PUBLIC FIRM SPONSORSHIP OF OPEN SOURCE SOFTWARE: A KNOWLEDGE-BASED APPROACH TO OPEN INNOVATION

BY

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DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Business Administration
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2011

Urbana, Illinois

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ABSTRACT

As an emerging innovation paradigm gaining momentum in recent years, the open innovation paradigm is calling for greater theoretical depth and more empirical research. This dissertation proposes that open innovation in the context of open source software sponsorship may be viewed as knowledge strategies of the firm. Hence, this dissertation examines the performance determinants of open innovation through the lens of knowledge-based perspectives. Using event study and regression methodologies, this dissertation found that these open source software sponsorship events can indeed boost the stock market performance of US public firms. In addition, both the knowledge capabilities of the firms and the knowledge profiles of the open source projects they sponsor matter for performance. In terms of firm knowledge capabilities, internet service firms perform better than other firms owing to their advantageous complementary capabilities. Also, strong knowledge exploitation capabilities of the firm are positively associated with performance. In terms of the knowledge profile of sponsored projects, platform projects perform better than component projects. Also, community-originated OSS projects outperform firm-originated OSS projects. Finally, based on these findings, this dissertation discussed the important theoretical implications for the strategic tradeoff between knowledge protection and sharing.

To My Mother

ACKNOWLEDGEMENTS

My PhD experience at Illinois may be compared to an adventurous journey at the sea. Looking back at the end of this unforgettable journey, I feel fulfilled and blessed. As an inexperienced sailor, I could have been lost in my journey without a group of people whose generous help I will be forever grateful.

I have benefitted tremendously from interacting with each and every member on my dissertation committee over the years. I feel particularly lucky to have Professor Joe Mahoney as my advisor, who took me under his wings and taught me how to fly. Despite his super-packed research, teaching and service schedule, he always makes himself available to his students who need help. His meticulous coaching showed his sincere care for his students. And his pure joy from the academic research itself is truly inspiring. Congratulations on his winning of the Irwin Outstanding Educator Award this year granted by the Academy of Management, which is well-deserved!

I am also very grateful to my committee co-chair Professor Glenn Hoetker, who opened the door for me and recruited me into this great Strategy PhD program. Without his help, I could have led a much easier life for the past five years working at a well-paid job as an IT professional, yet my life would not have been so meaningful and fulfilled as it is right now. I also benefitted a great deal from his superior knowledge in methodology, and his abilities in critical thinking. These will be invaluable assets for my future career as a scholar.

As both my co-author and mentor, Professor Douglas Miller has the closest working relationship with me over the years. I am truly lucky to have learned from him not only about academic research itself, but also about work ethics and family value. I also had the great honor to co-author with Professor Eric Fang, who is a star researcher not only in the marketing strategy field, but also in many other areas such as international business. My first completed paper draft was under his guidance. This experience taught me a lot about how to conduct academic research, and benefitted me tremendously in my dissertation research. I am very grateful for his help.

My thanks also go to Professor Janet Bercovitz, who is kind enough to bring me on board to co-author with her on an exciting project, and during the past year patiently waited for me to finish my dissertation before we can proceed. I still remember her many insightful comments on the PhD process, which somewhat eased the pain for me when navigating through it. Additionally, special thanks to Professor Rajshree Agarwal, who led me into the fascinating research area of open innovation. Her inexhaustible energy and passion for research are indeed unparalleled and inspirational.

I am very proud to be a part of the great Strategy Group at UIUC. Over the years I have benefitted immensely in one shape or another from Professor Deepak Somaya, Professor Steven Michael and my co-author Professor Anju Seth. They have set great examples for what a true strategy scholar would be like. My cohorts are another source of inspiration for me. I want to thank Lihong Qian, Mahka Moeen, Martin Ganco, Denisa Mindruta, Barclay James and Amit Jain in particular for their great friendship and support during my PhD process.

The other groups of the Department of Business Administration at UIUC also had great influences on me. Over the years I had the honor to take the courses from Professor Huseyin Leblebici, Professor Madhu Viswanathan, Professor Joe Cheng and Professor Joe Broschak. Their insights have been and will be great sources of inspiration for me for the future. I also want to thank the department staff whose support has been indispensable for me during my PhD process. They are Claudia Gaston, Julie Monroe, and JE Miller, among many others.

I also want to thank the following people who helped me in various ways during my dissertation research: Joel West, Glenda Kao, Shihchi Chiu, and Vivian Guo.

Finally, I dedicate this dissertation to my mother. I would not have pursued my PhD without the encouragement and support from her. She is the ultimate inspiration of my life. I am also grateful to the support from my father, my sister and my girl friend. It would be unimaginable that I could complete my PhD process without their support.

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CHAPTER 1: INTRODUCTION

If the rise of modern corporations is the inevitable consequence of the age of industrialization, then the emergence of the open innovation paradigm may be an equally inevitable consequence of the age of internet. The internet is fundamentally an open infrastructure for information exchange with open access, open protocols, and open collaborative culture from the very first day it was born. This openness of the internet contrasts sharply with the traditionally closed model of information exchange in industries such as telecommunications, where restricted access and proprietary platforms still dominate. In recent years, the open innovation paradigm (Chesbrough, Vanhaverbeke, & West, 2006b) has gained notable attention in the industry as well as academia, as evidenced by a growing number of publications and dedicated conferences to this topic area. This fast-growing popularity may reflect the potential of open innovation as a promising new theoretical approach to the growth of technology-based firms in the new millennium.

As a young paradigm, the open innovation literature stream is still in its early stage of development. Although there has been a proliferation of open innovation related studies, the theoretical depth is still lacking. In particular, the extant research literature in this area is characterized by a fascination for the open innovation concept itself, and shallow explanations of this concept in various contexts (Fredberg, Elmquist, & Ollila - Chalmers, 2008). Additionally, with few exceptions (Henkel, 2006; Laursen & Salter, 2006), most of the empirical studies on open innovation were based on case studies, which could provide rich and valuable insights for exploratory research, yet may lack the generalizable evidence typically supported by quantitative studies.

At the same time, the open source software (OSS) movement has made significant strides in reshaping the competitive landscape of the information technology industry. For instance, the Linux open source software is now the dominant operating system in the web-server market, with 60% market share (http://en.wikipedia.org/wiki/Linux). One prominent yet often neglected aspect of this change is the increasing endorsement of open source software projects by public firms. Although the open source software movement appears to be without a profit motive during its early days, the emerging trend of public firm sponsorship of open source software has steered the movement into a new, commercially-motivated era known as "OSS 2.0" (Fitzgerald, 2006). As a result, open source software is increasingly converging with the phenomenon of open innovation in recent years. Indeed, the open innovation motive has been cited by many public firms in their open source software strategy statement (e.g. http://software.intel.com/sites/oss/). Thus, these corporate endeavors in open source software sponsorship provide an ideal setting as well as a rare opportunity for an empirical study of the performance impacts of open innovation. *Sponsorship* in this dissertation is defined as a publicly displayed affiliation between an OSS project and a firm, whether this affiliation is achieved through financial, intellectual property or human resource allocations by the firm to the OSS project. This definition follows similar constructs used in extant literature in this area (Stewart, Ammeter, & Maruping, 2006).

Overall, this dissertation attempts to answer the call for more in-depth theoretical underpinnings of the open innovation paradigm. Specifically this dissertation aims to contribute to the open innovation literature by addressing the following issues: (1) Exploring the impacts of open source software-based open innovation strategy on firm value creation. Several value creation mechanisms have been identified for firm sponsorship of open source software, including innovation improvements, signaling effects, and competitive positioning effects;

(2) Proposing a knowledge-based theoretical approach to better understand heterogeneous open innovation performance outcomes. This dissertation emphasizes the role of firms' knowledge capabilities in determining their open innovation performance. Thus, relevant perspectives are juxtaposed to compare and contrast their views on knowledge capabilities with those of the open innovation paradigm; (3) Empirically testing the relationship between firms' knowledge-based resources and capabilities and their stock market performance, using quantitative data obtained in the context of public firm open source software sponsorship events; and (4) Countering the conventional wisdom regarding the role of knowledge protection on firm competitiveness, by proposing a more sophisticated knowledge strategy balancing the tradeoffs between knowledge protection and external knowledge sharing.

The findings of this dissertation suggest that, on the one hand, open innovation indeed creates value for the practicing firms. On the other hand, there are substantial variations among firms in terms of their open innovation performance, due to the heterogeneity in firm resources and capabilities. In particular, firms' knowledge-based assets and capabilities play a key role in determining their open innovation performance. Hence, open innovation is not a panacea for everyone. Firms need to carefully consider the strategic fit between open innovation strategies and their knowledge capabilities, in order to achieve high payoffs from their open innovation endeavors.

This dissertation is organized as follows: Chapter 2 and 3 will review the research literature on open source software and open innovation, respectively. Chapter 4 connects these two literature streams together and makes the case for firm value creation though open source software sponsorship. Chapter 5 proposes that open source sponsorship may be viewed as a knowledge strategy of the firm, and thus its stock market performance may be determined by the firm's knowledge capabilities. Chapter 6 presents hypotheses concerning open innovation performance in the open source software sponsorship context, derived from the knowledge-based perspectives discussed in Chapter 5. Chapter 7 conducts an event study to test the significance of these open source software sponsorship events. Chapter 8 uses the cumulative abnormal return (CAR) from chapter 7 to test the impacts of firm knowledge resources and capabilities on the stock market performance of the sponsorship events. Chapter 9 discusses the implications of open innovation on the knowledge-based perspectives, exploring the potential theoretical contributions regarding the balance and tradeoff between knowledge protection and external knowledge sharing. Finally, chapter 10 discusses the contributions and limitations of this dissertation, and suggests future avenues of research worth pursuing.

CHAPTER 2: OPEN SOURCE SOFTWARE

The Open Source Phenomenon

Open source software (OSS) used to be developed primarily by volunteers who are also users of the software themselves, in a loosely connected developer community, and distributed free of charge. The Linux operating system and Apache web server are perhaps the most prominent examples of open source software projects. Together they have taken a dominant share of the web server market. Open source software represents a major departure from proprietary software in almost all major aspects, including input, output, development process, and value proposition (Fitzgerald, 2006).

The proprietary software development process is similar to traditional product development. It involves development stages such as planning, requirement analysis, design, implementation, and testing. These tasks are typically carried out within the boundary of a single firm. The firm provides all the resources for the development, controls the process, and appropriates all the profits from the final product. In contrast, open source software projects are developed beyond the confines of any single firm. They are typically initiated by individual developers or small groups of developers who are also users of the software. The planning and design phases are often simplified due to the generalized nature of the problems these open source software projects attempt to address. Little resources are needed as input to the open source software development process because open source software relies on volunteer contributions. The coordination of the development process is usually achieved through online development forums and mailing-lists. Finally, the output is freely available to everyone. This "private-collective" development model of open source software fits perfectly with the description of a public good (von Hippel & von Krogh, 2003).

Beyond the differences in the development process, the most fundamental distinction between open source and proprietary software is the value proposition. While proprietary software firms can appropriate all the rents generated by their products, nobody is supposed to directly profit from open source software. As a public good, open source software is supposed to be free to the masses and not to generate private profits for those who contributed to its development. On the other hand, public firms are under pressure to create value for their shareholders. This creates a seemingly paradoxical situation: profit-oriented firms making investments in non-profit-generating open source software development. Prior empirical studies on open source software have examined the motivations of individual developers who contribute their software development efforts for free (Hertel, Niedner, & Herrmann, 2003; Lakhani & von Hippel, 2003; Roberts, Il-Horn, & Slaughter, 2006), or factors affecting the outcome of open source software development processes (Grewal, Lilien, & Mallapragada, 2006; Lerner & Tirole, 2005; O'Mahony & Ferraro, 2007; Shah, 2006). However, little research attention has been given to the case of firm sponsorship of open source software, or its performance implications. Among the research studies that did examine firm involvement in open source software, most adopted a case study approach (West & Gallagher, 2006a) and were concerned with small, entrepreneurial firms adopting OSS-based business models (Bonaccorsi, Giannangeli, & Rossi, 2006; Dahlander, 2007; Dahlander & Magnusson, 2005; O'Mahony & Bechky, 2008; Stam & Elfring, 2008). Nevertheless, it is a well-known fact that sponsorship by large, established firms, such as IBM, HP and SUN, is crucial for the commercial success of open source software today. This research attempts to explain this seemingly paradoxical phenomenon of public firm sponsorship of open source software through the theoretical lens of open innovation and knowledge-based perspectives.

Evolution of the OSS literature

Taking a longitudinal view of the management literature on open source software, we may identify two distinct phases of open source software research, which also correspond with the evolution of the open source movement. The inward-looking phase (OSS 1.0), in which the newly-emerged open source software movement phenomenon is at center stage. Then came the outward-looking phase (OSS 2.0) (Fitzgerald, 2006), in which the relationships between open source software and business firms captured academic attention and became the new research focus. Next I review some of the influential literature in each of these two stages.

OSS 1.0

In the early days of the open source software movement, much attention in the economics and business research has been devoted to the interpretation of the open source phenomenon. The common goal of these early research studies was to reconcile the seemingly unorthodox approach of software development with the traditional economic paradigm. Specifically, the open source software movement presents research challenges in the following two interrelated aspects: (1) individual incentives – can open source software really be understood as "gift economies" (Bergquist & Ljungberg, 2001; Raymond, 1999b)? How does it reconcile with the self-interest-seeking behavioral assumptions of the economics discipline? (2) Innovation model – is this self-managed innovation model a sustainable new innovation model? How to reconcile this model with the traditional innovation processes driven by protection of intellectual property rights, such as patents, copy rights and trademarks (Lerner & Tirole, 2001)? These concerns are valid, and resolving them will enhance the understanding of the open source software phenomenon itself, as well as theoretical understanding.

Researchers conducted mostly case studies and surveys in order to answer the first set of questions. While the gift economy explanation may have certain merits judging by the special norms and ideology within the open source community (Stewart & Gosain, 2006), individual participants are more likely driven by user value (Franke & von Hippel, 2003; Lakhani & von Hippel, 2003), reputation and status (Zeitlyn, 2003) or career advancement concerns (Lerner & Tirole, 2002). Other researchers found these individual motives to be interrelated in complex ways, which could impact the level of participation and contribution (Roberts et al., 2006). Overall, the motivations of open source software developers can indeed be reconciled with the conventional individual behavioral assumptions in business and economics.

The second set of questions is more intriguing to firms trying to understand the viability as well as sustainability of open source software as a new innovation model (Dalle & Jullien, 2003; Osterloh & Rota, 2007). The tremendous potential of the open source innovation model could be invigorating for some industry players, and threatening for others. Proprietary software giant Microsoft assessed open source software such as the Linux operating system, and came to the conclusion that this threat is real and could turn into a horror story for its monopoly position in the market if unchecked (http://en.wikipedia.org/wiki/Halloween_Documents). This perceived threat explained why Microsoft took on an aggressive role from the beginning of the open source movement, by launching numerous lawsuits aimed at undermining the legitimacy of Linux (http://money.cnn.com/magazines/fortune/fortune_archive/2007/05/28/100033867/index.htm), and the open source software innovation model in general. On the theory building side, academics have attempted to define this new innovation model as a "private-collective" innovation model (von Hippel & von Krogh, 2003), with private efforts from user-innovators amounting to collective innovation that benefits the society at large. At the same time, the open source innovation model was recognized as a community-based knowledge creation model, distinct from firm-based commercial software development model (Lee & Cole, 2003). Empirically, substantial research efforts have been devoted to in-depth examination of the determinants of successful open source software development processes. Observations have been made about contributor behavior (David & Rullani, 2008), impact of social network structure (Grewal et al., 2006; Hahn, Moon, & Zhang, 2008), knowledge sharing (Kuk, 2006), modularity of code structure (MacCormack, Rusnak, & Baldwin, 2006), among other factors. Another important area of the open source innovation process is its governance. Important determinants related to governance include license choices (Lerner & Tirole, 2005), conceptions of authority (O'Mahony & Ferraro, 2007), and control mechanisms (Shah, 2006).

In summary, the research questions in the OSS 1.0 phase mostly aimed at making sense of the new phenomenon of open source software movement, connecting it to conventional economics reasoning, and examining the specific innovation processes. In other words, the focus is inside the open source innovation model. Therefore, research in this stage is considered inward-looking (Fitzgerald, 2006).

OSS 2.0

In the OSS 1.0 phase, important research questions regarding the relationship between open source software and its external environments have been to a large extent neglected. For example, few research studies have examined the competitive implications of open source software in high-tech industries. The development of the industry is leading to the call for more outward-looking research studies of the open source software phenomenon, with a focus on its competitive impacts. For instance, a recent survey among Norwegian software companies confirmed that close to 50% of the software industry integrated open source software into their solutions, and more than 30% of the firms surveyed have more than 40% of their incomes from products or services related to open source software (Hauge, Sørensen, & Conradi, 2008).

In answering this call, in recent years the open source literature has witnessed a boom of new research studies looking beyond the open source community into its social impacts on business firm competition as well as government environments (Simon, 2005). This is a major shift from the OSS 1.0 stage, representing a more outward-looking research focus. Increasingly, the interactions between firms and the open source software communities are being studied. Further, more diverse methodologies have been used as well, including case study, survey, archival data and simulations. This new stage of the open source software research has been labeled “OSS 2.0” (Fitzgerald, 2006), to distinguish it from the previously inward-looking focus in the earlier stage of open source research.

In fact, research related to the interrelationship between open source software and firm involvement dates back to the beginning of the open source movement. Early work linking open source software to business strategy proposed that open source software is ideal for platform-based strategies, mainly because open source software developers have the most experiences in the infrastructure/back-end software space (Behlendorf, 1999). In other words, this work acknowledged: (1) the path-dependent nature of knowledge creation in open source movement, and (2) both strengths and weaknesses exist for open source software-based business strategies. Early academic research in open source software also noticed the phenomenon of corporate resource allocation to foster open source activities, thus putting the research question about the motives for corporate sponsorship of open source software on the future research agenda (Lerner & Tirole, 2001). This literature stream on firm involvement in open source software witnessed a takeoff soon afterwards.

