. Since limited alliance partners can be accessed, the available sources of complementary knowledge and external environmental information are dwindled. The focal firm may only receive repeated, irrelevant or scant knowledge complementarity from the fewer alliance partners. Limited internal knowledge enhancement can be achieved. The focal firm is required to learn and invent new products or process by itself. Worse still, little environmental information is collected which mitigates the responsiveness to the volatile market by making immediate and corresponding actions (Hoffmann, 2007). Longer time may be spent on the innovation process to develop suitable inventions for the market and solve various innovation problems. Therefore, a larger APS is more likely to facilitate OI in strategic knowledge development and use for innovation improvement than a small APS. Accordingly, we hypothesize that:

Hypothesis 2b (H2b). *Alliance portfolio size positively moderates the relationship between open innovation and innovation performance.*

3.2 Methodology

3.2.1 Sample and Data Collection

In the first study, we examine the abnormal innovation performance under OI implementation in high-technology industries. The results show that significant abnormal innovation performance begins in year t+3, whether for the annual (Panel A in Table 2.6) or cumulative change (Panel B in Table 2.6). It suggests that a five-year window (e.g., year -2 to +3) reflects the significant effect of OI implementation. Thus, we rely on the CARs from year -2 to +3 as the dependent variable in our second study to examine the moderating effects in such relationship. The hypothesized moderating variables are KAC and APS. The number of observations is reduced from 42 to 39 due to the missing data of some moderating and control variables such as firm size (e.g., number of employees).

We collected data describing the moderating and control factors from various sources to address hypotheses H2a and H2b. We obtained financial data from Compustat and firms' annual reports. For alliances' data, we obtained it from Thomson's SDC Platinum database (Lahiri and Narayanan, 2013; Bellamy et al., 2014). For other firms' data such as firm age, number of employees and origin of headquarters, we obtained it from firms' official websites, annual reports, and through web search.

3.2.2 Measurements

Knowledge absorptive capacity

Consistent with previous studies (Cohen and Levinthal, 1990; Bellamy et al., 2014), we measured a firm's KAC by its R&D intensity. As discussed above, the capacity greatly relies on the accumulated prior knowledge base. The base is developed by R&D activities that cultivate technological know-how, expertise and other organizational abilities

(Cohen and Levinthal, 1990; Foss et al., 2013; Rothaermel and Alexandre, 2009; Volberda et al., 2010). Hence, we employed R&D intensity as the indicator of KAC. We calculated the intensity by dividing the firm's R&D expenditures to sales in year -1, representing the accumulated prior knowledge base one year immediately before OI implementation. R&D expenditure and sales data were collected from Compustat.

Alliance portfolio size

In accordance with prior research (Lahiri and Narayanan, 2013; Wassmer et al., 2017), we measured APS as the natural logarithm of the cumulative number of a firm's alliances in year -1. As the alliance portfolio is formed by different alliances that link outside parties with the focal firm, we counted the cumulative number of alliances involved one year immediately before OI implementation. The alliance data was obtained from the Thomson's SDC Platinum database, a commonly used source consisting of alliance data on strategic alliances, joint ventures, contractual agreements and other forms of interfirm networks (Lahiri and Narayanan, 2013; Bellamy et al., 2014).

Control Variables

We included both firm-level and industry-level control variables that may affect the impact of OI on a firm's innovation performance in our study. The firm-level controls were firm size, firm age, firm's profitability, dummies of types of OI platform and year of OI implementation. The industry-level controls were country and industry dummies. Considering that firm size represents the available resources and abilities in a firm to be used, firms with larger size are more able to employ greater resources to process information (Lavie and Miller, 2008; Patel et al., 2012). We controlled this factor by taking the natural logarithm of the firm's total assets (Lavie and Miller, 2008; Patel et al., 2012) and the natural logarithm of number of employees (Foss et al., 2013; Leone and Reichstein, 2012). For firm age, we measured it as the natural logarithm of the number of years since operation (Kortmann et al., 2014; Lahiri and Narayanan, 2013; Patel et al., 2012). Older firms often possess more innovation experience, which embodies more mature innovation systems and routine activities (Bellamy et al., 2014; Kortmann et al., 2014; Lahiri and Narayanan, 2013). Greater efficacy in knowledge processing and its use for R&D is obtained; therefore, we controlled this factor. Firm profitability was also controlled because it reflects the financial resources of a firm to invest in R&D. We measured it as return on assets (ROA), calculated as the ratio of net income to total assets (Lam et al., 2016; Lavie and Miller, 2008). Types of OI platform dummies were created to control the effectiveness of different OI platforms established by the firm itself and other parties such as OI intermediaries. Given that higher flexibility is given under direct management, self-established platforms are likely to provide tailored design structures for the firm to better present their problems and find solutions from the communities. Platforms offered by other parties may require users to follow certain regulations, creating restrictions to transfer information and knowledge between the firm and external parties. Absent or ambiguous messages may occur that lead to improper and deficient knowledge flows. Hence, we controlled type of OI platforms by using dummies, which were coded 1 for self-established OI platforms and 0 for OI platforms established by others. In addition, we created the year of OI implementation dummies to control the idiosyncratic factor related to the varying effect of time and general economic conditions (Lahiri and Narayanan, 2013) in the year of OI implementation. For the industry-level controls, a firm's country of origin was used to code country as a dummy variable (Lahiri and Narayanan, 2013; Wassmer et al., 2017), and 2-digit SIC code was used to code industry (Leiponen and Helfat, 2010). Taking the cultural and geographical differences into consideration, available knowledge sources and market demand may vary from countries. Firms may discover more opportunities for knowledge acquisition in developed than developing countries. Besides, the propensity of knowledge exchange activities, such as technological collaboration or shared R&D, differ from industries. It may influence the creation of purposive knowledge flows between the focal firm and external parties for innovation purpose. Hence, we controlled these two industry-level controls. All control variables, except year of OI implementation dummies, were based on the data collected in year -2 as it is the base year believed to have no effect from OI implementation.