Similar to the research questions in OSS 1.0 stage, the most important research areas in the OSS 2.0 era also have to do with two interrelated questions regarding the motives for participation and process issues, although this time the questions are asked at the firm level: (1) what are the key motives for business corporations to sponsor open source software? (2) How do they successfully leverage open source software in their business strategies, so as to achieve competitive advantage? A quick review of the extant open source software literature may help us to answer these two questions.

For the first question regarding firm motives in sponsoring open source software, researchers proposed that both firms and the individual open source programmer within them can benefit from contributing to the open source community. The firm-employed open source developers can benefit from skill improvement, pleasure away from routine work, and better career opportunities. Firms can benefit from proprietary expertise that is complementary to the open source software, and also from learning effects and good public relations (Lerner, Pathak, & Tirole, 2006). Empirical support for this complementary expertise motive has been found (Fosfuri, Giarratana, & Luzzi, 2008), in which a firm's expertise is measured by patents and trademarks. In addition, open source communities have been recognized as complementary assets for business firms to leverage during their innovation processes (Ågerfalk & Fitzgerald, 2008; Dahlander & Magnusson, 2008; Dahlander & Wallin, 2006; Stam, 2009). Based on a comparison between firm and individual motives in open source participation, a systematic framework has been proposed. This framework suggests that firms may be motivated by (1) economic factors such as profiting from complementary software-related services and products, (2) social factors such as the norms and expectations for firms utilizing open source software to contribute back to the open source community, and (3) technological factors such as the reduction in R&D costs and enhancement of software quality. A survey of 146 Italian open source software vendors found that a minority of firms (19%) were altruistically motivated (e.g., following norms of the open source community), the rest of them are either entirely motivated by profit concerns (34%), or motivated by a mixture of profit and other concerns (Bonaccorsi & Rossi, 2006). Finally, the innovation-enhancing potential of open source software has been noted in both theoretical and empirical papers. The open source software-based innovation model is viewed as a form of user innovation that could contribute to the firm competitiveness (Kuan, 2001; Stuermer, Spaeth, & von Krogh, 2009; von Hippel & von Krogh, 2003). The collaborative development model and shared property rights associated with open source software have also made it a quintessential example of open innovation. Scholars have proposed four types of open source strategies as solutions to meet the challenges of open innovation: pooled R&D, spinouts, selling complements, and donated complements (West & Gallagher, 2006a).

For the second question regarding open source software-based competitive strategy, empirical studies have examined cases from companies like Apple, IBM, and Sun Microsystems. These case studies found that successful platforms typically require hybrid strategies, combing proprietary and open source components (West, 2003). The benefits of hybrid strategies are also corroborated by other studies (Bonaccorsi et al., 2006). Start-up companies may represent the most innovative and dynamic members of the technology economy. Researchers have examined how effective these new ventures were able to leverage the open source-based business strategies in market entry and competition (Dahlander, 2007; Gruber & Henkel, 2006; Lamastra, 2009; Stam & Elfring, 2008). In particular, the availability of open source software project repositories like SourceForge.net and Freshmeat.net enabled large scale quantitative studies to examine corporate contributions to open source software projects, leading to the findings of a number of determinants for effective firm involvement in open source sponsorship, such as the choice of license scheme (Stewart et al., 2006). Also, simulation techniques have been adopted by a number of economics researchers to model the effects of open source software in business competitions (Casadesus-Masanell & Ghemawat, 2006; Economides & Katsamakas, 2006; Raghu, Sinha, Vinze, & Burton, 2009).

Overall, the OSS 2.0 phase research studies turned their attentions outside the open source movement itself into the business environment, acknowledging the important role played by open source software in business strategies of firms (West & Gallagher, 2006a), particularly as complementary assets allowing firms to profit from their advantageous resource positions (Fosfuri et al., 2008; Pisano, 2006). On the other hand, researchers have also recognized both the strengths and the limitations of open source-based strategies, such as the strength in platform strategies and the weakness in end-user applications (Behlendorf, 1999; Fitzgerald, 2006). These limitations lead to the “essential tension” between innovation adoption vs. profit appropriation (West, 2003). Hence hybrid business strategies are postulated as the best ways to leverage open source software (Bonaccorsi et al., 2006; West, 2003). Last but not least, the connection between open source software and firm open innovation activities have been identified by extant literature (Grand, von Krogh, Leonard, & Swap, 2004; Henkel, 2006; Lamastra, 2009). We will take a closer look at the open innovation paradigm in the next chapter.

CHAPTER 3: OPEN INNOVATION

The Open Innovation Paradigm

In recent years, the open innovation model has emerged as a new innovation paradigm in contrast with the traditionally closed, vertically integrated model of firm innovation.

The closed innovation model is also called the "producer's model" (Baldwin & Von Hippel, 2009), in which producers of goods and services for sale are assumed to be the dominant sources of innovation. Innovation scholars since Schumpeter (1934) have focused on the role of corporate R&D labs in innovation (Mowery, 1983). The corporate R&D labs typically grew out of the need to sustain and improve production activities (Chandler & Hikino, 1990). These internal R&D activities allow firms to leverage their firm-specific knowledge assets within their vertically-integrated boundaries, in order to enhance the competitiveness of their products. Famous examples of corporate R&D labs include AT&T's Bell Lab and Xerox's PARC, which has generated numerous innovations with far-reaching impacts, such as the Graphical User Interface (GUI) which later propelled Microsoft and Apple Computer to great successes. One of the distinctive characteristics of the management approach of these corporate internal R&D efforts is the reliance on internal talents, or "men of genius" (Conant, 2002). Also, due to the need to recoup the huge investments in corporate R&D, intellectual property protection mechanisms including patenting and secrecy are of primary concern in the closed innovation model (Hertzfeld, Link, & Vonortas, 2006; Oxley, 1999; Zhao, 2006). Please see Figure 3.1 for details.

In contrast to the closed innovation model, the open innovation model emphasizes the need to acquire knowledge and information from outside the firm boundary, and to deliberately utilize knowledge spillover as a business strategy. Open innovation is defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" (Chesbrough et al., 2006b: p.1). The two key capabilities emphasized in this definition are: (a) the value creation capability utilizing both external and internal knowledge; and (b) the value appropriation capability exploiting both external and internal market channels. In terms of the direction of knowledge flow, firms can engage in either inbound or outbound open innovation. In inbound open innovation, firms actively monitor the environment in search for useful knowledge to in-source, in order to complement their in-house innovation processes. In outbound open innovation, firms not only rely on internal path to market (i.e. R&D, manufacturing, marketing and distribution) to profit from their internal innovations, but also seek to participate in external innovation opportunities with various partners, in order to profit from their under-utilized knowledge assets and capabilities (Chesbrough & Crowther, 2006). In order to effectively implement open innovation, two impeding attitudes to openness, Not-Invented-Here (NIH) (Katz & Allen, 1982) and Not-Sold-Here (NSH) (Lichtenthaler, Ernst, & Hoegl, 2010) need to be overcome. The former refers to a negative attitude toward external knowledge utilization, while the latter refers to an over-protective stance on internal knowledge which inhibits external knowledge exploitation (Lichtenthaler et al., 2010).

The emergence of the open innovation model was motivated by the observations of innovation anomalies that cannot be explained by the closed innovation model, such as spillovers that could not be internally commercialized. The aforementioned case of GUI is a famous example of such unintentional spillover by Xerox PARC (Chesbrough, 2002; Chesbrough & Rosenbloom, 2002; Smith & Alexander, 1988). There are a number of other changing dynamics undermining the effectiveness of the closed model of innovation and favoring the shift toward the open innovation model. These include the increasingly dispersed knowledge landscape, the higher mobility of knowledge workers, the flourishing of the venture capital market specializing in creating new firms, and the increasing scope of capable external suppliers (Christensen, Olesen, & Kjaer, 2005). Building on these new factors, the open innovation paradigm offers new insights in many respects. For example, external knowledge played a useful but supplemental role in the closed innovation model. Open innovation model emphasizes the importance of external knowledge, granting it equal importance as internal knowledge in firm's innovation activities. Also, the closed innovation model management emphasized the recruitment and retention of internal talents, while paying little attention to the business model in organizing for innovation. In contrast, the open innovation model stresses the centrality of the business model for innovation value capturing. Other important insights of the open innovation paradigm include the identification of purposive knowledge spillovers, the abundant underlying knowledge landscape, and new metrics for measuring innovation performance, among others (Chesbrough et al., 2006b). The Figure 3.2 illustrates the concept of the open innovation model.

The Growth of Open Innovation Literature

The concept of open innovation is not entirely new. It draws on a number of theoretical perspectives in the extant innovation literature, and provides a comprehensive and systematic synthesis of the innovation process with an external orientation (Christensen et al., 2005). Prior research on the importance of external technology served as theoretical antecedence of the open innovation paradigm. Influential literature include firm decision to search for external new technology (Nelson & Winter, 1982), importance of firm capability in utilizing external knowledge – absorptive capacity (Cohen & Levinthal, 1990), and various external sources of useful knowledge (von Hippel, 1988). In addition, the research literature on innovation within the context of firm alliances and networks (Dyer, 1996; Nooteboom, 1999; Powell, Koput, & Smith-Doerr, 1996) also inspired the open innovation paradigm.

Partly due to the fact that the open innovation model originates from the practitioner world, the theoretical development of the literature has lagged the industry embracement of the open innovation concept. Furthermore, due to the newness of the open innovation field, early studies in this literature suffered from: (1) superficial fascination about the open innovation concept itself, and (2) lack of in-depth theoretical understanding of the new paradigm (Fredberg et al., 2008). Fortunately, recent development in the open innovation literature witnessed not only a takeoff in terms of the number of published papers in this field (Dahlander & Gann, 2010), but also encouraging improvements in both the scope and depth of this research field.

In terms of the scope, the open innovation literature has seen at least three areas of progress in recent years. First, the field has matured beyond the stage of conceptualization (Chesbrough, 2003a; Chesbrough, 2003b; Chesbrough, Vanhaverbeke, & West, 2006a; Helfat, 2006) into a new stage of application of the open innovation idea in various contexts, including firm boundary (Jacobides & Billinger, 2006), university-industry relationship (Fontana, Geuna, & Matt, 2006; Perkmann & Walsh, 2007), innovation communities (Ebner, Leimeister, & Krcmar, 2009; Fichter, 2009; Fleming & Waguespack, 2007), small and medium enterprises (SME) (Lee, Park, Yoon, & Park, 2010), non-profit organizations (Müller-Seitz & Reger, 2009), and regional innovation systems (Cooke, 2005). Second, the field is moving toward addressing the problem of imbalance (Dahlander & Gann, 2010) through research studies of both the benefits and costs/risks of open innovation (Lichtenthaler, 2010; Torkkeli, Kock, & Salmi, 2009), and studies of outbound (Lichtenthaler, 2009b; Lichtenthaler & Ernst, 2007) as well as inbound open innovation. Last but not least, the methodologies adopted by open innovation studies have expanded from mostly case studies to survey (Laursen & Salter, 2006; Lichtenthaler, 2009b) and simulation (Almirall & Casadesus-Masanell, 2010; Terwiesch & Xu, 2008).

In terms of depth, the open innovation literature has not only gained better understanding about the concept of openness thorough various efforts to interpret its meaning (Dahlander & Gann, 2010; Pénin, 2008), but also has seen the development of more sophisticated theoretical frameworks for the open innovation model (Lichtenthaler & Lichtenthaler, 2009; Stevens, Schwartz, & Meurer, 2009; Torkkeli et al., 2009). More importantly, the purpose of open innovation is profit-maximization for the focal firm, based on innovation. Thus, it is an important development in the open innovation literature that more research studies have moved beyond the examination of innovation performance (Boudreau, 2010; Laursen & Salter, 2006) into investigations of the relationship between open innovation strategies and firm financial performance (Lichtenthaler, 2009b; Lichtenthaler et al., 2010). In the same vein, this dissertation aims to empirically test the relationship between heterogeneous firm knowledge characteristics and firm financial market performance in response to their open innovation activities. The findings could enhance our understanding about the contingencies for open innovation performance.

Boundary of Open Innovation

With the recent growth of open innovation literature in terms of both scope and depth, it might become necessary to delineate the boundary of open innovation. Here I propose two ways through which the boundary of open innovation model may be delineated: (1) comparison with the closed innovation model, and (2) comparison with other competitive frameworks.

First and foremost, open innovation hinges on the openness of firm attitude toward external knowledge as well as external innovation opportunities. Openness was originally defined as “use external ideas as well as internal ideas, and internal and external paths to market” (Chesbrough, 2003b: p.xxiv). Since this is a very broad definition, so far in the open innovation literature, the concept of “openness” has been used liberally to refer to many different things in different contexts. Examples include breadth and depth of external knowledge search (Laursen & Salter, 2006), level of platform control (Boudreau, 2010), level of utilization of open source software (West, 2003), and revealing of ideas previously hidden in the organization (Henkel, 2006). Recent research has attempted to address this issue of overly broad reference to openness by specifying more refined open innovation contexts based on knowledge access conditions (Penin & Wack, 2008). The latest efforts aimed at building a common ground for the understanding of openness culminated in the synthesis of Dahlander and Gann (2010), which proposed that the meaning of openness varies according to the context (e.g., innovation acquisition, sourcing, selling and revealing), and openness should be a continuum rather than a dichotomy. Their observation that there is not a universal definition of openness is an important one. Rather than focusing on whether a firm has passed certain threshold of openness, we should instead evaluate a firm’s openness in specific contexts and from multiple angles. Open innovation distinguishes itself from closed innovation in the proactiveness of the firm in exploring external knowledge as well as exploiting internal knowledge outside the firm boundary. Closed innovation may involve external knowledge acquisition as well, but mostly in a passive and random fashion. In contrast, open innovation represents an approach characterized by aggressive external knowledge sourcing and exploitation in a systemic and routine fashion. In closed innovation, NIH and NSH are common attitudes that are never questioned. In open innovation, NIH and NSH attitudes become impediments to the implementation of open innovation. Hence they are cast in doubt and no longer tolerated. Therefore, an important criterion for determining the boundary of firm open innovation might be the presence of proactive behavior in engaging in external knowledge sourcing and exploitation activities. In the context of open source software sponsorship, public firms are going out of their ways to embrace a collaborative innovation model characterized by knowledge exchange across firm boundaries, which showcases their proactiveness in sourcing external knowledge and seeking exploitation opportunities. Based on the criteria above, open source software sponsorship by public firms indeed fits the open innovation model.

Secondly, openness is a means rather than an end. Open innovation by definition is not just a model for innovation, but also a model for competitive advantage and profit-appropriation. Its ultimate goal is for firms to profit from their innovations. Thus, useful comparisons may be drawn between open innovation and other competitive models. In fact, open innovation as a competitive strategy has been widely studied in the extant literature (Dahlander & Wallin, 2006; O'Mahony & Bechky, 2008; West & Gallagher, 2006b). These open innovation competitive strategies are different from the traditional competitive strategies in multiple ways. First of all, they typically involve R&D collaboration with other firms and entities, including value networks (Chesbrough et al., 2006b). Therefore, traditional competitive strategy for isolated firms, such as price and differentiation strategies, would not fully capture what is happening in open innovation-based competitions. Further, open innovation strategies typically involve innovative business models focusing on innovations and intellectual property (IP), such as IP licensing and corporate venturing (Chesbrough, 2003b). For example, open source software-based open innovation strategies may involve pooled R&D, spinouts of seed technology, and selling complementary component services for technology platforms, etc (West & Gallagher, 2006a). In contrast, traditional product-centric strategies may also involve alliances and partnerships with other firms or entities. Yet if IP transfer and knowledge spillover among partners do not constitute an essential component of the business model, then these strategies are not considered open innovation strategies. Last but not least, open innovation-based competitive strategies often aim to proactively reshape the focal firm's appropriability regime, or institutional environment, through redesigning IP access rights to its technology (Spencer, 2003), as illustrated in the case of open source software (Pisano, 2006). In contrast, traditional competitive strategies related to industry structure changes typically have more to do with market power (Porter, 1985) than appropriability regime changes, and thus falls outside the realm of open innovation-based competition.

The above clarifications of the boundary of open innovation aim to pave the way for further discussions in this dissertation. Next I take a closer look at one aspects of the extant open innovation literature that is most relevant to this dissertation – the performance implications of open innovation strategies.

Open Innovation Performance

Distinctive from tendencies in prior literature to paint a rosy picture about the benefits of open innovation while neglecting its potential downsides (Dahlander & Gann, 2010), recent open innovation research started to explicitly discuss the costs and risks of the open innovation strategies (Lichtenthaler, 2010). These may include the inherent risks associated with openness that could reduce the rarity of firm knowledge assets (Torkkeli et al., 2009), and attitudes that may hamper the efforts in implementing open innovation strategies (Lichtenthaler et al., 2010). In the same vein, contingency frameworks for the adoption of the open innovation model have been proposed. The contigencies identified range from firm resources and capabilities (Keupp & Gassmann, 2009; Torkkeli et al., 2009), to stage of technology development (Christensen et al., 2005), to environmental conditions such as technological turbulence and competitive intensity (Lichtenthaler, 2009b), or inter-firm relationships (Torkkeli et al., 2009). All these research studies helped to raise our awareness of the limitations of open innovation, suggesting that firm performance may not always be enhanced by following the open innovation model.

Direct empirical evidence on the performance impacts of open innovation strategies have been provided, both in terms of innovation and financial outcomes. For example, different innovation outcomes among distinctive choices of open innovation strategies have been tested empirically in the context of handheld computing platforms (Boudreau, 2010). Also, relying on large-scale survey data from medium and large firms in Germany, Switzerland and Austria, Lichtenthaler pioneered the study of outbound open innovation by examining various aspects of the relationship between external technology commercialization activities and firm performance (Lichtenthaler, 2009b; Lichtenthaler & Ernst, 2007; Lichtenthaler et al., 2010). This dissertation aims to provide further empirical evidence about the heterogenous performance outcome of open innovation, in the context of firm sponsorship of open source software.