3.2.3 Cross-sectional Regression Analysis

Consistent with prior event studies (Hendricks and Singhal, 2005; Lo et al., 2018), we conducted a cross-sectional regression analysis to analyze how CARs of innovation performance may vary from different moderating effects under OI. The ordinary least squares (OLS) regression model shown below was employed for the analysis. It also allows us to control firm-, industry- and time-specific factors that may be related to the abnormal innovation performance under OI. The tested moderating factors are KAC and APS.

$$CARs_i = \beta_0 + \beta_1 APS + \beta_2 KAC + \beta_3 Firm\ Size - total\ assets + \beta_4 Firm\ Size - number\ of\ employees + \beta_5 Firm\ Age + \beta_6 Firm\ Profitability + Types\ of\ OI\ Platform\ Dummies + Year\ of\ OI\ Implementation\ Dummies + Country\ Dummies + Industry\ Dummies + \varepsilon_i$$

where i refers to the i th sample firm. $CARs_i$ is the cumulative abnormal innovation performance of firm *i* from year -2 to +3. Moderating variables are measured in year -1 (the year prior to OI implementation) while control variables are in year -2 (the base year).

3.3 Results

Table 3.1 reports the descriptive statistics and correlations of the variables in our regression analysis, and Table 3.2 shows the cross-sectional regression analysis results. Model 1 is the basic model with all the control variables including dummy variables. Models 2 and 3 add the hypothesized moderating variables of KAC (H2a) and APS (H2b) to Model 1 sequentially. Three models are highly significant ($F \geq 8.571$, $p < 0.01$). The adjusted R-squares increased from .845 to .892 in Model 2; however, it decreased in Model 3 to .879. It means that the explanatory power of the model on cumulative abnormal innovation performance is reduced after adding the moderating variable of APS.

Model 2 shows that the moderating effect of KAC is significantly positive for cumulative abnormal innovation performance ($p < 0.05$). The result suggests that firms with higher KAC achieve better innovation performance three years after OI implementation. Thus, H2a is supported. The moderating factor improved the explanatory power of the model by 4.7% (based on adjusted R-square). However, the moderating effect of APS is not a significant predictor of firms' cumulative abnormal innovation performance although a positive effect is shown in Model 3. Thus, H2b is not supported. The variable also decreased the explanatory power of the model by 1.3%.

Table 3.1 Descriptive Statistics and Correlations

Variable	Mean	Std. dev.	1.	2.	3.	4.	5.	6.
1. CARs of innovation performance	175.460	641.944						
2. Log firm size [i]	4.190	.904	.287**					
3. Log firm size [ii]	4.460	.795	.272*	.938***				
4. Log firm age	1.570	.393	.069	.304**	.353**			
5. Firm profitability [iii]	.0509	.128	.017	.431***	.445***	.248*		

6. Log knowledge absorptive capacity (KAC)	-1.213	.673	-.048	-.503 ***	-.559 ***	-.219*	-.562 ***	
7. Log alliance portfolio size (APS)	1.331	.530	.214	.683***	.700***	.384***	.387***	-.357 **

Notes: *p < 0.10; **p < 0.05; ***p<0.01 (one-tailed tests).

[i] in Total Assets; [ii] in Number of Employees; [iii] in ROA.

Types of OI platforms dummies, Year of OI Implementation dummies, *Country dummies and Industry dummies* are not shown in this table—they are categorical dummy variables.