CHAPTER 4: OPEN SOURCE SOFTWARE AND OPEN INNOVATION

In order to gain in-depth understanding about how open source software sponsorship influence the stock market performance of its sponsoring firms, it might be helpful for us to take a closer look at the relationship between open source software and the open innovation strategies of the firm. I first try to distinguish between these two interrelated yet distinctive concepts. Then I attempt to make the case of open source software value creation for the firms.

Open Source Software and Open Innovation

Open source software has been used as a quintessential context of open innovation (West & Gallagher, 2006b). Here we are only concerned with open source software with firm sponsorship, or OSS 2.0 (Fitzgerald, 2006). OSS 2.0 involves R&D collaboration between firms, suppliers, customers, complementors and the open source community. By engaging in open source software, firms may attract potential customers at low costs, and benefit from the positive returns to adoption of their technologies (West, 2003).

Open source software-based innovations by firms fit the definition of open innovation because they facilitate innovation through knowledge flows cross firm boundaries, and are profit-oriented. Thus, OSS 2.0 represents a new "private-collective innovation" model (von Hippel & von Krogh, 2003), and has become a manifestation of the open innovation strategy. Prior reseach literature has classified open source software-based open innovation strategies into four categories: pooled R&D, spinouts, selling complements, donating complements. All these strategies can address the requirements of open innovation in terms of appropriating return from internal innovation, incorporating external innovation, and motivating knowledge spillovers (West & Gallagher, 2006b).

Although most cases of firm involvement in open source software fit the definition of open innovation (Chesbrough, 2003b; West & Gallagher, 2006b), not all open source software projects are cases of open innovation. For example, Project GNU is an open source software project motivated by ideology instead of pecuniary rewards. Thus it does not fit the open innovation definition. Open source software without firm involvement are more likely utility-oriented than profit-motivated, thus clearly do not fit the open innovation concept. In this sense, OSS 2.0 may be more closely related to open innovation due to firm involvement. In short, the overlap between open source software and open innovation is not one hundred percent. Hence researchers have concluded that "Open Source is only Open Innovation if it has a business model" (West & Gallagher, 2006b).

Now that we have distinguished between open source software and the open innovation model, we next shift our attention to explore the various mechanisms through which open source software projects may impact the performance of their sponsoring public firms.

OSS and Firm Value Creation

Much has changed since the beginning of open source movement a few decades ago. Over the years, open source software has transformed itself from a grassroots movement confined within software developer communities into a mainstream and commercially viable form of business model (Fitzgerald, 2006). In the era of OSS 2.0, open source software has become increasingly leveraged by commercial firms in their business strategies. By "leverage" I refer to not only the internal use of open source software, but also to the proactive incorporation of open source software into firms' product and service offerings as well as their business models. Contributions to open source software projects no longer come primarily from individual developers who volunteer their work, but increasingly from for-profit companies (http://news.cnet.com/8301-13846_3-10315545-62.html). In certain product markets such as embedded systems, open source software has become widely adopted by commercial firms (Henkel, 2006). As a matter of fact, recent studies show that 40% of all open source software codes are contributed by corporate employed programmers (Lakhani & Wolf, 2005). Further, 75% of Linux codes are written by paid software developers at major corporations (http://apcmag.com/linux-now-75-corporate.htm). The recent takeoff of the open source based Android system in the smart phone market (http://news.cnet.com/8301-1035_3-20015799-94.html) serves as a good example of the growing popularity of open source software in the business world.

Although the main competitive advantage of open source software seems to be its low cost, an independent survey by Yankee Group reveals no clear-cut advantage in terms of Total Cost of Ownership (TCO) when comparing mainstream Linux systems (e.g., Red Hat) with Windows Server software (DiDio, 2005). Typically, many corporations are embracing open source software such as Linux not for low cost goals, but for its openness and innovation potential. For example, Oracle is an active contributor to Linux development. As a widely-adopted open source platform, Linux enables Oracle to tweak the operating system kernel in order to enhance the performance and functionalities of its cash-cow database product (http://www.oracle.com/us/technologies/linux/026042.htm). This outcome would not likely be accomplished with closed source operating systems like Windows. Another good example would be Apple, whose proprietary operating system has been plagued with instability problems (http://whynotmac.net76.net/reason12.html), and consequently has suffered from a loss in market share for a long time. Apple achieved a dramatic comeback in the PC market around year 2000 (http://www.bspcn.com/2007/10/16/1997-2007-the-10-year-apple-comeback/) with the launch of

Mac OS X, which signaled a major strategic change in which Apple abandoned their crash-prone proprietary operating system and rebuilt their PC operating system on top of open source software (West, 2003). As a result, the stability of Mac OS was greatly improved, and Apple regained their PC market share. This critical strategic decision to embrace open source software provided a foundation for Apple's later spectacular expansion in its iPod/iPhone/iPad businesses. The list goes on. Based on recent study on how firms deal with the tradeoff between open source software and proprietary software, researchers found that a "comingled code" approach – hybrid strategies combining open source and proprietary software to leverage their complementarities – is the common pattern for businesses across countries (Lerner & Schankerman, 2010).

In the following sections, a literature review of prior studies on the relationship between open source software and firm value creation may help to shed light into the corporate motives in embracing open source software and allow us to gain a deeper understanding of the value creation potential of open source software.

Innovation Enhancing

There have been some debates in the literature about the implications of open source software on firm innoation (Bonaccorsi & Rossi, 2006). Despite some concerns that open source software is mostly imitation of proprietary software, the positive impacts of open source software on firm innovation seem to have gained more support. It has been argued that the collaborative nature of open source software development is particularly suitable for innovation (Raymond, 1999a). Open source software projects are often tightly linked with firms' user communities (Dahlander & Magnusson, 2005; Dahlander & Wallin, 2006; Henkel, 2009). They are not only open for user access, but also open for user modification and contribution. It is also crucial that many of the open source software projects are highly modularized, horizontal platforms by nature (Fitzgerald, 2006). These features facilitate the incorporation of new ideas into the open source software projects, and enhancing both the innovativeness and competitiveness of these software products (Dalle & Jullien, 2003). In addition, customers may participate in the customization of the product and become more committed (Goldman & Gabriel, 2005; Von Hippel, 2001), and open source community developers can help to improve and support the software as well (Lakhani & von Hippel, 2003). Hence, firm sponsorship of open source software projects could potentially stimulate knowledge exchange between internal and external developers and to enhance the firms' innovation capabilities through collaborative innovation activities (Baldwin & Von Hippel, 2009). Finally, open source software platforms allow firms with limited R&D budgets to focus on the technology niche that their competitiveness is dependent on. Many of the afore-mentioned innovation-enhancing benefits of open source software can be found in this recent quote from the VP of Systems & E-Commerce Engineering at Netflix (http://techblog.netflix.com/2010/12/why-we-use-and-contribute-to-open.html):

"We develop and apply great software technology to deliver a great streaming video experience. Our budget, measured in dollars, time, people, and energy, is limited and we must therefore focus our technology development efforts on that streaming video software that clearly differentiates Netflix and creates delight for our customers. These limits require that we stand on the shoulders of giants who have solved technology challenges shared in common by all companies that operate at Internet scale…….We do utilize some commercial software but there is often the alternative choice of utilizing open source software, preferably open source software that implements an open standard…….The great thing about a good open source project that solves a shared challenge is that it develops its own momentum and it is sustained for a long time by a virtuous cycle of continuous improvement…….By sharing our bug fixes and new features

back out into the community, the community then in turn continues to improve upon bug fixes and new features that originated at Netflix and then we complete the cycle by bring those improvements back into Netflix"

The innovation-enhancing effects of open source software is most closely related to the concept of open innovation, which is the reason that open source software development has been one of the most widely studied contexts in the open innovation literature.

Signaling

Public firms are concerned with shareholder value creation. The stock market value of a public firm depends to a large extent on the market perception of the value of its assets, among which a firm's knowledge endowments may be a key component (Grant, 1996b; Liebeskind, 1996). Thus, it is necessary for public firms to try to influence this market perception in its favor. However, knowledge assets are notoriously difficult for the market to evaluate due to information asymmetry (Akerlof, 1970). Furthermore, a thorough transfer of knowledge for the purpose of informing external stakeholders about firm value may potentially result in profit expropriation by imitators (Kogut & Zander, 1992). Therefore, firms may choose to signal the value of their knowledge instead of transferring it for the market to recognize its value, in which signaling is defined as "conduct and observable attributes that alter the beliefs of, or convey information to, other individuals in the market about unobservable attributes and intentions" (Ndofor & Levitas, 2004: p688).

Open source software release could be used as the tool for signaling, resulting in at least two types of outcomes. First, in the case of firms make major investments in open source software, such as IBM and Sun Microsystems, effective signals can be sent to the market that create a *separating equilibrium* (Ndofor & Levitas, 2004), indicating superior knowledge endowments related to this kind of collaborative innovation. Second, in the case of firms making tentative investments in open source software, such as Computer Associates, a *pooling equilibrium* (Ndofor & Levitas, 2004) may be achieved, with less distinctive separation from other firms but favorable association with the innovation enhancing potential of open source innovation model. Both of these two types of signaling effects may positively influence the market perception of the value of the focal firm's knowledge assets. Therefore, a signaling effect could be a viable value creation mechanism adopted by public firms in sponsoring open source software.

Competitive Positioning

Open source software may facilitate adoption. This outcome is not only because open source software is freely available, but because it can help to reduce the risks of adoption. First, their openness facilitates modification and customization, which supports greater opportunity of learning and experimentation. Second, the open and participative development processes of open source software enable a smooth migration path, which helps to ensure backward and forward compatibility. Third, the low cost nature of open source software reduces barriers to ownership, thus enhancing the network externality effect. Finally, the fact that open source software is not controlled by any single firm virtually eliminates the risk of technological lock-in (Arthur, 1989). Even though open source software wins in adoption at the cost of direct profit appropriation (West, 2003), indirect rents can be generated for the sponsoring firm through at least two mechanisms: (1) complementary assets and capabilities, and (2) increasing returns to adoption.

First, firms may profit from their complementary assets or capabilities (Teece, 1986) for the open source software, which might include advantageous downstream asset positions in middleware, applications, hardware and services (Pisano, 2006). For example, the business models of the leading open source software firms, such as Redhat Inc., is primarily based on selling support and service to their open source software products. Additionally, extant research literature has identified open source communities as complementary assets for firms (Dahlander & Wallin, 2006). Thus, firms may gain from support of the open source communities in terms of development costs and user support.

Second, increasing returns to adoption is a common phenomenon in network industries such as telecommunication and software industries. The concept of increasing returns to adoption refers to the fact that the more a technology is adopted, the more improvement, or value its adopters get (Arthur, 1989). This kind of increase in value may be found either in direct physical networks such as the telephone network, or indirectly through wider availability of products compatible to each other, also known as the hardware-software paradigm (Katz & Shapiro, 1985). The drivers of this phenomenon include learning, network externalities (Teece, 2006) and signaling effects (Schilling, 1999). Hence, the increased returns to adoption tend to create a "virtuous cycle" for the adoption of open source software (Schilling, 1999). As a result, firms may release open source software as a means to achieve dominant position in the market against their competitors. Later on they may leverage their advantageous positions in market through exercise of market power or complementary assets. Economic value would thereby be created for these sponsor firms for open source software. Please see Table 4.1 for details.

Challenges for Firms in Managing OSS Value Creation

The open innovation and value creation model for public firms based on open source software and open source communities is not without its risks and challenges. The fundamental issue here is that the individuals involved in these open source communities are beyond the hierarchical control of the firm. In contrast to the case in the closed innovation model, the diverse background of the participants, the decentralized and hierarchical innovation processes (Pitt, Watson, Berthon, Wynn, & Zinkhan, 2006), and the heterogeneous motives in this open source innovation model together determine that the benefits of innovative discovery also comes with the costs of misaligned interests and divergent goals (Almirall & Casadesus-Masanell, 2010). This misalignment increases the risks of firm investment in sponsoring these open source software projects (Dahlander, Frederiksen, & Rullani, 2008), which largely explains why there are substantial performance variance among public firm sponsorship events as evaluated by the stock market. Considering these challenges of managing the open source-based innovation, this study proposes that only firms with strong knowledge capabilities may effectively leverage the knowledge resources within these open source communities and fully benefit from the open source software-based innovation model. In fact, this knowledge and capability-based perspective resonates with a number of extant open innovation literature in various contexts (Grand et al., 2004; Harison & Koski, 2010; Lichtenthaler & Lichtenthaler, 2009). In the next chapter I explore these knowledge capabilities relevant to open innovation in the context of open source software sponsorship.

CHAPTER 5: KNOWLEDGE-BASED APPROACH TO OPEN INNOVATION

The knowledge-based approach is particularly relevant for research on the open innovation paradigm, which was originated from industry practice and has suffered from a lacking of in-depth theoretical foundations in its academic research development (Fredberg et al., 2008). First, as an extension of the resource-based view (RBV), the knowledge-based view (KBV) has its strength in explaining performance heterogeneities among firms. Given the high failure rates in open innovation, this understanding is particularly desirable and long over-due (Chesbrough, 2007). Hence, a knowledge-based capability framework can certainly contribute to the open innovation literature in this respect. Indeed, pioneering theoretical research in open innovation has pointed out the need for more research in this direction and provided a blue-print of such capability-based framework to examine open innovation performance (Lichtenthaler & Lichtenthaler, 2009). However, empirical studies in this area are still lacking, which is the research gap this dissertation aims to fill. Second, a knowledge and capability-based approach can help to reveal the mechanisms through which firms can profit from their open innovation endeavors. The point has also been made by extant theoretical research within the open innovation literature (Lichtenthaler & Lichtenthaler, 2009). Third, relevant knowledge-based literature streams such as absorptive capacity have been identified as the theoretical antecedents of the open innovation paradigm (Chesbrough et al., 2006b). Thus, an in-depth examination of how absorptive capacity can impact open innovation performance may be justified. Fourth, the open innovation paradigm is very much related to the profiting from innovation (PFI) framework (Teece, 1986, 2006), in the sense that they share a common interest of profiting from firm innovations, whether the source of the innovation is internal or external to the firm boundaries.

Despite all the close linkages between these various knowledge-based perspectives and the open innovation paradigm, with few exceptions (Lichtenthaler & Lichtenthaler, 2009; Vanhaverbeke, Van de Vrande, & Cloodt, 2008), there have not been enough research efforts explicitly linking them together. This dissertation aims to seize the opportunity for this connection to be made, and to contribute theoretically and empirically to the understanding of open innovation paradigm by making the connection between firms' knowledge characteristics and their open innovation activities.

The knowledge-based perspectives discussed here include not only the knowledge-based view (Grant, 1996b; Kogut & Zander, 1992), but also the absorptive capacity (Cohen & Levinthal, 1990) perspective and the profiting-from-innovation (PFI) framework (Pisano, 2006; Teece, 1986). All these theoretical perspectives view firm knowledge-based capabilities as the fundamental source of firm competitive advantage. Further, these perspectives are intrinsically intertwined (Easterby-Smith & Lyles, 2003). Hence, this dissertation puts these perspectives together and collectively calls them the knowledge-based approach.

In the following sections, I first define the concept of knowledge in this dissertation, then address two issues in order to make the case for using knowledge-based perspectives to understand the open innovation paradigm in the context of open source software sponsorship by public firms: (1) firm sponsorship of open source software projects may be viewed as manifestations of their knowledge strategies; and (2) knowledge-based perspectives can help to explain the heterogeneous performance outcomes for firms engaged in open innovation, in the context of open source software sponsorship.

OSS Sponsorship as Knowledge Strategy

Knowledge

The concept of knowledge is intuitive yet difficult to define. The extant knowledge-based literature is characterized by diverse academic interests and a proliferation of loosely-defined terminologies (Vera & Crossan, 2003), which can sometimes lead to confusions in understanding. Following the epistemology tradition, knowledge has been defined as "justified true belief" (Nonaka, 1994). On the other hand, the constructivists view organizational knowledge as the outcome of complex social processes of collective learning (Brown & Duguid, 2001; Cook & Brown, 1999), which also echoes with the on-going debates about whether the locus of knowledge of the firm should reside in the individual or collective level (Felin & Hesterly, 2007; Nahapiet & Ghoshal, 1998). Alternatively, knowledge can be viewed as a state of knowing and understanding, an object, a process, a condition of access to information, and a capability (Alavi & Leidner, 2001). In the strategic management literature, knowledge is often linked to information. However, the definitions are not always consistent. Some scholars suggest that the concept of knowledge should include both information (know-what) and know-how (Kogut & Zander, 1992), while others propose that knowledge is simply validated information (Liebeskind, 1996). At the same time, scholars from the information system field submit that knowledge is processed and personalized information, thus at a higher level of cognition (Alavi & Leidner, 2001). This dissertation follows the tradition of strategy literature in broadly defining *knowledge* as informational resource stock that can be transferred, integrated and leveraged to achieve competitive advantage. In addition, the focus of this dissertation is on organizational knowledge rather than knowledge residing in an individual's mind.

Knowledge Strategy

Given the proposed importance of knowledge as a strategic resource of the firm, the issue of designing a knowledge strategy to effectively manage organizational knowledge naturally follows as a critical strategic decision for the firm. Bierly and Chakrabarti (1996) define knowledge strategy as the collective responses to strategic choices that shape and direct the organization's learning process, and subsequently determine the firm's knowledge base. These strategic choices involve tensions between: internal and external learning, radical and incremental learning, fast and slow learning, and the depth and breadth of a firm’s knowledge base. While this definition provides a nice elaboration of the dimensions of knowledge strategy, its sole focus is on the management of organizational learning processes and firm knowledge base. In contrast, Zack (1999) advanced the definition of knowledge strategy by explicitly including considerations for the competitive performance of the firm. He defines knowledge strategy as “the overall approach an organization intends to take to align its knowledge resources and capabilities to the intellectual requirements of its strategy”. The two primary dimensions in his definition of knowledge strategy include strategic choices between exploration and exploitation, and between internal and external knowledge sourcing (Zack, 1999). This definition resonates with the results from knowledge-based empirical studies suggesting that it is not the more knowledge the better for firm performance. Rather, it is knowledge that is relevant to business strategy that may have a positive impact on firm performance (Appleyard, 1996; Decarolis & Deeds, 1999). Therefore, an effective knowledge strategy must incorporate the element of fit, or “co-alignment” (Vera & Crossan, 2003), with a firm’s overall business strategy.