Table 3.2 Cross-sectional Regression Analysis Results

	Dependent variable: cumulative abnormal number of patents (t-2 to t+3)		
Variable	Model 1	Model 2	Model 3
Intercept	-429.798 [-.665] (646.176)	-502.489 [-.929] (540.840)	-521.281 [-.880] (592.541)
Firm size [i]	-104.988 [-.489] (214.748)	-404.690 [-1.827] (221.519)	-407.433 [-1.728] (235.754)
Firm size [ii]	219.175 [.972] (225.438)	654.416 [2.455] (266.587) **	647.053 [2.242] (288.578) *
Firm age	-204.163 [-1.260] (162.060)	-234.718 [-1.725] (136.058)	-248.515 [-1.368] (181.674)
Firm profitability [iii]	23.995 [.023] (1044.464)	691.361 [.752] (919.403)	640.725 [.607] (1055.330)
Knowledge absorptive capacity (KAC)		347.835 [2.307] (150.760) **	339.767 [1.972] (172.334) *

Alliance portfolio size (APS)			26.977 [.125] (216.152)
Types of OI platform dummies	Included	Included	Included
Year of OI implementation dummies	Included	Included	Included
Country dummies	Included	Included	Included
Industry dummies	Included	Included	Included
Number of observations	37	37	37
R-square	.957	.973	.973
Incremental R-square		.016	.000
Adjusted R-square	.845	.892	.879
Incremental adjusted R-square		.047	-.013
F-value	8.571***	12.019***	10.322***

Notes: t-Statistics in the bracket []; standard error in the parenthesis ().

* p<0.10 (two-tailed); ** p<0.05 (two-tailed); *** p<0.01(two-tailed).

[i] in Total Assets; [ii] in Number of Employees; [iii] in ROA.

3.4 Discussion and Conclusion

This study further examines the moderating effects of KAC and APS on the relationship between OI and innovation performance. Consistent with our argument developed from the KBV of the firm, we find that firms with higher KAC are more capable to obtain better innovation performance through the implementation of OI. The finding might imply that higher KAC provides a stronger internal knowledge base, a more favorable communication network and climate to the firm for obtaining more effective knowledge integration and its use. It leads to better innovation performance under OI. In addition, we find that no significant moderating effect of APS exists between OI and innovation performance. Contrary to our expectation, the result is not significant although positive association is carried out. It might imply that a larger alliance portfolio does not help a firm to create strategic knowledge under OI for innovation use. We attribute this finding to two possible reasons. First, inappropriate alliance partners who can barely provide suitable and compatible complementary knowledge and resources to enhance internal knowledge base for innovation use may be selected. Fang (2011) explains that low complementarity of alliances' input is caused by high redundancy, which involves a considerable amount of same or overlapping knowledge and resources between the focal firm and partners. Appropriate complementarity cannot be provided by the alliances' input as similar knowledge and resources already exist in the focal firm. Conversely, too diverse alliances with extreme new knowledge and resources may also lead to low complementarity. Since considerable time and effort are required to learn the completely new inputs and employ them internally (Liu and Ravichandran, 2015), the process of knowledge integration is complicated. Therefore, lower and insignificant level of knowledge complementarity may be obtained because of the inappropriate selection of alliance partners in the portfolio (Vasudeva et al., 2013). Second, unaligned alliance purposes may prevent useful and accurate complementary knowledge from flowing into the business. Zollo et al. (2002) revealed that different strategic intents of alliance formation, together with the lack of common syntax (Wilhelm and Dolfsma, 2018), between alliance partners and the focal firm create difficulties in transferring desired complementary input from the alliances. For instance, an alliance partner intends to expand its advertising channel is less likely to offer relevant and complementary knowledge to the focal firm who wants to develop a new product. Meanwhile, failing to establish a well-specified agreement of knowledge exchange may also create misunderstandings or obstacles in obtaining useful complementarity. Therefore, rather than focusing on the size of alliance portfolio, we suggest that firms may shed light on the selection of appropriate alliance partners with aligned formation purposes to seize effective knowledge complementarity under OI. Based on these findings, we discuss the theoretical and practical implications below.

3.4.1 Theoretical Implications

To obtain a more comprehensive view of OI, the inclusion of moderating effects helps us understand more about how and why the benefits received from OI vary. This study contributes to the existing literature on OI implementation in terms of better innovation performance can be achieved by the specific moderating factor. We stress the potential moderating effects of KAC and APS in OI for improved innovation performance. Earlier studies indicate that KAC is one of the most concerned issues affecting effective knowledge search, transfer, integration, and exploitation in OI (Billington and Davidson, 2013; Chesbrough, 2012a, 2017; Chesbrough and Crowther, 2006; Foss et al., 2011; King and Lakhani, 2013; Laursen and Salter, 2006; Lichtenthaler, 2008; Von Krogh et al., 2018). Applying the KBV of a firm, we reveal that KAC facilitates OI in strategic knowledge creation and development for receiving innovation advantage. It illustrates that a stronger internal knowledge base enables the firm to understand and assimilate the external knowledge more effectively. At the same time, a closely connected communication network and open climate create an advantageous environment in the organization to exploit new knowledge, overcoming the not-invented-here (NIH) syndrome that prevents employees from learning external knowledge (Billington and Davidson, 2013; Laursen and Salter, 2006; Lichtenthaler, 2008).