OSS-based Knowledge Strategy

Consistent with the Zack (1999) definition, this dissertation defines *knowledge strategy* as the set of strategic choices a firm makes, in an effort to align its knowledge resources and capabilities with its business strategy, in order to achieve competitive advantage. Based on this definition, the sponsorship of open source software projects by public firms may be viewed as a manifestation of these firms' knowledge strategy. First, open source software represents a form of external knowledge, which can be utilized to complement and reshape the sponsoring firm's private knowledge base. Second, the choice of which open source software projects to sponsor is typically based on a firm's self-evaluation of its current knowledge base and the target knowledge resources and capabilities it intends to build up to. In other words, these are strategic choices aimed at filling a firm's knowledge gaps and transforming its knowledge base into a more desirable state. Third, open source software is not directly profit-generating. Thus the sponsorship of open source software projects is not in itself a business strategy, at least not in a narrow sense. Lastly and most importantly, these firm initiatives in open source software sponsorship are planned rather than random efforts, aimed at aligning firms' knowledge resource base with their business strategies to improve firm performance. Even though some of these sponsored open source software projects may turn out to be casual experimentations with a new and fashionable idea, by and large most firms in my sample are making serious investments in these open source software initiatives in terms of both capital and human resources. For these public firms, such investments necessarily demand financial payoff. Thus, these open source software initiatives are ultimately profit-motivated. The best way to achieve the profit goals of these sponsoring firms is to adapt their knowledge bases to achieve co-alignment with their business strategies. In this sense, we may best categorize these open source software sponsorship initiatives as knowledge strategy, based on its definition in this study.

Following prior research literature prescriptions of the dimensions of knowledge strategy (Bierly & Chakrabarti, 1996), open source software sponsorship as a knowledge strategy touches on almost all the major dimensions including: (1) internal vs. external learning; (2) radical vs. incremental learning; (3) fast vs. slow learning; (4) depth and breadth of firm knowledge base. In addition, the unique nature of open source software production process presents a brand-new knowledge strategy dimension: (5) collaborative vs. competitive learning. Next I discuss the characteristics of the open source software-based knowledge strategy along each of these dimensions.

Internal vs. External Learning

Internal learning occurs within the boundary of the firm. External learning depends on knowledge acquisition and transfer across firm boundaries. Extant literature suggests that internal learning is better for complex and systemic knowledge, due to more control over the development process and better understanding of the tacit nature of the knowledge (Chesbrough & Teece, 1996). In contrast, external learning facilitates the development of a broader knowledge base and increases the flexibility of the firm, which is critical in a dynamically-competitive environment (Grant, 1996a). However, internal and external learning are also mutually interdependent and complementary (Cassiman & Veugelers, 2006; Cohen & Levinthal, 1990).

The most prominent characteristic of open source software sponsorship as a knowledge strategy may reside in its external learning orientation. Sponsoring firms are learning not only the explicit knowledge codified into software code, but also the innovative, large-scale collaborative software production processes exemplified by major open source software projects.

This kind of learning can help the established firms to refresh their mindset and catch up with the latest techniques in software engineering. Nevertheless, the effectiveness of this external learning orientation would at least in part depend on how well the firm can align externally-gained knowledge with its internal learning processes to achieve the necessary balance.

Radical vs. Incremental Learning

The radicalness of learning refers to whether the learning processes focuses on incremental knowledge development built on current knowledge base, or path-breaking knowledge development in radically new areas. The former is good for short-term financial gains, while the latter can be critical for long term survival. This dimension can be mapped readily into the exploitation vs. exploration dimension of knowledge strategy (Zack, 1999).

Open source software-based knowledge strategy may be either explorative or exploitative. While some firms leverage the open source community as a learning channel to gain access to radically new knowledge, others may try to use this channel to influence the direction of the community (Dahlander & Wallin, 2006). However, the latter case may exemplify competitive more than learning motives. Therefore we may consider learning through open source software as largely radical rather than incremental. The effectiveness of such knowledge strategies depend on the perceived knowledge gap between firm's current knowledge base and its desired new knowledge base.

Fast vs. Slow Learning

The speed of learning is associated with the strategic choice between internal and external learning. Due to the lack of control over the learning process, as well as cognitive barriers such as "Not-invented-here" behavior (Katz & Allen, 1982), external learning tends to be more costly and therefore slower than internal learning. Additionally, investment in fast learning may commit the firm too quickly into a particular technological trajectory, which may create undesirable lock-in effect in environments with high technological uncertainties (Bierly & Chakrabarti, 1996).

Open source software-based knowledge strategy facilitates fast learning, mainly due to the real-time feedbacks provided through the collaborative software development processes, including mailing-lists and online forums. The feedbacks from the open source community may not only enhance the technology aspects of the product, but more importantly allow the sponsoring firm to experiment at a relatively low cost and learn about the market potential of their future product offerings. In this sense, open source software-based knowledge strategy can be very effective in achieving first mover advantage, while at the same time avoiding the downside of technological lock-in.

Depth vs. Breadth of Knowledge Base

The breadth vs. depth tradeoff in a firm's knowledge base has major implications on its capabilities and performance. Extant literature has suggested that knowledge base depth, or a dedicated focus on a narrow-defined knowledge domain is a crucial factor for a firm to develop core competences (Prahalad & Hamel, 1990). On the other hand, knowledge base breadth, or the degree of exposure to diverse knowledge domains, is positively associated with the knowledge integration capabilities of the firm, which is the key to firm performance (Grant, 1996b; Henderson & Cockburn, 1994). Also, a broad knowledge base may result in strategic flexibility and adaptability necessary for survival in turbulent environments (Volberda, 1996).

Open source software-based knowledge strategy involves boundary-spanning efforts for external knowledge acquisition. Given the dispersed nature of the open source community, the knowledge structures within them tend to be more diverse than narrow. Therefore, open source software-based knowledge strategies are most likely more effective in achieving knowledge base breadth rather than depth.

Collaborative vs. Competitive Learning

As an extension to the knowledge strategy dimensions prescribed in the extant literature, the open source software production processes showcased a brand new tension or potential tradeoff, between collaborative and competitive learning. The former is a learning mode involving knowledge sharing and common knowledge pool development, while the latter is more focused on knowledge protection and proprietary knowledge base building. In the collaborative learning mode, all participants make contributions to the common knowledge pool. Due to the non-rival nature of knowledge, all firms can benefit from a bigger knowledge pie. Conversely, in the competitive learning mode, firms are engaged in a learning race attempting to grow its own small knowledge pie while protecting it from knowledge imitation by other competing firms, which may result in higher potential of profit appropriation but lower level of knowledge base development.

Open source software-based knowledge strategy is clearly favoring the collaborative learning over competitive learning. The open source community is built on the premise of knowledge sharing (Stewart & Gosain, 2006), which has proven to be a successful model as far as knowledge base development is concerned. Firms may as well benefit from this collaborative learning model if they are willing to tradeoff certain profit appropriation for the benefit of knowledge acquisition.

Summary

In summary, the open source software-based knowledge strategy emphasizes external, radical, fast, and collaborative learning, in favor of a broad knowledge base. The ultimate goal of this open source software-based knowledge strategy is to achieve a balance between flexibility through external knowledge exploration with the help from the open source community, and long term performance improvement through development of new knowledge resources and capabilities. This view of open source software sponsorship as knowledge strategy not only sheds new light on this phenomenon itself, but more importantly, it provides guidance for us to further investigate the underlying factors that may determine the heterogeneous performance outcomes of these open source initiatives. Please see table 5.1 for details.

In the following sections we turn to the knowledge-based view and other relevant knowledge-based perspectives as our theoretical foundations for this purpose.

Knowledge Capabilities and Open Innovation

As outlined at the onset of this thesis, one of the primary research questions of this dissertation is to identify the determinants of the heterogeneous performance outcomes of open innovation, in the context of public firm sponsorship for open source software projects. The previous section has made the case that the open source software sponsorship initiatives may be viewed as knowledge strategies of the sponsoring firms. As a result, the knowledge-based resources and capabilities may thus become the fundamental determinants of the performance outcomes for these open source initiatives. Also, knowledge-based perspectives become the key lenses to examine this knowledge capability–open innovation performance relationship. The most prominent knowledge-based perspectives related to knowledge capabilities are knowledge-based view (KBV) (Grant, 1996b; Kogut & Zander, 1992), the absorptive capacity (Cohen & Levinthal, 1990) perspective and the profiting-from-innovation (PFI) framework (Pisano, 2006; Teece, 1986). These are also the most relevant knowledge perspectives that collectively form the theoretical foundation for this study.

Knowledge-based View and Knowledge Capabilities

Based on the definition of knowledge in the beginning of this chapter, the knowledge-based view of the firm has been generally considered an outgrowth of the resource-based view (Eisenhardt & Santos, 2002; Grant, 1996b). The resource-based view of the firm (Penrose, 1959) has become one of the dominant logics in the strategic management field, which is useful for explaining the hetergeneous performances among firms within the same industry or sector. The resource-based view contends that sustainable competitive advantage is ultimately attributable to the unique resource endowments of the firm (Barney, 1991; Mahoney & Pandian, 1992; Wernerfelt, 1984), rather than the firm's choice of market segment or positioning, as proposed by strategy scholars from the industrial organization school (Porter, 1985). These resource-based advantages are especially important in dynamically-competitive environments, such as in the information technology industries examined in this dissertation (Grant, 1996a). The resources that can confer such sustainable competitive advantage to the firm must satisfy the requirements of being valuable, rare, inimitable and non-substitutable (VRIN) (Barney, 1991). Knowledge, particularly tacit knowledge (Polanyi, 1967) incorporated in the products and processes of firms, tends to be valuable, scarce and not easily transferable or imitable (Grant, 1991; Grant, 1996a). Thus, the knowledge-based view extends the resource-based view by identifying organizational knowledge as the prominent strategic resource that the firm can control and manage, in order to achieve sustainable advantages in market competition (Liebeskind, 1996; Quinn, 1992).

The extant literature on knowledge-based view spans a wide range of domains in strategic management. Important research questions addressed include the theory of the firm (Conner, 1991; Conner & Prahalad, 1996; Grant, 1996b; Kogut & Zander, 1992; Liebeskind, 1996; Nickerson & Zenger, 2004; Spender, 1996), knowledge management strategy (Almeida, 1996; Sanchez & Mahoney, 1996; Teece, 2000), knowledge-related capabilities (Grant, 1996a; Nonaka, 1994; Nonaka & Takeuchi, 1995), knowledge transfer and diffusion (Hoetker & Agarwal, 2007; Mowery, Oxley, & Silverman, 1996; Szulanski, 1996), and the implications of firm knowledge on competitive performance (Bierly & Chakrabarti, 1996; Decarolis & Deeds, 1999). The knowledge-based view is particularly relevant to research on firm innovations, due to the fact that knowledge has been widely recognized as the foundation of innovation. While some innovations are developed through the application of new knowledge, other innovations are the outcomes of new combination, new configuration, or new application of existing knowledge (Henderson & Clark, 1990; Henderson & Cockburn, 1994; Kogut & Zander, 1992; Schumpeter, 1934). In particular, knowledge has been found as "one of the principle inputs into the innovation process" (Miller, Fern, & Cardinal, 2007, p.309; Rosenkopf & Almeida, 2003).

Knowledge-based scholars have rightfully pointed out that "… it is knowledge application strategy rather than knowledge per se that matters for competitive advantage" (Alavi & Leidner, 2001). In order words, the knowledge base of the firm in itself is not sufficient to achieve competitive advantage. Rather, it is the knowledge capabilities such as sourcing, transfer, or integration of knowledge that constitute the fundamental sources of firms' sustainable competitive advantage (Grant, 1996a). Thus, the theoretical emphasis of knowledge-based view in strategic management need to be to "understand the knowledge base of a firm as leading to a set of capabilities that enhance the chances for growth and survival" (Kogut & Zander, 1992, p.384).

Knowledge sourcing, transfer and integration are perhaps the most extensively studied knowledge capabilities (Eisenhardt & Santos, 2002). There have been a large number of empirical studies on the issue of *knowledge transfer*, both internal and external to the firm

(Gupta & Govindarajan, 2000; Inkpen & Dinur, 1998; Lane & Lubatkin, 1998; Miller et al., 2007; Mowery et al., 1996; Simonin, 1999; Szulanski, 1996; Tsai, 2001; Zander & Kogut, 1995). However, in our context of OSS-based innovation, knowledge is almost perfectly codified in the form of source codes. Thus, knowledge transfer is less of a concern in this context. Moreover, knowledge transfer may impede the efficiency of knowledge integration, and therefore should be minimized (Grant, 1996b). In contrast, the knowledge sourcing and knowledge integration capabilities, plus the knowledge exploitation capability, are key aspects of the open innovation paradigm (Chesbrough et al., 2006b). Therefore, this dissertation focuses on these three types of knowledge capabilities.

Knowledge sourcing is one form of organizational learning. It is defined as the managerial efforts to actively search for and gain access to knowledge both internal and external to the firm, for the purpose of adaptation of the knowledge base of the firm (Eisenhardt & Santos, 2002; Gray & Meister, 2004). Based on the communication mode, knowledge sourcing behaviors may be categorized into dyadic, published and group knowledge sourcing modes (Gray & Meister, 2004). Both published and group knowledge sourcing modes are relevant to the open source software context. Published knowledge sourcing occurs through the sharing of source codes, while group knowledge sourcing takes place through the two most common approaches of communication among open source software developers – mailing-lists and online discussion groups. The external knowledge sourcing capability is a fundamental firm capability for open innovation, since the notion of open innovation is based on the premise that firms are able to enhance their innovation performance though external knowledge sourcing (Chesbrough et al., 2006b)

Although different viewpoints exist regarding the locus of organizational knowledge (Grant, 1996b; Kogut & Zander, 1992), the knowledge-based view literature is consistent in identifying the *knowledge integration* capability, also known as "combinative capabilities" (Kogut & Zander, 1992, p.391), as the "essence of organizational capability" (Grant, 1996a, p.375). Knowledge integration capability is defined as the capability of the firm to generate new combinations and applications from its existing knowledge, so as to leverage the potential of its knowledge base in developing new technological opportunities (Kogut & Zander, 1992). Based on the types of interdependency among individuals with specialized knowledge, organizational knowledge integration can be achieved through four mechanisms – rules and directives, sequencing, routines and group problem solving (Grant, 1996b). In the open innovation model, the knowledge integration capability plays a pivotal role. It not only facilitates the generation of innovation through reconfiguration of existing knowledge, but also enables the firm to effectively absorb knowledge across firm boundaries, so that external knowledge can become successfully assimilated into the firm's own knowledge base[1].

Knowledge exploitation is one of the key components in absorptive capacity (Cohen & Levinthal, 1990). In this dissertation, the *knowledge exploitation* capability refers to the ability of the firm to profit from its organizational knowledge. The concept of knowledge exploitation is implicitly rather than explicitly addressed in the knowledge-based view. The line of reasoning is that knowledge integration capabilities, or combinative capabilities, are the key to competitive advantage (Grant, 1996a, b; Kogut & Zander, 1992) essentially posits that the products or

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[1] In this sense, the knowledge integration capability is connected to the concept of absorptive capacity (Cohen & Levinthal, 1990). The distinction between the two resides in the fact that absorptive capacity is a broader concept that also addresses knowledge identification, transfer, and other capability development. Thus, the knowledge integration capability may be viewed as a subset of absorptive capacity (see also Van den Bosch, Volberda, & De Boer, 1999).

services of the firm embody the integrated knowledge of the firm. Thus, knowledge exploitation by the firm is implied through profiting from their product or service offerings. In contrast, the profiting-from-innovation (PFI) framework not only focuses on the issue of how to profit from firm innovations in the form of products and services (Teece, 1986), but also discusses the possibility of profiting from firm knowledge in endogenously-created appropriability regimes (Pisano, 2006). Similarly, the open innovation model stresses the need for firms to capture the value created by their knowledge and innovations through both internal and external market channels (Chesbrough et al., 2006b), emphasizing the potential opportunities to profit from knowledge through innovation processes located outside firm boundaries. Thus, both the PFI framework and the open innovation paradigm are more explicitly interested in knowledge exploitation through external opportunities, such as open source software projects.

Absorptive Capacity

Absorptive capacity is defined as "the ability of the firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends" (Cohen & Levinthal, 1990, p.128), which is determined by the firm's prior related knowledge. By this definition, absorptive capacity is concerned with the knowledge capabilities of the firm. The three building blocks, or key knowledge capabilities of absorptive capacity include external knowledge identification, knowledge assimilation and knowledge exploitation (Cohen & Levinthal, 1990). This important construct has instantly attracted a significant amount of academic attention. However, a recent review of the absorptive capacity literature has raised the concern of the "reification" problem, in which ritual citations of the construct seems to be more prevalent than meaningful contributions (Lane, Koka, & Pathak, 2006). Only a few research studies are making serious efforts in deepening our understanding about the construct of absorptive capacity. One of these efforts attempted to extend the construct to include knowledge transformation, and to break it down to realized capacity vs. potential capacity (Zahra & George, 2002). This particular extension has been challenged on the basis of the ambiguous meaning of "transformation," which may be understood as an alternative path of assimilation rather than its follow-on step from a cognitive perspective (Todorova & Durisin, 2007). The empirical usefulness of the potential vs. realized capacity dichotomy was also questioned. Research in this area has found that knowledge acquisition, assimilation, transformation and exploitation need to be treated as separate dimensions of the absorptive capacity construct (Jansen, Van Den Bosch, & Volberda, 2005). As another major extension, the determinants of absorptive capacity have been proposed to include organization forms and combinative capabilities (Van den Bosch et al., 1999). Despite all of these extensions and ramifications, the fundamental implication from the absorptive capacity construct remains the same: firms need to invest in the development of their internal knowledge capabilities, in order to effectively identify and utilize external knowledge (Cohen & Levinthal, 1990).