We further demonstrate that APS has no moderating effect on the relationship between OI and innovation performance. Although anecdotal evidence proposes that alliances provide complementary knowledge and resources to the focal firm for improving firm performance (Gaimon et al., 2017; Wassmer et al., 2017), the effectiveness of complementarity is likely to depend on other factors rather than the size of the portfolio. As discussed above, the insignificant moderating effect may stem from the selection of inappropriate alliance partners and unaligned alliance formation purposes. Hence, we suggest that future research may take a contingency perspective to investigate the characteristics of alliance partners including their business nature, backgrounds and fields of expertise and their formation purposes (Hora and Dutta, 2013; Wassmer et al., 2017) on the impact of OI on innovation performance.

3.4.2 Managerial Implications

Our study is also important from a managerial perspective. Particularly for the managers in high-technology firms, they are required to respond to the market promptly for seizing the first mover advantages. Our study provides empirical evidence on how to strengthen the effect of OI on innovation performance. First, the results verify that KAC plays a significant role in OI implementation for obtaining innovation benefits, using R&D intensity as the proxy. It provides a reference for managers to enhance the efficacy of external knowledge integration and its use under OI through higher KAC. In particular, building a stronger internal knowledge base amplifies the capability to identify useful knowledge externally and assimilate it for problem-solving and new product and process development. Managers may thus consider devoting more effort in internal R&D for obtaining superior strategic knowledge to improve innovation performance from OI.

An additional insight for practice that emerged from our study is that there is no moderating effect of APS on the relationship between OI and innovation performance. The result shows that the number of alliances does not influence strategic knowledge development and use for generating novel ideas in OI. Instead, it is advisable that managers should consider the characteristics of alliance partners when forming the portfolio for obtaining effective knowledge and resource complementarity. The greater attention paid to the selection of suitable alliance partners, the more applicable and useful knowledge and resources are likely to be accessed (Hora and Dutta, 2013; Wassmer et al., 2017). Besides, the purpose of alliance formation may also influence appropriate knowledge and resources transfer. Managers are suggested to focus on the innovation activities with their alliance partners for receiving relevant alliances' knowledge input. Thus, the focal firm may experience greater success in knowledge complementarity and its use with the help of appropriate alliances under OI to innovate. In this sense, we advise that managers should consider the above mentioned issues when employing an alliance portfolio for innovation improvement under OI.

3.4.3 Conclusion

Presently, little research has been done to provide a complete account of how firms might leverage the innovation benefits from OI. We examine the moderating effects of KAC and APS on the relationship between OI and innovation performance. On the basis of the empirical evidence from our study, KAC positively moderates such relationship whereas APS does not have a moderating effect on OI implementation to the improved innovation performance. Higher KAC provides a stronger accumulated prior knowledge base, a closely connected communication network and an open communication climate. It enables the firm to process diverse external knowledge by enhancing its organizational learning ability and overcoming the NIH syndrome. However, APS conveys no significant moderating effect on the impact of OI on innovation performance. Scholars and practitioners are advised to shift the focus to the selection of appropriate alliance partners and alliance formation purposes in the implementation of OI for gaining sufficient knowledge complementarity to augment internal knowledge base for innovation improvement.

CHAPTER FOUR

CONCLUSION

4.1 General Conclusion and Research Contribution

Organizations across the globe are increasingly engaging in OI for business improvements. Yet in light of the largely unexplored field regarding the impact of OI, numbers of firms still face the challenge of deciding whether to implement OI. It becomes imperative to capture the phenomenon and understand the impact of OI. Based on the KBV of a firm, we conducted an empirical study to investigate OI and conclude that the implementation of OI is beneficial to innovation performance. Through dynamic knowledge flows between the firm and the external parties, external knowledge is integrated into the firm and developed as the strategic knowledge for idea generation and problem-solving. The globally dispersed expertise can be accessed to advance the internal knowledge base while spurring breakthroughs. Meanwhile, internal knowledge, unused or underutilized knowledge in particular, can be shared out with outside parties for exploring innovation opportunities. In fact, previous literature also shows that external knowledge supports innovation activities by providing knowledge attacks and environmental information to the firm (Cassiman and Veugelers, 2006; Fang, 2011; Lahiri and Narayanan, 2013). Employing the event study methodology, we demonstrate that OI enhances innovation performance. In particular, significant innovation improvement is gained three years after the implementation. Meanwhile, an amplified OI effect can be achieved through higher KAC. More explicitly, firms experience greater innovation performance if they have higher R&D intensity, the proxy of KAC. It provides a stronger internal accumulated prior knowledge base and a closely connected communication network with an open communication climate in a firm. More appropriate external knowledge can be recognized, assimilated, and applied for internal use. For instance, the stronger base helps understand more new knowledge input from relevant fields and apply it to the appropriate innovation activities of the firm. Also, the dense network and open communication culture encourages effective knowledge diffusion among employees. However, we find no advantage of a larger or smaller APS to firms in OI implementation for innovation improvements.

Important implications for scholars can be drawn from this research. First, our empirical evidence highlights that OI generates innovation benefits to high-technology industries, based on the KBV of a firm, three years after the implementation. It adds to the existing literature on OI studies for a more comprehensive understanding. Researchers can understand that OI provides strategic knowledge for innovation improvements in firms. Moreover, observable characteristics of OI implementation in firms are identified, helping to overcome the difficulties in sample collection in future studies. Second, to the best of our knowledge, this research is the first to consider KAC and APS as the moderating variables of the relationship between OI and innovation performance. Based on the cross-sectional regression analysis, the results show that KAC plays a significant role in affecting the impact of OI on innovation performance positively while APS carries no moderating effect on OI implementation to innovation performance. Third, based on the KBV of a firm, researchers can understand how OI generates positive impact on innovation performance and how such impact varies under different levels of KAC. Through the use of purposive knowledge flows, OI is able to acquire useful knowledge from the outside world to internal environment. The knowledge is transferred and developed internally to be the strategic knowledge for particular innovation use. It significantly improves the innovation performance three years after the implementation of OI. Further, a higher KAC facilitates OI in external knowledge processing and application to create strategic knowledge for obtaining better innovation performance.

Our research also offers important practical implications to managers. We provide empirical evidence that OI benefits innovation performance. Through knowledge flows occurred between the firm and outside parties, OI acquires external knowledge and integrates it with internal knowledge. The firm is able to advance the internal knowledge base and discover innovation opportunities for product and process developments. To be specific, managers are suggested to employ the internet-based implementation practices to create the collaborative communities including external parties beyond firm boundaries and invite them to participate in and contribute to the innovation activities. Furthermore, firms can achieve greater innovation improvements by putting more effort in R&D intensity to augment the KAC. Therefore, more effective knowledge integration and use can be attained under OI. We also suggest managers paying attention to the selection of alliance partners and their alliance formation purposes rather than the portfolio size, given that no significant moderating effect on OI implementation to innovation performance is found. The number of alliances was examined to provide no facilitation for the firm to innovate under OI. Alternately, we suggest that the focus may shift to the characteristics of the alliance partners and aligned purposes of alliance formation. The two issues possibly determine the knowledge and resource complementarity to the focal firm for effective knowledge integration and exploitation under OI implementation to improve innovation.

4.2 Limitations and Recommendations for Future Research

Inevitably, our research suffers from several limitations that might provide new opportunities for future research. For one, we focus on the listed high-technology firms with adequate financial resources and available data to be retrieved from the Compustat database. The characteristics of high-technology industries include short product life cycles, rapid product and process development, and a high level of ambiguous environmental information and uncertainties. They receive benefits from OI implementation to innovate faster and fulfill the volatile market needs. As such, the research scope is limited to this field, non-listed firms such as the privately-owned firms and other industries are not examined. Hence, our results cannot be applied to the general context without considering the specified business features. Second, we acknowledge that our measure of OI based on firms' announcements in Factiva and other web sources is not perfect. Considering that some firms may not announce their implementation of OI, potential samples can be disregarded. An alternative measurement approach is to interview firms' innovation or operations managers directly. However, replies may contain bias because OI is becoming a norm (Chesbrough and Brunswicker, 2014;

Chesbrough and Crowther, 2006; Lichtenthaler, 2008) that possibly creates an institutional force for organizations to conform with. Positive answers may be driven and provided. Also, the data collection process may take a relatively longer time for individual interviews. Thus, OI announcements with detailed descriptions of the implementation process can still be considered a good proxy to measure the actual OI implementation of a firm. In addition, we crosschecked and verified the implementation in two or above data sources, giving further support to our measurement approach. Third, our study only focuses on the impact of OI on innovation performance, although other business performances may also be affected. For instance, future research can broaden the understanding of OI by examining its effect on operational efficiency. Arend et al. (2014) indicate that external knowledge helps improve operational performance. Updated and relevant environmental information and expertise in diverse domains advance a firm's organizational routines and capabilities, creating more flexible and responsive operational structures (Peng et al., 2008). Prior literature and case studies also propose that OI reduces R&D cost and operational expenses through external and internal knowledge use (Billington and Davidson, 2013; Kumar, 2016; Laursen and Salter 2006; Sakkab, 2007). Hence, it is advisable to take other performance variables into consideration in future studies. Fourth, investigating other moderating variables may yield additional insights to the impact of OI. Since our emphasis in this research is on the moderating effects of KAC and APS, some underlying factors that may also influence the impact of OI on innovation performance may be overlooked. For instance, researchers may consider assessing alliance partners' characteristics (e.g., business nature, resource availability, organizational culture) and alliance formation purposes. Earlier studies have suggested that they have influence on knowledge and resource complementarity, affecting the focal firm's performance (Hora and Dutta, 2013; Vasudeva et al., 2013; Wassmer et al., 2017). It may help enhance a firm's innovativeness and create operational advantages in the implementation of OI.