The absorptive capacity perspective is closely related to the knowledge-base view literature. First, the concept of absorptive capacity is built on the premise of cumulative learning and incremental change in the knowledge base of the firm. Cumulative learning implies a self-reinforcing effect in the capability development of the firm, through the interactions between expectation formation and subsequent investment in absorptive capacity. This path-dependent view of learning and capability development reaffirms the postulations by knowledge-based view that learning is based on local search, and firm capability development is constrained by the firm's current structure of relationships (Kogut & Zander, 1992). Second, the absorptive capacity perspective suggests that knowledge diversity plays an important role in organizational learning.

It can strengthen the firm's assimilative powers as well as facilitate innovation through "novel associations and linkages" (Cohen & Levinthal, 1990, p.131) to the existing knowledge base of the firm. Similarly in the knowledge-based view, while common knowledge is considered necessary for the efficiency of knowledge integration, the scope of integration or the diversity of specialized knowledge to be integrated is postulated to be the source of sustainable competitive advantage (Grant, 1996a). Thus, the knowledge-based view and absorptive capacity literature both agree that the optimal knowledge structure of the firm should reflect a balance between the depth of relevant knowledge in strategically important domains, and the breadth of knowledge in order to enhance firms' innovation performance.

The absorptive capacity perspective serves as the theoretical antecedent as well as the guiding principle for open innovation. First, the primary focus of the absorptive capacity concept is in the identification, assimilation and exploitation of external knowledge (Cohen & Levinthal, 1989). These processes are the foundation on which the open innovation paradigm is built. Second, the absorptive capacity literature has identified specific communication structures for external knowledge sourcing and integration. A centralized gate-keeper or boundary-spanner may facilitate the acquisition and assimilation of external knowledge in stable environment, while decentralized "receptors" may be more effective in linking to the external knowledge sources in rapidly-changing and uncertain environments (Cohen & Levinthal, 1990). Third and most importantly, the knowledge capabilities prescribed in the absorptive capacity perspective are fundamental determinants in achieving success in firms' open innovation activities. If internal knowledge resource and capabilities are the determinants of external knowledge evaluation and utilization (Cohen & Levinthal, 1990), then they would also be the prerequisites for firms to effectively engage in the open innovation process. Thus, we may be able to predict the performance outcomes of firm sponsorship of open source software by examining the firm's internal knowledge capabilities, particularly those related to knowledge sourcing, integration and commercial exploitation.

To sum up, the insights from absorptive capacity perspective regarding knowledge capabilities coincide with those from the knowledge-based view. Both perspectives emphasize the set of knowledge capabilities in sourcing, integration and exploitation as key determinants to consider in examining open innovation performance.

Profiting-From-Innovation Framework

Teece (1986) proposed the *profiting-from-innovation* (PFI) framework, which for the first time linked together the innovation and strategic management literature streams (Pisano, 2006). The PFI framework is concerned with the conditions under which innovating firms can profit from their innovations. Among its three building blocks of appropriability regime, dominant design and complementary assets, the business strategy related to complementary asset matters the most. The access to complementary assets is proposed to be the key determinant of the distribution of economic value generated by innovations. Hence complementary resources become the key determinant of commercial success for innovators (Teece, 1986).

Compared with other innovation literature based on the resource-based view of the firm, a distinctive aspect of PFI framework is in its emphasis on the proactive role managers can play to increase the profit potential of the innovating firm. The value of assets are not just passively increasing or decreasing in the face of disruptive technological changes (Tushman & Anderson, 1986). Rather, the PFI framework suggests the possibility of appropriability enhancements, through business strategies enabling access to complementary assets (Teece, 2006).

The PFI framework is intrinsically linked to the knowledge-based view. First, protecting innovations from profit expropriation by knowledge imitators is a primary concern in both the knowledge-based view literature and the PFI framework. The notion of “bottleneck capability” (Kogut & Zander, 1992, p.392) may be interpreted as an alternative phrasing of having access to key complementary assets. Second, complementary assets in the form of complementary knowledge may have become the most important assets that can determine the profit potential of the innovating firm. Indeed, in a later piece reflecting on his initial conceptualization of the PFI framework, Teece (2006) acknowledged that the PFI frame-work highlighted the rent-generating ability of intangible assets such as know-how, and stressed the importance of knowledge integration and conversion capabilities. Indeed, leveraging complementary assets implicitly requires integration between the knowledge about the focal innovation and the knowledge about the complementary assets. Thus, knowledge integration is crucial for the PFI framework as well.

In the original PFI framework, only complementary assets were considered manageable and thus fall within the realm of business strategy. Both appropriability regime and dominant design were taken as given. As an important extension, Pisano (2006) revised this assumption by suggesting that firms may take their existing assets as given instead, while trying to shape appropriability regimes through their business strategies. This view fits into the outbound dimension of open innovation, which emphasizes the need for firms to proactively find external market channels for commercialization opportunities of their existing knowledge (Chesbrough et al., 2006b). More importantly, the insights of PFI framework on the antecedents of innovation profitability as well as the risks innovators face in the market, would be particularly valuable for innovating firms exposed to increased level of opportunism-derived risks in their interactions with other firms.

The most important insight from the PFI framework is identifying complementary assets as the key component of a firm's knowledge base for profit appropriation from innovations. Consequently, the knowledge exploitation capability in aligning a firm's complementary assets with its business strategy becomes a crucial determinant in firm financial performance. In addition, because knowledge combination is needed to effectively combine the various complementary assets, the knowledge integration capability is also a key factor to the leveraging of these complementary assets to create competitive advantage for the firm. Therefore, the PFI framework focuses on both knowledge integration and knowledge exploitation capabilities, with an emphasis on the leverage of complementary knowledge and assets.

Synthesis

As outlined above, the most important common characteristics among these knowledge-based perspectives may be the recognition of a set of knowledge capabilities as the key determinants of firm innovation and financial performance. Specifically, knowledge sourcing, integration, and exploitation capabilities are identified as the core capabilities that are closely related to firm open innovation. Thus, it may be useful to join together these different literatures through comparing and contrasting the three capabilities of knowledge sourcing, integration and exploitation.

As discussed in the previous section, the open innovation strategy of open source software sponsorship may be viewed as a knowledge strategy. Hence, the knowledge capabilities should be viewed as the underlying sources of competitive advantage that may impact the open innovation performance. Conversely, the open innovation paradigm also enriches the knowledge-based perspectives by explicitly emphasizing the external dimension for knowledge capabilities.

In the discussions below, I illustrate the distinctions and connections among these theoretical perspectives.

Knowledge sourcing is considered one of the fundamental firm capabilities in the knowledge-based view. Both internal and external knowledge sourcing are proposed to be necessary, either for the purpose of organizational flexibility (Grant, 1996a), or for positive impacts on innovation performance (Henderson & Cockburn, 1994; Rosenkopf & Nerkar, 2001; Tripsas, 1997). Knowledge sourcing is particularly necessary in dynamic environments where firm adaptation is the key to survival (Powell et al., 1996). In comparison, the focus of the absorptive capacity literature is on external knowledge assimilation rather than knowledge sourcing. Instead of actively scanning their environments seeking for useful knowledge, firms are assumed to take a somewhat passive role reacting to knowledge showing up on their radar screens (Cohen & Levinthal, 1990). The PFI framework emphasizes the need for access to complementary assets, both within and outside the firm boundary. But it did not explicitly address the knowledge dimension in these complementary assets. Open innovation, on the other hand, is built on the premise of both internal external knowledge sourcing (Chesbrough et al., 2006b).

The knowledge-based view proposes that knowledge integration is the primary task of the firm (Grant, 1996b), which involves knowledge both inside and outside the firm boundary (Grant, 1996a). Similarly, knowledge assimilation, including both internal and external knowledge, is one of the central components of the absorptive capacity concept (Cohen & Levinthal, 1990). In the sense that knowledge integration is necessary to leverage the complementary assets for an innovation, the PFI framework implicitly assumes the crucial role of knowledge integration between the focal innovation and its complementary assets (Teece, 1986). Open innovation emphasized the firm capability to effectively utilize knowledge both within and outside of the firm boundaries (Chesbrough et al., 2006b). Thus, knowledge integration can be viewed as a necessary precondition for firm success in the open innovation paradigm.

In the sense that firm product and service offerings are presumed to be the result of firm knowledge application, both the knowledge-based view and the absorptive capacity perspective are inward-looking when it comes to knowledge exploitation. The original PFI framework is only concerned with the protection of innovation products in the market, and did not address the issue of knowledge exploitation outside the firm boundary (Teece, 1986). However, the extension to the PFI framework by Pisano (2006) suggested the possibility of endogenously-created appropriation regimes through firm strategies. In particular, open source software is claimed to be one example of such business strategies that is devised to weaken the appropriability regimes for some firms while benefitting others (Pisano, 2006). Thus, we may say that external knowledge exploitation is now part of the extended PFI framework. In comparison, the open innovation paradigm clearly states that knowledge exploitation must be a two-way process. Firms need to not only exploit external knowledge internally, but also find external market channels to better leverage underutilized internal knowledge (Chesbrough et al., 2006b). The comparisons of knowledge capabilities across these different theoretical perspectives are illustrated in table 5.2.

In summary, knowledge capabilities are the unifying theme for all these theoretical perspectives. Despite differences in research questions being addressed, the knowledge-based view, absorptive capacity, and PFI framework all provide useful insights regarding how knowledge capabilities can influence innovation performance in dynamic competitive environments, particularly for firms in high-tech industries. The Knowledge-based View provides the foundational building blocks for -- Absorptive Capacity explains the processes of -- and PFI framework reveals the mechanisms of a knowledge-based approach to Open Innovation. Each of these views contributes to a better understanding of how Open Innovation performance is determined by firm knowledge capabilities in a complementary fashion. In the following empirical development section, hypotheses regarding the performance impacts of these knowledge capabilities on firm open source software sponsorship events will be formulated and tested.

CHAPTER 6: HYPOTHESES

Profiting from Open Source Software

The view that firm sponsorships of open source software represent strategic decisions may raise skepticisms, based on the perception that firms only release their proprietary code into the open source community because these are dead-end software products that could not generate enough profit worthy of the firm's attention. Even if this may be the case in some instances, I suggest that this is a false perception in most of the cases of firm sponsorship of open source software. Firms are typically making serious strategic moves instead of cheap talks when they announce their endorsements of open source software projects.

First, public firms have strategically allocated substantial amount of resources to open source software initiatives. For example, IBM alone has invested billions of dollars in Linux (http://news.cnet.com/2100-1001-249750.html), as well as committed over 600 people to open source development (http://www-03.ibm.com/linux/community.html). Such investments in open source software are irreversible and therefore strategic in nature.

Second, as discussed in the previous section on value creation effects of open source software for sponsoring firms, we can expect at least four competitive advantages derived from firm sponsorship of open source software. First, from the open innovation perspective, the innovation performance of firms could potentially be enhanced by the sharing of the open source software, which facilitates collaborative innovative effort between the focal firm and the open source community. Indeed, firms investing in open source software are citing open innovation as a main strategic driver for, as evidenced by the open source strategy statements of firms such as IBM (http://www-03.ibm.com/linux/community.html). Second, from the PFI framework point of view, open source software may represent a conscious firm strategy to weaken the appropriation regime and profit from its advantageous complementary asset positions (Pisano, 2006). Hence, firms with complementary services or assets can profit from their sponsorship of the open source software. Third, open source software facilitates technology adoption (West, 2003). The powerful principle of increasing returns to adoption predicts that open source software sponsoring firms may likely benefit from a dominant market position against its competitors with proprietary competing software products. Finally, the signaling effects of superior knowledge assets by open source software sponsorship could have a direct positive impact on the financial market.

Granted, there may be potential downsides to the open source software sponsorship as well. First, firms lacking in complementary assets and capabilities may not fully realize the economic benefits mentioned above. Second, certain open source software projects are prone to failure due to the misfit of the business model. Researchers have found evidence that open source software projects that do not present opportunities for firms to exploit their complementary assets may not have the chance to attract business investments at all (Iansiti & Richards, 2006). Finally, the knowledge spillover effects facilitated by firm release of proprietary software into open source community may trigger imitation, which may cause a negative impact on the competitiveness of the sponsoring firm and its market value.

Nevertheless, there are many value creating opportunities enabled by open source software, and much empirical evidence that firms have indeed recouped their investments in open source software (http://news.cnet.com/2100-1001-825723.html). There are enough reasons to believe that the benefits of open source software sponsorship shall outweigh its downsides, provided that sponsoring firms are capable of choosing the right open source software projects to sponsor, as well as managing these efforts effectively. Hence, we may expect the stock market to favorably respond to public firms' announcements of open source software sponsorship.

H1: The announcements of public firm OSS sponsorship are associated with positive stock market reactions for the sponsoring firm.

All firms do not benefit equally from open source software sponsorship. Just as performance variance exists for firms in the same industry due to resource heterogeneity, firms involved in OSS-based open innovation may experience different performance outcomes due to heterogeneous firm characteristics. Following in a knowledge-based approach to open innovation, next I examine how the heterogeneity among firms' knowledge-based resources and capabilities impact the variance in stock market reactions to their open source software sponsorship.

Complementary Assets

Complementary assets have been widely recognized as one of the most important means to appropriate rents from innovation (Teece, 1986). The PFI framework proposes that firms with strong downstream asset positions in middleware, applications, hardware and services may be motivated to sponsor open source software, as a strategy to weaken the appropriability regime and gain competitive advantage (Pisano, 2006). Empirical evidence suggests that intellectual properties such as patents and copyrights could be the complementary assets driving firm investment in open source software (Fosfuri et al., 2008). As mentioned before, open source software projects that do not fit with the complementary expertise of business firms may not attract investments in the first place (Iansiti & Richards, 2006). For those open source software projects that do get firm sponsorship, the financial market may form its judgment on how well the fit is between the focal open source software project and its sponsoring firm.

Based on their product profile, four types of public firms can be identified in our sample of open source software sponsorship firms – software, hardware, system integration, and internet service firms. Based on the PFI framework as well as the previous analyses on how value is created for firms sponsoring open source software projects, complementary expertise in product, services and capabilities are the main determinant of how much profit a firm can appropriate from its sponsorship of open source software. Thus, we may expect that hardware, internet and system integrator firms, represented by Intel, Google and IBM, would benefit more from their open source software investments than pure software firms. These firms with complementary assets and capabilities are protected by their proprietary assets in hardware manufacturing and internet services. In contrast, software firms are generally more vulnerable to the potential competitive threat of open source software, particularly if their proprietary software products are facing direct challenges from strong open source software competitors, such as the case of Microsoft. Hence:

H2a: The stock market reaction to public firm OSS sponsorship is more positive for hardware firms than software firms.

H2b: The stock market reaction to public firm OSS sponsorship is more positive for internet service firms than software firms

H2c: The stock market reaction to public firm OSS sponsorship is more positive for system integrator firms than software firms

Knowledge Type

Organizational knowledge has many dimensions and consequently many different types. The knowledge typology of architectural knowledge vs. component knowledge may be most relevant for open innovation in the context of open source software. Component knowledge is defined as design concepts related to the functioning of an independent component of a product, while architectural knowledge specifies how these components are linked together (Henderson & Clark, 1990). As a knowledge sharing pattern, researchers have made the observation that most open source software projects tend to be infrastructural systems in horizontal domains (Fitzgerald, 2006), which suggests open source software release mostly involve sharing of architectural or platform knowledge.

Architectural knowledge is more suitable than component knowledge for external knowledge sharing for the following reasons. First, component knowledge by definition is related to a physically distinct entity that performs a well-defined function, while architectural knowledge is about the specification of the linkages or interdependencies among components (Henderson & Clark, 1990). Knowledge complexity in the system design context may be understood as the degree to which the knowledge is independent or interdependent with other components of the system (Hansen, 1999). Thus, the highly interdependent nature of architectural knowledge makes it more complex than component knowledge (Hansen, 1999). Further, higher complexity in the knowledge resources of a firm can generate more causal ambiguity in its competence-based advantages, thus raising the barriers to imitation (Reed & DeFillippi, 1990). Therefore firms sharing architectural knowledge are better protected from profit expropriation than firms sharing component knowledge. Second, compatibility standards consist of interface specifications aimed to achieve interoperability between components of a larger system (David & Greenstein, 1990). Architectural knowledge fits with the concept of compatibility standards due to its focus on linkages between components (Henderson & Clark, 1990). Hence, architectural knowledge is more likely than component knowledge to become the basis of compatibility standards. Since compatibility standards can exhibit increasing return to adoption (Arthur, 1989; Schilling, 1999), so can architectural knowledge. Therefore, firms sharing their architectural knowledge may potentially reap more benefits than firms sharing their component knowledge. Finally, architectural knowledge is about the design of systems. The systems or platforms allow components from various sources to interact via well-specified interfaces, and together accomplish highly complex tasks. Thus, firms with component knowledge may be attracted to participate in the platform and become complementors of firms sharing their architectural knowledge. All these reasons make platform knowledge the ideal knowledge type to be shared with external innovation system of the firm. At the same time, not all open source software projects are platforms. Open source software projects based on component knowledge have also been sponsored by firms. Hence:

H3: The stock market reaction to public firm OSS sponsorship is more positive for platform OSS projects than component OSS projects.

Community-originated vs. Firm-originated

In contrast to the grass-root approach of setting up open source software projects in OSS 1.0, an increasing number of firms are engaged in creating their own open source projects and communities in OSS 2.0 after recognizing the value of open source communities as complementary assets to the firm (Dahlander & Wallin, 2006). Here I make the distinction between open source software projects originated from the community and those originated from the firm. *Community-originated OSS project* refers to an open source project initiated by one or more individuals, in which no employment relationships are specified. *Firm-originated OSS project* refers to an open source project initiated by the firm through the donation of previously proprietary software into the open source community, which typically involves the designation of developer resources and financial support. Although these two types of open source software projects both fall in the category of sponsored open source software projects rather than non-sponsored/purely community-supported open source software projects, they have distinctive characteristics in terms of their knowledge profiles and competitive implications.