OI has become an increasingly imperative strategy for firms to create value and obtain competitive advantage. Given that the wider use of it and its implementation challenges exist simultaneously, there is a clear need for us to understand and investigate the impact of OI. This study makes important contribution to researchers in related fields and to firm managers who are deciding to implement the strategy. We reveal whether and how firms can improve innovation performance through external and internal knowledge integration and use under OI. Further, the moderating effects of KAC and APS in the relationship between OI and innovation performance are examined. Implications in terms of positive and strengthened OI impact through higher KAC and insignificant moderating effect of APS on OI implementation are discussed. We hope that our empirical findings set the stage for future research to continue exploring OI, enriching the understanding of its value.

APPENDIX A

Examples of Open Innovation Implementation Extracted from Factiva

DOW JONES

PR Newswire
a CISION company

HD	Lilly Launches Open Innovation Drug Discovery Platform to Help Find Potential New Medicines Where Medical Need is Great
WC	1,008 字
PD	2011 年 9 月 27 日 08:00
SN	PR Newswire (U.S.)
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INDIANAPOLIS, Sept. 26, 2011 /PRNewswire/ -- Eli Lilly and Company (NYSE: LLY) today announced the launch of a new open innovation platform designed to help build the company's pipeline of tomorrow and, from a philanthropic perspective, identify molecules that may have application for treating multi-drug resistant tuberculosis (MDR-TB). The new platform, titled Open Innovation Drug Discovery, is supported by an innovative new website available at openinnovation.Lilly.com. It builds on the success of Lilly's Phenotypic Drug Discovery Initiative (PD(2)) that was launched in 2009 to facilitate research on molecules around the world that have the potential to ultimately be developed into medicines.

The new platform consists of three components:

TD

-- TD2, or target drug discovery, a new component that screens submitted molecules for their potential to interact with known disease targets.

-- PD2, which continues to screen submitted molecules in complex cellular assays with the goal of identifying potential new medicines acting by novel mechanisms or pathways.

-- An additional new component that screens molecules for their potential in the fight against MDR-TB--a form of tuberculosis (TB) that is resistant to at least two first-line TB medicines--through the Lilly TB Drug Discovery Initiative. Lilly has long been involved in global efforts to stop the spread of TB and MDR-TB, which disproportionately affects underserved populations. Given the recent emergence of MDR-TB, there is an urgent need to find breakthrough treatments.(i)

"I think of Open Innovation Drug Discovery as a platform consisting of multiple superhighways all pointed towards the final destination of discovering novel medicines that we believe have the potential to improve patients' lives," said Alan D. Palkowitz, Ph.D., vice president of discovery chemistry research and technologies, Lilly. "These superhighways connect scientists from all over the world with Lilly, for the common goal of finding new treatments for diseases where patients are in need and looking for answers, such as cancer, diabetes and MDR-TB."

Many scientists have molecules they would like to explore as potential medicines, but for a range of reasons, including the lack of resources or barriers to engaging in the drug discovery and development process, they are not able to advance their work. The Open Innovation Drug Discovery platform is designed to minimize these obstacles and benefit continued research that supplements the innovation of Lilly's scientists.

In addition to focusing on research areas in which Lilly has an internal strategic focus and deep expertise--cancer, endocrine, cardiovascular and neuroscience--the open innovation platform now will serve as a bridge between external scientists and the not-for-profit Lilly TB Drug Discovery Initiative, whose mission is to accelerate early-stage drug discovery and help identify the TB medicines of the future. Leading members of the Lilly TB Drug Discovery Initiative include the Infectious Disease Research Institute (IDRI) and the National Institutes of Health (NIH).

How the Open Innovation Drug Discovery Platform Works

The Open Innovation Drug Discovery platform utilizes a secure website that offers Lilly's proprietary computational and informatics tools to aid scientists in the design and selection of molecules. Once a scientist submits a molecule to the website and it meets certain specified requirements, Lilly tests it -- free of charge -- in a series of biological assay panels that evaluate it for its uniqueness and potential to be further optimized into a drug candidate. Comprehensive data reports are then provided to the submitting scientist.

In the case of the cancer, endocrine, cardiovascular and neuroscience screenings, in return for providing the data Lilly retains first rights to negotiate a collaboration or licensing agreement with the submitter. If no such agreement is reached, the external scientist retains "no-strings-attached" ownership of the data and can choose to use it in publications, grant proposals or to further refine his or her hypotheses about the molecule's potential as a medicine. In the case of the MDR-TB screening, promising data could result in a collaboration between the submitting organization and the Lilly TB Drug Discovery Initiative.

"Our mission at Lilly is to help people live longer, healthier lives," said Jan Lundberg, Ph.D., executive vice president, science and technology, and president, Lilly Research Laboratories. "In doing so, we look for where there is a need and forge ahead within our own labs and through partnerships. In that spirit, we recognize that there are many untapped sources of ideas and molecules outside of Lilly that would otherwise go unnoticed without initiatives like this one that advance science."

HD Intuit Announces New Open Innovation Challenges in Mobile Space; Recognizes Recent Winner

WC 844 字

PD 2011 年 3 月 22 日 15:46

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Bring Ideas to IntuitCollaboratory.com for Chance to Win Cash Prizes

MOUNTAIN VIEW, Calif.--(BUSINESS WIRE)--March 22, 2011--

TD

Intuit Inc. (Nasdaq: INTU), today unveiled two new open innovation challenges hosted on IntuitCollaboratory.com, offering cash prizes for winning ideas.

The company also announced the winner of its first Collaboratory prize challenge. CloudSway, a cloud computing-solutions company based in University Place, Wash., won $5,000 for answering the receipts challenge with a solution that captures receipt images using a smartphone and makes the data dynamic for uploading into an online financial system.

"Intuit is always looking to tap into entrepreneurial minds inside and outside the company to discover ways to make the most of new technologies that can solve important problems for our customers," said Susan Harman, manager of open innovation at Intuit. "IntuitCollaboratory.com provides an easy way for innovators to connect with Intuit and find exciting projects and information on how to work with us."

New Prize Challenges Announced

To participate in Intuit's open innovation challenges, visitors go to www.IntuitCollaboratory.com and respond to specific Intuit business needs, called "challenges," and potentially win a cash reward plus an opportunity to enter into a pilot test with Intuit. These challenges relate to new products or extensions of existing products and involve areas such as mobile technology, software-as-a-service solutions and data analysis. The opportunities span Intuit's consumer, accounting professional, financial services, technology innovation and small business groups.

Two of the new challenges offer a $5,000 cash prize for the winning idea.

-- Make Mobile Payments Easy with QR CodesQuick Response barcodes, those black-and-white matrixes composed of tiny squares, are popping up in store windows and magazine ads everywhere. These two-dimensional codes give consumers a way to easily make purchases and payments from a mobile device. Some large companies already benefit from using QR codes for purchasing and invoicing. The challenge asks whether the average consumer could also benefit from receiving a bill or invoice information via a QR barcode, or perhaps pay it at the same time. The prize will go to an innovator who finds a way to allow consumers to instantly pay by simply scanning the QR code with their mobile device, and have both consumer and seller receive immediate confirmation of the payment.

-- Help Small Businesses Get Productive With iPad and Other TabletsTablet devices, such as iPads, present interesting possibilities for helping small businesses. The challenge is to come up with apps for tablets that can save time and/or money for small businesses on the go.

"For small businesses, the relationship between productivity and profitability is direct and results are quickly evident when looking at the bottom line," said Hugh Molotsi, vice president of the Technology Innovation Group at Intuit. "Starting with the iPad, it became clear that the potential with tablet devices and the apps being created for them could be particularly significant for small businesses. Now we want to explore some ways to make these potential benefits real."

The Future of Collaboration

Intuit, which created Quicken and QuickBooks, the revolutionary personal and small business financial management software, launched IntuitCollaboratory.com in December 2010. Intuit Collaboratory is a website that offers individuals, academia and businesses the chance to grow together with Intuit through open innovation partnerships. The potential payoff for budding entrepreneurs is significant: the chance to bring a new idea or product to market with the support of a global company with leading brands, a large customer base, award-winning products and extensive marketing and distribution channels.

Experts expect collaborative partnerships between big and small firms to increase in the coming decade. The recently released Intuit 2020 report predicts that small firms will contribute innovative practices with market agility that bigger companies cannot achieve as easily. At the same time, big firms will offer small businesses marketing and distribution power, enabling them to penetrate broader markets more effectively.

APPENDIX B

Examples of Open Innovation Implementation Extracted from IdeaConnection

Mobile Phone Microscopy for the Developing World and Other Ideas

Published Feb-09-10

Breakthrough:
Four innovative winning solutions submitted to an Intel open innovation competition to address some of the developing world's most pressing problems.

Company:
Intel Corporation

The Story:

Businesses are not the only beneficiaries of an open innovation approach to discovering new technologies; communities in the developing world are also benefiting from solutions to some of the most challenging problems they face.