Prior studies examining individual motives in open source software participation found that one of the major motives for these open source software developers is private utility – these developers are also users of the software they develop (von Hippel & von Krogh, 2003). As is indicated by one of the leading promoters of open source, "Every good work of software starts by scratching a developer's personal itch..." (Raymond, 1999a). This suggests that community-originated OSS projects are intrinsically user-oriented, with knowledge profiles geared toward problem-solving for the user community, which contrasts with the knowledge profile of firm-originated OSS projects. Given the sponsoring firms' profit-orientation, firm-originated projects tend to be tightly coupled with the firms' advantageous asset positions, in order to combine "the best of both worlds" (von Hippel & von Krogh, 2003) into firm competitive advantage.

However, the firm-sponsored community-originated OSS projects tend to have several competitive advantages over the firm-originated OSS projects. First, firms have the option to choose from a large pool of community-originated OSS projects and sponsor only the most well-established ones. Therefore, these OSS projects tend to be more mature than firm-originated OSS projects, which are mostly in their startup phase when announced (West & O'Mahony, 2005). In the iterative process of knowledge creation through "variation-selection-retention" (Lee & Cole, 2003), these community-originated OSS projects are much more advanced than the firm-originated OSS projects in terms of knowledge development. Second, prior research has found two prominent motives for firms to release code to open source – to win adoption or to gain development assistance in non-critical areas (West, 2003). As discussed above, community-originated OSS projects have a knowledge profile of problem-solving for the users. As a result, they already have a much more established user base than firm-originated OSS projects. Additionally, unlike these community-originated OSS projects, most firm-originated OSS projects are unproven in technology and uncertain in market acceptance due to their newness. Hence, firm-sponsored community-originated OSS projects win in adoption. Finally, some of the firm-originated OSS projects may indeed be non-essential or out-dated technology for the focal firm, which are expected to get free support from the open source community. Examples of such include Ingres Database released by Computer Associates and OpenSolaris released by Sun Microsystems. In summary, firm sponsorship of community-originated OSS projects tend to be perceived by the stock market to have greater value than firm-originated OSS projects, based on their knowledge profiles and competitive advantages. Hence,

H4: The stock market reaction to public firm OSS sponsorship is more positive for community-originated OSS projects than firm-originated OSS projects.

Knowledge Integration Capability

The knowledge-based view contends that the knowledge integration capability is the critical source of a firm's competitive advantage, especially in dynamically-competitive environments like the information and communication industries in our sample (Grant, 1996a, b). More importantly, knowledge integration capability can influence a firm's innovation performance as well as open innovation behavior. For example, The concept of "architectural innovation" (Abernathy & Clark, 1985, p.7) is closely related to knowledge integration, in the sense that architectural knowledge is defined as the "knowledge about the ways in which the components are integrated and linked together into a coherent whole" (Henderson & Clark, 1990, p.11). Thus, the knowledge integration capability can directly impact the firm's architectural innovation performance. In addition, the knowledge-based view also proposes that firm boundary may be determined by the alignment between its product domain and its knowledge domain (Grant, 1996a). Given the fact that perfect alignment is difficult to achieve, knowledge under-utilization would occur. In order to integrate the under-utilized knowledge, firms may resort to open innovation to fill its knowledge gaps. In essence, the sponsorship of open source software represents a means for firms to expand their boundaries to reach into the knowledge assets in the open source communities. The minimal costs incurred in open source software investments could potentially be outweighed by the benefits of more efficient knowledge integration and better product-knowledge alignment.

The main tasks involved in firm sponsorship of open source software projects are typically twofold: (1) allocate financial and human resources to support the open source software development process, and (2) to monitor the progress of the open source software development and manage the software release processes. Knowledge integration is necessarily a major component of the latter. Thus in the OSS-based open innovation context, a firm's knowledge integration capabilities may be reflected in its effectiveness in managing previous open source software projects, measured by the releases rates of its open source software projects since each major release signals a successful integration of knowledge both from open source developers both within the firm and within the open source community. Hence:

H5: The stock market reaction to public firm OSS sponsorship is more positive for firms with higher OSS release rates in the past.

Knowledge Exploitation Capability

Knowledge exploitation may be carried out inside or outside the firm. Internal knowledge exploitation results in the creation of knowledge assets that can create value once utilized in the market. External knowledge exploitation refers to the application of firms' knowledge assets in innovation processes outside the firm boundary. As discussed in the first hypothesis, open source software sponsorship is a good example of external knowledge exploitation by the sponsoring firm. By and large, the stock market reactions to OSS-based open innovation would be based on the market's evaluations of the profit potential of the open source software project, as well as the external knowledge exploitation capabilities of the sponsoring firm.

Internal knowledge exploitation can be a good indicator of a firm's capability in knowledge exploitation in general. The absorptive capacity literature suggests that internal and external innovation activities are complements rather than substitutes (Cassiman & Veugelers, 2002, 2006; Cohen & Levinthal, 1990; Vanhaverbeke et al., 2008). Hence, internal knowledge exploitation capability could benefit and reinforce external knowledge exploitation capability. Thus they are positively correlated. Prior literature proposes that a firm's patenting productivity (Zahra & George, 2002) would most likely enhance a firm's profit appropriation potential, when the firm engage in cross-boundary innovation activities such as technology alliances. Therefore we hypothesize:

H6: The stock market reaction to public firm OSS sponsorship is more positive for firms with higher patenting productivity

A summary diagram illustrating all the hypotheses is shown in Figure 6.1.

CHAPTER 7: EVENT STUDY

Overview

This research takes a two-step approach in examining the open source software sponsorship by public firms. In the first step, I apply the event study method to find out the overall stock market reactions to the collection of open source software sponsorship announcements made by public firms. This step aims at corroborating the first hypothesis. In the second step, based on the cumulative abnormal return (CAR) for the events in the first step, I apply ordinary least square (OLS) linear regression to examine the knowledge-based characteristics of the firm that may determine the variance in CARs among these events. This chapter provides event study research concerning the impact of the announcement of open source software sponsorship by public firms on their stock market performance.

Sample

Following the sampling methodology of (Fosfuri et al., 2008), the sample of this dissertation consists of all major open source software product announcements reported by specialized press between 11/4/2003 and 9/5/2008[2], collected from the Infotrac General Business File ASAP database. Most of these announcements are found in press articles from highly reputable publications such as eWeek, InformationWeek, PC Magazine Online, and PR Newswire.

In this dissertation, an *event* is defined as the earliest official announcement by a firm of its affiliation with an OSS project under an Open Source Initiative (OSI) approved license. Firms may either release their own proprietary source code to the OSS community, or sponsor existing

[2] The time window is chosen to capture the important OSS developments during the past decade, while trying to minimize the impact of the two stock market crises during that period, in 2001 and 2008.

community-originated OSS projects. The former typically involves an allocation of intellectual as well as financial and human resources to the OSS project, while the latter mostly involves financial and human resource allocation. Both activities involve a public announcement of an affiliation between one firm and one OSS project, thus fitting the definition of sponsorship given previously.

Additionally, my data sample only includes open source software sponsorship events that satisfy the following selection criteria:

1. Only includes announcements with clear and specific announcement dates;
2. Only includes announcements made by US-based public firms that are traded on major US stock-exchanges such as NYSE, NASDAQ and AMEX;
3. Only includes announcements about open source software release or open source software project sponsorship events, the latter mostly involve acquisitions of open source software firms, which typically focus on the development of a single well-established open source software project; and
4. Only includes the earliest official announcements made by the focal firm, which implies that: (1) only initial announcements are considered. Repeated or follow-up announcements are excluded from the sample; (2) only formal announcements made by the company are considered. News reports involving speculations or informal comments by individuals associated with the company are excluded.

Based on these criteria, a total of 116 open source software sponsorship announcements made by 24 US-based public firms were identified. Two events were dropped later due to lack of stock market data. Thus, a total of 114 open source software sponsorship announcement events were included in our final sample. Please see Table 7.1 for the event details.

Event Study Method

The event study method is a powerful tool used extensively by business scholars to examine the financial impacts of corporate policy changes, including strategic investment decisions. In this method, the significance of a corporate event can be inferred from the determination of whether there is a "abnormal" stock price effect associated with that event (McWilliams & Siegel, 1997). Since open source software sponsorship announcements represent strategic investment decisions in open innovation, the event study method would be appropriate in this research context.

This dissertation examines the financial market reactions to the sample of open source software product announcements following the commonly used capital market residual analysis techniques, based on the OLS market model (Brown & Warner, 1985; Linn & McConnell, 1983; Mahoney & Mahoney, 1993). Specifically, assuming the market model is a valid representation of the stochastic process which generates returns for security j in the time period t:

$$\widetilde{R_{jt}} = \alpha_j + \beta_j \widetilde{R_{mt}} + \widetilde{\varepsilon_{jt}}$$

Where $\widetilde{R_{jt}}$ = stochastic return on security j over time period t

$\widetilde{R_{mt}}$ = stochastic return on a market portfolio of common stocks over time period t

$\widetilde{\varepsilon_{jt}}$ = disturbance term for security j at time period t, which is assumed to be normally distributed with zero mean, serially uncorrelated and has constant variance over time

According to this model each security's period t return is expressed as a linear function of the return on the market portfolio during the same time period, plus a random error term which reflects security specific effects. The abnormal return for each security is computed as:

$$AR_{jt} = R_{jt} - (\widehat{\alpha_j} + \widehat{\beta_j} R_{mt})$$

Where R_{jt} and R_{mt} are the observed returns for security j and the market portfolio, respectively, in time period t relative to the event date of interest. The parameters $\widehat{\alpha_J}$ and $\widehat{\beta_J}$ are security specific, estimated over a period of 110 days preceding the event date (Linn & McConnell, 1983; Mahoney & Mahoney, 1993).

To reduce the impact of random estimation errors and the confounding effects due to other unrelated events, a portfolio of securities were formed in an event time window such that each daily portfolio abnormal return is an equally weighted average of individual security's abnormal returns for that common relative event date,

$$\overline{AR_t} = \sum_{j=1}^{N} AR_{jt} / N$$

Where N = number of securities in the portfolio on event date t. Thus, cumulative abnormal returns can be calculated:

$$CAR_t = \sum_{k=\mathrm{t}0}^{t} \overline{AR_k}$$

The statistical significance of the average abnormal returns is determined by parametric mean test (Linn & McConnell, 1983). The statistic used to test the null hypothesis is computed as:

$$Z = \overline{\overline{AR_t}} / S(\overline{\overline{AR}})$$

Where

$$AR_t = \frac{1}{N}\left(\sum_{j=1}^{N} \widehat{AR_{Jt}}\right), \quad S(\overline{\overline{AR}}) = \left(\frac{T-2}{N(T-4)}\right)^{\frac{1}{2}}$$

And

$$\widehat{AR_{Jt}} = AR_{jt} / S_t(AR_j)$$

Where

$$S_t(AR_j) = \left\{S_j^2\left(1 + \frac{1}{T} + \frac{(R_{mt} - \overline{R_m})^2}{\sum_{t=1}^{T}(R_{mt} - \overline{R_m})^2}\right)\right\}^{\frac{1}{2}}$$

And

S_j^2 = residual variance from the ordinary least squares estimation of the market model for security j

$\overline{R_m}$ = average return on the market portfolio computed over the same event period used to estimate the market model for security j

T = total number of days in the interval used to estimate the market model (110)

N = number of items in the portfolio of interest

In order to test the null hypothesis that the cumulative average residual (CAR) is equal to zero, we use the following statistic (Mahoney & Mahoney, 1993):

$$Z_t = \overline{CAR_t}/S(\overline{\overline{AR}})$$

Where

$$\overline{CAR}_t = \left(\frac{1}{N}\sum_{j=1}^{N}\widehat{CAR_j}\right), \quad \widehat{CAR_j} = \left(\sum_{t=1}^{T}\widehat{AR_{jt}}\right)/T^{\frac{1}{2}}$$

Where

T = total number of days in the event time window

N = number of items in the portfolio of interest

This Z statistic is distributed approximately unit normal for large N.

Results

The event study results were calculated using both programming and the Eventus software. Both approaches turned out consistent results. Here I report the Eventus results. Eventus is a widely adopted, specialized tool for event study research. The daily stock returns used came from the CRSP (Center for Research in Security Prices, University of Chicago) database. The following table presents the mean abnormal return as well as the cumulative abnormal return (CAR) for the event portfolio in my sample, during the time period (-5, +5) surrounding the open source software sponsorship announcement events. Please see Table 7.2 for details.

As we can see from the results in the table, there are random fluctuations in mean abnormal returns during the event window, due to market noises commonly attributable to other contemporaneous events. Nevertheless, the average abnormal returns surrounding the open source software announcement date are all positive (dates -1 to +2). Most importantly, the mean abnormal returns closest to the event announcement date are both positive and statistically significant. The most significant change in the portfolio CAR occurred in two consecutive days right around the announcement date, with 0.35% increase on the day before the event, and 0.52% increase on the announcement date, respectively.

Eventus also compares and reports CARs for different time windows. For the 2 day event window (-1, 0) around the open source software sponsorship announcement date, the portfolio CAR is 0.87%, which is statistically significant at the p=0.001 level (Patell Z = +3.296, Generalized Sign Z = +1.872). For the 3 day event window (-1, +1) surrounding the open source software announcement, the portfolio CAR is 0.92%. This CAR is significantly different from zero at the p=0.01 level (Patell Z = +3.042, Generalized Sign Z = +2.622). The 5-day event window (-2, +2) also has a statistically significant CAR of 1.05%, at the p=0.01 level (Patell Z = +2.839, Generalized Sign Z =2.060). In comparison, the CAR for time window (-30,-2) is -0.82% and not statistically significant, which shows that the portfolio of stocks in our sample were not systematically performing better than the market on average, prior to the open source software announcements. These results provide strong evidences for the positive performance impacts of open source software sponsorship for public firms. Thus, hypothesis 1 is supported. Please see Table 7.3 and Figure 7.1 for details.

CHAPTER 8: LINEAR REGRESSION

Sample

The sample used in the event study above contains 114 events. After removing three outliers, 111 open source software announcement events are used for the regression analysis of this empirical study, which corresponds to 23 sponsoring firms. The knowledge bases of the firms consist of their patent portfolios spanning the time window between 1985 and 2009. The patents are retrieved from the Delphion database. A total of 155,722 patents are retrieved for this study. It is worth noting that the Delphion database only keeps track of the latest corporate structure, while in this study of stock market responses to corporate announcements, it is necessary to take into consideration the fluid nature of the corporations due to frequent corporate restructuring. Therefore, I have devised a methodology to dynamically construct the corporate structure at any event date, such that a more accurate snapshot of the knowledge base of the firm at the event time can be captured. For details please refer the Appendix B.

Measures

Dependent variable

The dependent variable is the stock market reactions to the events, measured by the cumulative abnormal return (CAR). This is a commonly used measure in event studies, which captures the difference between the predicted return based on capital asset pricing model (CAPM) and the actual return (Sundaramurthy, Mahoney, & Mahoney, 1997). The choice of the appropriate event window is critical in determining the CAR. A long event window may be viewed as a violation of the market efficiency assumption (McWilliams & Siegel, 1997).

Therefore, I have tested the model using CAR corresponding to the 2 day time window (-1, 0) as the dependent variable.

Independent variables

Complementary assets. Based on a firm's main product and service offerings, my data sample consists of four types of firms: software, hardware, internet service providers and system integrators (Firms involved in both hardware and software businesses), since they possess the complementary assets in hardware manufacturing, which is necessary to profit from their OSS-based innovations. Thus, the complementary assets variable is operationalized as a dummy variable with software as the default category to compare with.

Knowledge type. This is a dichotomous variable categorizing an open source software project as either platform project or component project. If an open source software project incorporates architectural knowledge, including interface specifications of a platform and integrated development environment (IDE) for software programming, it is considered a platform project. Otherwise, if the project is characterized by narrowly-defined knowledge about relatively independent functions, such as a testing tool or a database management system, it is considered a component project.

Community-originated vs. Firm-originated. This is a dichotomous variable indicating whether the open source software event relates to firm sponsoring well-established projects from the open source community (e.g. Sun acquires MySQL), or related to firm releasing software to the open source community (e.g. IBM release its Eclipse integrated software development platform to open source).

Knowledge integration capability is measured by the average open source software release rate in its past open source software projects. Each release of open source software signals the successful accomplishment of a development milestone. Consequently, the release rate of open source software sponsored by a firm reflects the capability of the focal firm to integrate knowledge input from both the firm and the open source community. For most firms in the sample, not all open source software projects it has sponsored may be found. Thus, I use the average release rate for identifiable open source software projects to proxy for this knowledge integration capability.

Knowledge exploitation capability is measured by the patenting intensity of the firm in the three years window prior to the open source software event, which is the average annual patents applied during this time window divided by the total asset of the firm. As a form of innovative output that can confer the firm with competitive advantage, patents are viewed by the absorptive capacity literature as an indicator of realized capacity, which centers around knowledge transformation and exploitation (Zahra & George, 2002). Thus, patenting intensity reflects the capability of the firm to exploit its knowledge base for profit appropriation. Hence it is used in this study to proxy for knowledge exploitation capability.

Control variables

Firm size is a variable that is obtained by taking a natural logarithm of the total assets of the firm: LN(AT), based on data from COMPUSTAT database. *OSS pure-play.* This is a dichotomous variable indicating whether the firm is an open source software pure-play, like Red Hat; or a traditional firm with proprietary products, like IBM.