Pressing issues such as irrigation, mosquito control, and disease management are just a handful of the urgent needs that have been addressed by open innovation.

Intel Open Innovation Competition

In 2008 Intel Corporation launched a competition seeking the best technology ideas in four areas of global need – economic development, education, the environment and healthcare. Winners in each category would be awarded $100,000 in development and implementation funding.

"Technology is a tool to address some of the world's most pressing challenges related to healthcare, education, economic development and the environment. No nations or individuals are untouched by these issues. Get involved. Be part of the solution," was the rallying cry of Intel chairman Craig Barrett.

Discovering New Ideas

The intent was to encourage individuals and organizations to come up with new ideas and to think of new ways of applying technology to solve some of the problems.

The contest was open for eight months and during that time more than 200 submissions were filed from companies, non-profit organizations, universities, non-governmental organizations and individuals from 44 countries around the world.

“The caliber of submissions demonstrates the incredible collaborative power of the developer community to use technology to help solve real-world problems," added Barrett.

The four winners were:

Cellscope: Telemicroscopy for disease diagnosis – submitted by Daniel Fletcher, a professor at the University of California, Berkeley. This is a way of turning a camera-enabled cell phone into a handheld microscope that can diagnose and monitor infectious diseases such as malaria. Images can be captured and transmitted.

Mobile Solar Computer Classroom (MSCC) – submitted by Eric Morrow, executive director of the Maendeleo Foundation in Uganda. Solar-powered computers for schools in poor, deprived and remote areas that have no access to the Internet or IT applications.

Rural Livelihood Enhancement – submitted by Bibek Chapagain, Clean Energy Group director at Winrock International. A proposal to use renewable energy from micro-hydro stations and solar cells to deliver communication technologies to parts of rural Nepal that are not on the electricity grid.

Great Lakes Cassava Initiative (GLCI) – submitted by Michael Potts, Catholic Relief Services' director for GLCI. A pilot project pioneering the use of laptops and data communication amongst farmers in Burundi, Democratic Republic of Congo, Kenya, Rwanda, Tanzania and Uganda to help them monitor disease threats and increase their crop yields.

Open Innovation Delivers

Initiatives such as Intel’s Inspire-Empower Challenge focus the power of open innovation on the developing world. It increases the scale and efficiency with which the social problems of the most vulnerable members of society can be solved.

For the problem solvers it is the satisfaction of knowing that their brainpower can transform, and in many case save the lives of millions of individuals.

Students Get into the Open Innovation Habit

Published Jan-26-15

Breakthrough:
An app to help blind students navigate their way round school and college campuses wins a school open innovation contest.

Company:
Verizon Communications, United States

The Story:

Crowdsourcing and collaboration offer huge potential for innovation and solving challenges efficiently and cost-effectively. Today, these are practices that some people are learning while young.

The Verizon Innovative App Challenge is an open innovation competition in the United States for middle schools and high schools. It offers grants to winning teams and was designed to fire up the creative and problem-solving abilities of children and show them exciting possibilities for the future.

The way the contest works is that teams of between 5 and 7 students develop an original concept that addresses a need in their school and community. Their work processes must incorporate STEM principles (science, technology, engineering and math). In 2014, more than 1,200 students took part.

Android App for the Blind

One of the standout successes of the 2014 contest was a team of six girls from Resaca Middle School in Los Fresnos, Texas. They developed an app concept to help visually-impaired people navigate new spaces.

They were inspired by observing difficulties experienced by blind students moving around parts of their campus. A mobility specialist spends a lot of time with them at the beginning of the school year so they can become familiar with the corridors, halls and spaces, but problems are still encountered.

The inventive students searched for current technology solutions that could make matters easier for their blind colleagues, but found nothing. So they invented their own.

To develop their concept, the pupils imagined they were visually impaired, by donning blindfolds and walking through the halls of their campus. Their experiences helped them to pinpoint features that the app would need.

The app is designed to measure a user's stride and then it combines this information with digital building blueprints. Directions are then given by VoiceOver technology. The app also includes Google Indoor.

The innovative app tells a visually impaired person where they are, where they need to go and it gives them directions, which can save a lot of time. It has not been designed as an obstacle avoidance system.

Prize Money

For their winning innovation, the students won a $20,000 check for their school. "I jumped, then screamed and cried tears of joy. I got up too fast from my chair when they announced we won that I even hurt my leg a little. I couldn't stop smiling," 12-year-old team member Grecía told PEOPLE.

App Development

As the girls didn't have any programming experience, a team from MIT Media Lab helped them put the app together. It is called 'Hello Navi' and can be downloaded from Google Play.

Other winning apps from the 2104 crowdsourcing competition were FITTASTICK, an app that tracks food intake and encourages exercises and Tactillium, an app to deliver science education through a chemistry simulator.

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