Empirical Methodology

I use the standard ordinary least squares (OLS) estimation technique to test the performance impact of the various knowledge-based firm characteristics on the cumulative abnormal return (CAR) of the open source software sponsorship events. Due to the fact that one firm may sponsor multiple open source software projects, error terms may be associated with firm characteristics such as size of the firm. To account for the heteroskedasticity related to firm scale, I adopt a generalized linear regression model with firm-based clustering option. At the same time, in order to address the concern that there may be heteroskedasticity among clusters of OSS events grouped by firm, I conducted tests proposed by Levene (1960) as well as Brown and Forsythe (1992). The F-test statistics is not significant, suggesting that heteroskedasticity across groups would not be a concern. Also, even though correlation matrix indicates that variables are not highly correlated with each other, I conducted additional test to detect collinearity among variables. The maximum variance inflation factor is 2.25, with a mean value of 1.46, which are well below the threshold of 10. This result confirms that there is no significant multi-collinearity issue in this test. Finally, outliers in all the dependent and independent variables are checked and discarded, ensuring all observations to be within three-time standard deviation range of their mean values.

The functional form of the linear regression model is specified as:

$$CAR_{-t,+t} = \beta_0 + \beta_1 \times HARDWARE + \beta_2 \times INET + \beta_3 \times System + \beta_4 \times Platform + \beta_5 \times Community\ Originated + \beta_6 \times OSS\ Release\ Rate + \beta_7 \times Patenting\ Intensity + \beta_8 \times Firm\ Size + \beta_9 \times OSS\ Pureplay$$

Results

Hypotheses 2 through 5 are tested with the linear regression model above. The preliminary regression results are illustrated in Table 8.2.

As we can see from this table, model (1) contains only the categorical independent variables corresponding to H2, H3 and H4. Model (2) contains all the independent variables. Model (3) adds control variables for firm size and OSS pure-play.

In the test for complementary asset effects, among the three types of firms, internet service firm have a positive and significant cumulative abnormal return within the (-1, 0) time window (CAR2). This statistically significant effect is consistent across models. However, open source software sponsorship does not show a significant effect on hardware and system integrator firms. For hardware firms, the positive impact of open source software may not be significant enough to affect its bottom-line. For system integrators, the sponsorship of open source software may undermine investments in its own proprietary software. Hence, H2 is partially supported. This result implies that the nature of the complementary assets and capabilities may be important to determine whether firms can appropriate enough profits from its open source software sponsorship to justify their investments in open innovation.

The results have shown that platform open source projects consistently outperform component open source projects, by a small margin. Thus, H3 is supported. Given the observation that the open source software projects sponsored by for-profit firms are mostly infrastructural systems in horizontal domains (Fitzgerald, 2006), this finding provides support to the central thesis of this study – that firm sponsorship of platform open source software projects is indeed rational behavior aimed at improving financial performance.

As hypothesized in H4, community-originated OSS projects consistently affects CAR2 in a more positive and statistically significant way than firm-originated OSS projects. Therefore H4 is supported. This result suggests that firm should carefully consider the tradeoffs between different strategic choices when engaging in open innovation activities. The market tend to reward those activities with more perceived value and less risks, rather than those early-stage experiments with higher technological and market uncertainties.

Average open source software release rate is not shown to be significant in the regression. Therefore H5 is not supported. This outcome may be due to data sampling issues since the information sources are not always consistent in their approaches in reporting and counting open source software releases. Alternative approaches to proxy for knowledge integration capabilities may include measurement of the size of the knowledge stock of the firm, since knowledge integration may also be interpreted as a knowledge transformation process involving knowledge retention and reactivation (Lichtenthaler, 2009a), which are intermediate steps in preparation for future knowledge exploitation. Thus, firms with larger size of knowledge stock tend to invest more resources in knowledge integration and/or transformation. In this sense, a potential robustness check is to use a firm's knowledge stock size as proxy for its knowledge integration capabilities.

Finally, patent intensity is positive and significantly affecting CAR2. Therefore H6 is supported. Also noteworthy is the fact that this variable has more substantive impact on CAR2 than the other variables. Considering the fact that knowledge exploitation capabilities are most relevant as far as firm financial performance is concerned, this outcome should not be surprising.

Overall, these empirical results to a large extent corroborate the theoretical arguments of the performance benefits of open innovation. In general, the stock market indeed rewards firm investments in open source software sponsorship, which should positively influence future endeavors in such area and create a virtuous cycle. However, not all firms are rewarded equally. Only those firms with (1) strong knowledge exploitation capabilities, and (2) good alignments between their open source-based knowledge strategies and their business strategies, can reap the reward from their open source software investments. Additionally, due to the relatively high risks and costs of open innovation, firms should be cautious about strategic decision in open innovation investments. Any naivety and unrealistic optimism about the positive performance effects of open innovation may penalize their efforts.

Finally, the most important insights provided by this empirical study on open innovation may have to do with its theoretical implication to the knowledge-based perspectives, regarding the need for balance between knowledge protection and external knowledge sharing. In the following chapter I try to elaborate on this important implication.

CHAPTER 9: IMPLICATIONS FOR KNOWLEDGE-BASED PERSPECTIVES

In the extant knowledge-based literature, knowledge protection has been viewed as one of the key capabilities to gain competitive advantage (Gold, Malhotra, & Segars, 2001; Liebeskind, 1996; Teece, 2000). This fundamental belief was originated from the resource-based view (RBV), which regards any resource publicly available to be unsuitable as a strategic resource that can confer sustainable competitive advantage (Barney, 1991). In the same vein of thinking, knowledge is considered a valuable strategic resource mostly because of its tacit dimension (Grant, 1996b; Polanyi, 1967). In contrast, codified knowledge is considered vulnerable to profit expropriation, not to mention externally shared knowledge, which is essentially public goods that should not have any competitive value.

The extant strategy literature has studied external knowledge sharing mainly in the context of alliances and joint ventures (Dyer & Nobeoka, 2000; Inkpen & Dinur, 1998; Mowery et al., 1996), in association with the knowledge transfer activities. Yet, with few exceptions (Spencer, 2003), external knowledge sharing has not been recognized as a firm strategy that may confer competitive advantages. Indeed, the current consensus in knowledge-based literature is heavily leaning toward knowledge protection rather than knowledge sharing, because firm knowledge is viewed as a strategic resource to protect from imitation and profit expropriation (Kogut & Zander, 1992; Liebeskind, 1996).

The empirical results of this open innovation study represent a direct challenge to this conventional wisdom. It has been shown that firms may improve their financial performance in the stock market by voluntarily sharing their knowledge across firm boundaries, through the sponsorship of open source software codes that allow free and open access. Based on these findings, I suggest that the view that competitive advantage rests solely upon knowledge protection is overly simplistic. Instead, a more sophisticated knowledge strategy would be a combination of knowledge protection and an appropriate amount of external knowledge sharing.

Knowledge Protection

Knowledge protection involves a firm's efforts aimed at maintaining the proprietary nature of its knowledge base (Chakravarthy, McEvily, Doz, & Rau, 2003; Kogut & Zander, 1992). The need for knowledge protection arises from the view of knowledge as the most important strategic resource of the firm (Kogut & Zander, 1992; Liebeskind, 1996), as well as the fact that explicit knowledge is easily expropriated. Resource-based view postulates that only valuable, immobile and inimitable resources have competitive potentials (Barney, 1991). However, the knowledge resource is mobile by nature, because it resides in people's minds (Grant, 1996a) and people tend to be mobile. In addition, the imitation and expropriation of knowledge resources are difficult to detect (Liebeskind, 1996). Thus, knowledge protection is inherently a challenging task, yet it is the necessary premise for a firm to leverage its knowledge base to create competitive advantages.

Given this rationale of knowledge protection, prior literature focused primarily on the mechanisms, or *how*, to protect knowledge. Legal protections of a firm's intellectual properties, such as patents, trademarks, copyrights are useful to a certain extent. However, these mechanisms could be "invented around" (Cohen, Nelson, & Walsh, 2000) or costly to enforce (Liebeskind, 1996). Further, tacit knowledge may not be easily codified and protected by property rights. From the transaction-cost perspective, firms have natural advantages in the governance of knowledge transactions compared with the market, due to its ability to create quasi-property rights in knowledge. Nevertheless, various incentive-based mechanisms, including employee contracts and deferred rewards, should be in place for firms to effectively protect their knowledge bases. Finally, firms may also rely on the knowledge tacitness, complexity and specificity as imitation barriers to achieve knowledge protection (Chakravarthy et al., 2003).

However, knowledge protection is not without its costs. First, investments in knowledge protection infrastructures are sunk costs, and the associated administration costs tend to be high as well. Furthermore, these knowledge protection infrastructures may not be very effective. They could be circumvented by imitators through various ways, such as reverse-engineering. And they are particularly susceptible to obsolescence (Liebeskind, 1996). Second, knowledge protection may hinder innovation. Firm innovation depends on unobstructed internal communication and knowledge transfer (Nonaka, 1994). Yet, “technology transfer and imitation are blades of the same scissor” (Winter, 1998). Hence, knowledge protection mechanisms may successfully deter imitation, while at the same time inadvertently stifle internal innovation (Liebeskind, 1996). Therefore, the costs of knowledge protection must be weighed against its benefits when firms are formulating their knowledge strategies. Balancing between knowledge protection and knowledge sharing remains as an important research gap to be explored.

External Knowledge Sharing

Knowledge sharing can occur within or across firm boundaries. This dissertation is only concerned with explicit knowledge and external knowledge sharing, which may be broadly defined as the proactive efforts of a firm to make available its proprietary knowledge outside its organizational boundaries, either to certain specific recipients or to the public at large. This definition helps to carve out several important distinctions between the closely related concepts of knowledge sharing and knowledge transfer. First, while knowledge transfer focuses on information communication, knowledge sharing focuses on information dissemination. Second, knowledge transfer typically implies two parties: a transmitting entity and a receiving entity that are clearly specified ex ante. Knowledge sharing on the other hand makes no such assumptions. It may take place in the form of one-on-one, or one-to-many, or many-to-many communications, as in the case of open source software developer forums. Also, the knowledge recipients may not have been identified at the time of sharing. Third, knowledge transfer may be understood as "a model of knowledge sharing and local knowledge (re)-creation" (von Krogh, 2003). Thus, knowledge transfer is concerned with both the quality of communication and the fidelity of the knowledge recreation. In contrast, knowledge sharing only ensures knowledge is made available for public access, without explicit concern about how this knowledge will be utilized, thus facilitating innovative ideas to emerge based on the knowledge shared.

External knowledge sharing has been studied in various contexts, including alliance and network (Appleyard, 1996; Dyer & Nobeoka, 2000; Mowery et al., 1996), joint venture (Inkpen & Dinur, 1998), regional cluster (Tallman, Jenkins, Henry, & Pinch, 2004), technological consortia (Sakakibara, 1997), and user communities (Jeppesen & Laursen, 2009). However in most cases, external knowledge sharing has been understood as a knowledge management process (Appleyard, 1996; Jiang & Li, 2009) or its associated outcome. Few researchers have viewed external knowledge sharing as a firm strategy. One notable exception is the work of Spencer (2003) which examines the interaction between firms and their innovation systems. This research identified external knowledge sharing as a viable firm strategy that can enhance innovation performance. Those firms that designed knowledge strategies to share their knowledge with their innovation systems, including their competitors, ended up earning higher innovation performance than firms that do not share knowledge. Additionally, due to the global nature of technology development and competition, firms that share knowledge with their global innovation system fared better than those only share knowledge with their national innovation system (Spencer, 2003). These findings raise the interesting question of why and when is external knowledge sharing a viable choice as knowledge strategy of the firm.

From a cost and benefit analysis perspective, economists tend to believe that external knowledge sharing is justifiable only when reciprocal knowledge or compensation such as licensing fee is provided by the knowledge recipient (Appleyard, 1996). On the other hand, management scholars propose that the fundamental reason that external knowledge sharing strategy may enhance performance is because it helps the firm to shape its institutional environment to favor its own technology (Spencer, 2003), especially during the "era of ferment" in technology life cycle before the dominant design is chosen by the market (Anderson & Tushman, 1990). This dominant design-based rationale for external knowledge sharing strategy entails two dimensions:

(1) *Shaping technological and evaluation standards*. As central components of a firm's institutional environment, these two standards determine the architectural interfaces and evaluation criteria for the dominant design, respectively. Further, both of these standards may be influenced by the endogenous efforts of the industry players. Through external knowledge sharing, firms can set the technical agenda of the industry and create a favorable perception of its own technology among industry experts.

(2) *Attracting collaborators*. During the "era of ferment," the number of firms participating in a certain technological trajectory may be an important determinant of the final dominant design. The more firms participate in the collaboration, the more resources will be invested in the technology, the faster the technology will progress toward commercially viable

stage (Podolny & Stuart, 1995). Further, collaborating firms can bring complementary and supporting products to accelerate the success of the focal firm's technology. Through external knowledge sharing, a firm can reduce the entry barriers to its own technological trajectory, thereby attracting more collaborating firms. Once a critical mass is formed around the firm's technology, the focal firm will be in a better position to compete for the dominant design with its existing technology.

Another important theoretical perspective advocating the knowledge sharing strategy claims that the extant literature on knowledge protection focuses too much on imitation prevention, while neglecting the threat of substitution. Knowledge sharing may be the answer to combat this threat of competence substitution (McEvily, Das, & McCabe, 2000). Specifically, the external knowledge sharing strategy can help to generate:

(3) *Credible commitments*. It has been proposed that firms may use three strategies to create barriers to substitution: a) continuous improvement, which requires the firm to improve its own performance continuously; b) lock-in, which increases the switching costs of its suppliers and customers; and c) market deterrence, which makes the market appear unattractive to potential entrants. All these strategies are based on the explicit knowledge about how the firm has achieved superior performance. This knowledge can then be shared with key stakeholders of the focal firm – including employees, suppliers and customers – in order to establish "credible commitments" which may allow cooperation from these key stakeholders to be gained to ensure the success of these barriers to substitution (McEvily et al., 2000).

To sum up, the extant strategy literature acknowledges that external knowledge sharing strategies can improve firm performance based on competitive perspectives. Through external knowledge sharing, firms may influence their institutional environment to favor their technological trajectory, attract more collaborators in competition for dominant design, or succeed in raising barriers to substitution. Hence, when properly managed, external knowledge sharing strategies may contribute to the competitive advantages of firms.

External Knowledge Sharing and Open Innovation

Knowledge outflow across firm boundaries is one of the four basic dimensions in the open innovation definition (Chesbrough et al., 2006a). In this sense, external knowledge sharing is a fundamental strategy in open innovation. In particular, external knowledge sharing fits very well with the outbound open innovation model. Empirical studies in this area have found positive relationship between outbound open innovation and firm performance (Lichtenthaler, 2009b). The general rationale for the adoption of external knowledge sharing strategy as discussed above still applies in the open innovation context. Corresponding to the standards-shaping and collaborator-attracting effects of external knowledge sharing, open innovation emphasizes the interaction between the firm and its institutional environment, and acknowledges the importance of the firm's value network for innovation performance (Vanhaverbeke & Cloodt, 2006). In addition, by facilitating open access to the knowledge pool, open innovation would increase the scale and scope of the value network, which can serve as a barrier to both imitation and substitution. Aside from these competitive rationales proposed by prior literature (McEvily et al., 2000; Spencer, 2003), the open innovation paradigm adds a few knowledge and innovation-based new rationales for the external knowledge sharing strategy:

(4) *Knowledge pool access*. The open innovation model emphasizes the potential for knowledge from diverse sources to be pooled together and become a semi-public good (von Hippel & von Krogh, 2003). The combination of easy access and knowledge diversity facilitates knowledge recombination and experimentation, which is the precursor to innovation. On the

other hand, though not explicitly specified, reciprocity may be an important premise for the open innovation model. Imagine if everyone only extracts knowledge from the pool, and no new contributions are made, the knowledge pool would dry out sooner or later. Indeed, researchers have identified reciprocity as an expected social norm in the open source community context (von Hippel & von Krogh, 2003). It is worth noting that in open innovation, reciprocity is likely to be the "generalized" type in which knowledge providers do not know the knowledge recipient directly (Lakhani & von Hippel, 2003), rather than the specific, tit-for-tat reciprocity considered by economists (Appleyard, 1996). The open source software community is a good example for this kind of generalized reciprocity. Therefore, external knowledge sharing may become a necessary condition for firms to gain access to the common knowledge pool, when generalized reciprocity is expected. The knowledge shared by the focal firm may be viewed as the price paid for a "ticket," which should typically be less than the benefits gained from the knowledge pool. In addition, experimentations can be particularly useful when a firm is uncertain about its technology trajectory choices. The technological lock-out effects (Schilling, 1998) associated with adoption of the wrong technological trajectory, or orphaning (Gandal, Greenstein, & Salant, 1999), could be very high. Thus, external knowledge sharing can be a justifiable strategy under such circumstances.

(5) *Knowledge base adaptation*. The knowledge resource of the firm is different from physical resources in that it follows increasing return to usage – the more it is used, the more valuable it becomes – thereby creating a "self-reinforcing cycle" (Zack, 1999). This effect has to do with the feedbacks that can change firm behavior during organizational learning (Cyert & March, 1963). External knowledge sharing gives outside knowledge recipient the opportunity to confirm or disconfirm their theories (Spencer, 2003). Conversely, these kinds of interactions may

help firms to gain deeper insights about its own knowledge and thereby improve its knowledge base. In open innovation, both inbound and outbound knowledge exchange are encouraged. Thus, there are more opportunities for a firm's knowledge to get feedbacks and be improved during the knowledge exchange processes. Furthermore, the open innovation paradigm views customers as an important source of innovation (Bogers, Afuah, & Bastian, 2010; von Hippel, 1988). When knowledge is shared with the customers, user innovators may likely contribute useful information and feedbacks on how to improve the firm's products and their associated knowledge bases (Fang, 2008; Jeppesen & Laursen, 2009; Lettl, Herstatt, & Gemuenden, 2006; Sawhney, Verona, & Prandelli, 2005). Indeed, the early studies on open source movement cited the user utility as major motives for their contribution to open source software projects (Hertel et al., 2003; Lakhani & von Hippel, 2003). Hence, from the open innovation perspective, external knowledge sharing facilitates firms' knowledge base adaptation, or learning processes, which are critical components of the dynamic capability of the firm (Zollo & Winter, 2002). In this sense, external knowledge sharing could be an important strategy to achieve long-term, sustainable competitive advantages for the firm.

Overall, external knowledge sharing has been recognized in prior strategy literature as a viable strategy, based on its potential in influencing the outcomes of technological trajectory competitions, as well as its potential in strengthening social ties with key stakeholders of the firm. The open innovation paradigm breaks new ground in this area by postulating new knowledge-based rationales for external knowledge sharing strategy. As illustrated above, firms engaged in open innovation may leverage external knowledge sharing strategy to gain access to common knowledge pool and continuously improve their knowledge bases, thereby achieve both innovation performance improvements and sustainable competitive advantages.

At the same time, one should not forget about the potential costs of external knowledge sharing. The biggest risk for external knowledge sharing is the knowledge spillover (Appleyard, 1996) which is considered damaging for firms' competitive advantages, thus justifying knowledge protection (Liebeskind, 1996). Please see Table 9.1 for details.

Next we will discuss the issue of how to manage the balance between knowledge protection and external knowledge sharing to achieve competitive performance.

Balance between Knowledge Protection and External Knowledge Sharing

So far we have discussed the pros and cons of knowledge protection as well as external knowledge sharing separately. It may be worth noting that the opposite of knowledge protection is not external knowledge sharing, but knowledge spillover. Knowledge spillover is passive loss of a firm's strategic resource, while external knowledge sharing is a proactive, managed strategy to better leverage firms' proprietary knowledge by making it available in the public domain. In fact, this paper would postulate that knowledge protection and external knowledge sharing are complementary rather than antithetical to each other, thus they may be combined together to achieve optimal firm performance. Next I discuss the factors and conditions that might impact the tradeoff and balance between these two knowledge strategies.

Knowledge type: As illustrated in the hypothesis testing, architectural knowledge sharing is more effective in performance improvement for the sponsoring firms than component knowledge sharing. This difference is to a large extent due to the fact that architectural knowledge facilitates protection while exerts greater impact through sharing. The complexity associated with architectural knowledge makes it easier to guard against imitation while being shared externally. Also, firms may gain more from sharing architectural knowledge through its standard-setting effects, which matches the first rationale of external knowledge sharing discussed above (Spencer, 2003). Finally, platforms knowledge sharing may attract firms with component knowledge to become collaborators, thus fitting the second rationale for external knowledge sharing above. However, not all architectural knowledge may be suitable for sharing. Key implementation knowledge may need to be kept proprietary, so as to maintain the causal ambiguity which leads to competitive advantage. For example, *Google* shared most of its Android operating system as open source, yet kept certain crucial architectural knowledge on platform development (http://www.theregister.co.uk/2010/07/22/android_open_development), as well as some critical components such as the Android market as proprietary code.

Environmental uncertainty: Both technological and market uncertainties may impact the strategic choice between knowledge protection and external knowledge sharing. When faced with high technological uncertainties, firms could benefit from experimentation of ideas which leads to more technological options. As discussed in the fourth rationale above, external knowledge sharing can grant the firm access to common knowledge pool consisting of diverse knowledge. Also according to the first rationale above, uncertainties in technological trajectories may prompt firms to try harder in influencing their institutional environments (Spencer, 2003). Therefore, under high technological uncertainty, external knowledge sharing may help the firm to enhance its innovation capabilities as well as to gain advantages in dominant design competitions. At the same time, when facing high market uncertainties, firms may need to adapt their knowledge bases to meet the needs of their customers. Based on the fifth rational above, external knowledge sharing should help in this aspect as well. Thus, overall, in environments with high technological and/or market uncertainties, external knowledge sharing may be beneficial for firms because it improves the flexibility and adaptability of the firm. Even though the empirical tests of this study do not directly make uncertainty a control variable, almost all firms in my sample belong to the information technology sector with high degrees of uncertainty in both technological and market environments. This fact may explain their proactiveness in engaging in external knowledge sharing.

Organizational capabilities and aspirations: Knowledge capabilities are the fundamental determinants of firm performance in their open innovation activities. When sharing knowledge to the external innovation systems, firms with a large knowledge base and strong knowledge capabilities tend to attract more attentions, which is the case for technology bellwethers like IBM when they releases software to the open source community. In contrast, firms with less knowledge capabilities may not achieve such great impacts in the market. The empirical results of this study provide corroborating evidences that external knowledge sharing through open source software release is beneficial if the firm has strong knowledge exploitation capabilities. At the same time, what the organization aspires to accomplish through external knowledge sharing is a critical factor as well. As discussed in previous chapters, a firm's knowledge strategy has to be co-aligned with its business strategy to achieve best performance (Vera & Crossan, 2003). For example, external knowledge sharing may be justified if the firm possesses complementary capabilities, which can also serve as barrier to imitation at the same time. This study also confirms this point by showing that firms in internet service sectors perform better in external knowledge sharing, which may be due to a better co-alignment between their knowledge strategies and business strategies.

In summary, the open innovation paradigm contributes to the knowledge-base perspectives by presenting the external knowledge sharing strategy as a useful complement to knowledge protection in achieving competitive advantage and superior financial performance. The tradeoff between external knowledge sharing and knowledge protection may be influenced by a number of factors including the type of knowledge considered, the degree of environmental uncertainty, and the knowledge capabilities and business strategy of the firm. Granted, external knowledge sharing may facilitate imitation. In this sense, knowledge protection may be the most risk-averse knowledge strategy that can maximize return from firms' knowledge assets. However, as outlined in this chapter, external knowledge sharing has its unique virtues under certain circumstances. In this sense, the distinction between knowledge protection and external knowledge sharing strategies may be mapped to that between conservative and aggressive knowledge strategies. Prior literature has insightfully pointed out that firms with conservative knowledge strategies takes the static view that knowledge is a proprietary asset to be protected, while firms with aggressive knowledge strategies "take a Schumpeterian view of knowledge as an ongoing process of creative destruction" (Zack, 1999). This empirical study provides evidences that the aggressive knowledge strategy may pay off. Thus, a sophisticated knowledge strategy should carefully weigh the benefits and costs between knowledge protection and external knowledge sharing, and choose the best mix of the two so as to achieve the optimal performance. Please see Figure 9.1 for an illustration of the ideas.

CHAPTER 10: CONCLUSION

The current literature on open innovation has generated many valuable insights, which have shown that many firms are successfully using open innovation to improve their innovation and financial performance. Yet as a newly emerging field, the research literature has been primarily case study-based and anecdotal, which inhibited examination of performance variance in open innovation activities across firms. This dissertation filled this research gap by carrying out a quantitative examination of the performance impacts of open innovation, in the context of open source software sponsorship. Furthermore, one of the main goals of this dissertation is to explore the connection between the knowledge based perspectives and open innovation. This linkage is intuitive, as innovation and the knowledge of the firm are closely related concepts. However, with few exceptions, prior open innovation literature has not built on this connection. Based on my findings in this dissertation, I consider it a primary and potentially fruitful avenue to examine the open innovation phenomenon through the lens of the knowledge-based approach. Hence, this dissertation represents a first step in this direction.

However, this dissertation only scratches the surface of the open innovation model and public firm sponsorship of open source software. Various limitations of this dissertation allow room for improvement. The first type of limitation has to do with econometric specification problems. There are data constraints that make some potentially important explanatory variables very difficult to obtain. For example, architectural projects tend to be larger in size and therefore more influential to the stock market. If we had a control variable for OSS project size (e.g., lines of code) by collecting data from each of the OSS project website, this concern may be addressed. Another example is related to the motives of the firms in their open source software sponsorship, which could affect the way the stock market perceives these sponsorship events. Thus, this could also be a useful control variable if the data are available.

The second type of limitation involves measurement. For example, the performance measure in this dissertation is the cumulative abnormal return (CAR) from the stock market. While this measure excels in enabling a focused, real-time examination of market reaction to strategic actions such as open source sponsorship, it may not help us understand the actual long-term consequences of such strategies. Thus, long-term performance measures such as return on investments may complement the CAR measure. Moreover, the knowledge integration capability is measured by the number of major releases of OSS projects. However, different OSS projects are managed differently. The frequency of major upgrades could be idiosyncratic across OSS projects. Thus, although theoretically sound, this particular measure may not consistently capture the knowledge integration capabilities of the firms.

The third type of limitation is related to econometric identification. For example, to a certain extent there exists the possibility of managerial self-selection in the OSS sponsorship, which may subsequently impact stock market performance of the sponsoring firms. This kind of endogeneity issue prevents us from revealing the actual causal relationship of the phenomenon being examined.

In order to address these limitations, in future research I plan to improve this dissertation in the following ways: (1) *Provide more control variables*. For H3, a control variable for OSS project size may address the concern that it is the size of the project rather than the knowledge type that determines project performance. The size of an OSS project may be measured by lines of code, which may be found in the corresponding OSS project website. Also, the technological impact of an OSS project might be useful as a control variable. This control variable may be proxied by the number of downloads or the level of participation in terms of the number of contributors.

(2) *Refine the measurements for my variables*. For example, an alternative measure for the knowledge integration capabilities may be the size of the knowledge base of the firm. According to the extant research literature, knowledge integration is an intermediate step between knowledge sourcing and exploitation. It involves the tasks of knowledge retention (Lichtenthaler & Lichtenthaler, 2009), requiring the capabilities to maintain knowledge in a firm's knowledge base for later reactivation (Garud & Nayyar, 1994). In other words, the knowledge integration capability is positively correlated with the size of the firm's existing knowledge base. The larger the size of the knowledge base, the higher the knowledge integration capability needs to be. Thus, the size of a firm's knowledge base may be a good proxy for this capability.

(3) *Consider adoption of two-stage models* (e.g., the Heckman model) to alleviate concerns about endogeneity. In order to apply this model, instrumental variables need to be identified first. In the context of this dissertation, the instrumental variables would be firm-level independent variables that determine the likelihood of OSS sponsorship by the firms. Another possible econometric identification may be treating the data sample as a panel, since it contains longitudinal information. This approach may help to reveal learning effects on the part of the firm and the market. All of these future improvements involve efforts to collect more data. Fortunately, recent exploration indicates that if we expand our event study from 1998 to now, the statistical significance still holds. Thus, we potentially have a larger OSS projects sample to examine and more data are available.

In terms of the open innovation paradigm itself, the knowledge-based approach only addresses one important theoretical area. Given its broad nature, the open innovation model may be interpreted in many other theoretical perspectives. A recent review of the open innovation literature pointed out at least four dimensions worth pursuing: business models, transaction/alliance with partners, (dynamic) capabilities, and technological/market uncertainties (Van de Vrande, Vanhaverbeke, & Gassmann, 2010). For instance, the real options perspective has strength in explaining firm behavior in face of uncertain environments. Given the fact that open innovation is closely related with high-tech industries characterized by such uncertainties, the real option perspective could be an important theoretical foundation for the open innovation paradigm as well. Finally, the knowledge-based approaches shed rich and powerful insights onto the understanding of open innovation and open source-based knowledge strategies. Yet, little is known about the specific requirements for new knowledge capabilities to meet the challenge of carrying out strategies in the open innovation model. For instance, given the need for more externally-oriented knowledge strategies, it might be useful to distinguish between internal and external knowledge capabilities (Lichtenthaler & Lichtenthaler, 2009). Research questions like these may be worth exploring in the future.

In terms of theoretical contributions, this dissertation proposes a two-way influence between the open innovation paradigm and the knowledge-based perspectives. First, the knowledge-based capabilities are postulated as fundamental determinants of open innovation performance, based on the interpretation of open innovation activities as knowledge strategies. Several hypotheses derived from this point of view were tested in the context of open source software sponsorship events, which yielded interesting insights. Though these results, we learned that open innovation performance are not uniformed positive among firms. Open innovation is best for stock market performance when: (1) the firm possesses complementary assets for its open source initiatives; (2) the knowledge being shared is related to platform architecture; (3) the open innovation activities have higher perceived value and lower uncertainties; (4) the firm has strong knowledge exploitation capabilities reflected in patenting productivities. These findings imply that the relatively high costs of open innovation must be considered before firms make the strategic move into it. Second, on the flip side, open innovation may provide new insights for the knowledge-based literature. As is proclaimed that "strategy has become, in large part, the art of influencing assets that you don't own" (http://hbswk.hbs.edu/item/5574.html).

In the same vein, the biggest contribution of open innovation to strategy may reside in the new perspectives on the balance between knowledge protection and external knowledge sharing strategies. In addition to the benefits of external knowledge sharing prescribed in prior strategy literature, open innovation added several new advantages of knowledge sharing including: (1) access to a common knowledge pool, which may facilitate innovation experimentations; and (2) knowledge adaptation, which may enhance the long-term viability of a firm's knowledge base and maintain its sustainable competitive advantage. Both benefits are especially important in environments characterized by high technological and market uncertainties.

Table 4.1: Open source software and firm value creation

OSS Value Creation Mechanisms	Details	Relevant Literature
Innovation Enhancing	Facilitates user innovation on modularized and open platforms. Stimulates knowledge exchange across firm boundaries. Enables smaller firms to focus on their technology niches instead of reinventing the wheel	Fitzgerald (2006) Dalle & Jullien (2003) Von Hippel (2001) Lakhani & von Hippel (2003)
Signaling	Alleviates the difficulties for the market to value firm knowledge assets caused by information asymmetry and knowledge transaction costs. OSS-based market signaling may be achieved through either separating equilibrium or pooling equilibrium.	Akerlof (1970) Kogut & Zander (1992) Ndofor & Levitas (2004)
Competitive Positioning	Facilitates technology adoption by reducing the associated risks. In terms of the tradeoff between adoption and appropriation, firms may rely on complementary assets as well as increasing returns to adoption to make profits.	West (2003) Teece (1986, 2006) Pisano (2006) Arthur (1989) Katz & Shapiro (1985) Schilling (1999)

Table 5.1: Open source software sponsorship as knowledge strategy

Knowledge Strategy Dimensions	Description	OSS Knowledge Strategy
Internal vs. External	Internal learning is good for complex, systemic, tacit knowledge. External learning facilitates broader knowledge base and increases flexibility	Emphasizes external learning, while its effect also depends on internal learning capabilities
Incremental vs. Radical	Incremental learning builds on current knowledge base, which is good for short-term exploitation. Radical learning involves path-breaking knowledge exploration necessary for long-term survival	Some firms use OSS community for knowledge access, while others use it to influence others in the community. But learning is more radical due to access to common knowledge pool.
Fast vs. Slow	External learning is more costly and slower than internal learning. Fast learning may prematurely commit to a technological trajectory	Facilitates fast learning through quick feedbacks, also reduces the risk of lock-in thanks to experimentation enabled by OSS knowledge pool
Depth vs. Breadth	Knowledge depth is the key to core competence development. Knowledge breadth facilitates knowledge integration as well as flexibility.	More effective in achieving knowledge breadth than depth
Collaborative vs. Competitive	Collaborative learning focuses on knowledge sharing and common knowledge pool building. Competitive learning focuses on protection of proprietary knowledge for profit appropriation.	Emphasizes collaborative learning and knowledge sharing, aimed at growing the OSS common knowledge pool

Table 5.2: Comparison of knowledge capabilities and firm orientations among literatures

Knowledge Capabilities	Knowledge Environment	Knowledge-based View	Absorptive Capacity	PFI Framework	Open Innovation
Knowledge Sourcing	*Internal*	Proactive	N/A	N/A	Proactive
	External	Proactive	Reactive	N/A	Proactive
Knowledge Integration	*Internal*	Proactive	Proactive	Proactive	Proactive
	External	Proactive	Proactive	Proactive	Proactive
Knowledge Exploitation	*Internal*	Implicit	Proactive	Protective	Proactive
	External	N/A	N/A	Proactive	Proactive

Table 7.1: List of public firm open source software announcement events (11/2003-9/2008)

Company	Announcement Date	Project Description
Apple	6/9/2005	WebKit
Actuate	8/24/2004	Actuate Joins Eclipse, starts BI Project.
Adobe	3/2/2005	ASL (Adobe Source Libraries)
Adobe	3/8/2006	Flex-AJAX Bridge
Adobe	11/7/2006	ActionScript Virtual Machine-Mozilla Tamarin
Adobe	4/26/2007	Flex Web development framework
Adobe	12/13/2007	BlazeDS
Autodesk	11/28/2005	MapServer Enterprise
Autodesk	3/7/2006	MapGuide Open Source
Autodesk	9/25/2007	Coordinate system/map projection technology
AMD	3/26/2007	Simfire - DASH'es Hardware Management
AMD	9/7/2007	ATI Graphic Specs
AMD	2/21/2008	Framewave
BEA System	12/15/2003	XML Beans as Apache Project
BEA System	5/19/2004	Project Beehive
BEA System	5/26/2004	BEA WebLogic Workshop Control Pack
BEA System	2/14/2006	Open JPA - BEA Kodo
Computer Associates	5/24/2004	Ingres Database
Citrix	8/15/2007	Citrix Buying XenSource
Citrix	7/16/2008	Project Kensho
Sourcefire	8/17/2007	Sourcefire buys ClamAV
Google	12/12/2006	Google Web Toolkit
Google	12/29/2006	Airbag - now breakpad
Google	5/31/2007	Google Gears
Google	11/5/2007	Android
Google	3/7/2008	Apps-for-Android
Google	7/7/2008	Protocol Buffers
Google	9/2/2008	Chrome browser
Hewlett-Packard	8/6/2007	Parallel Compositing Library
Hewlett-Packard	6/23/2008	Tru64 file system
IBM	8/3/2004	Cloudscape - Apache Derby
IBM	9/13/2004	RDCs (reusable dialog components)
IBM	5/10/2005	Buys Gluecode - sponsors Apache Geronimo
IBM	8/8/2005	UIMA framework
IBM	8/22/2005	Donation of the DHTML accessibility code
IBM	10/12/2005	Donation of RUP subset to Eclipse Foundation
IBM	1/19/2006	Proposes AJAX Toolkit Framework to Eclipse
IBM	6/6/2006	Jazz collaboration platform
IBM	6/28/2006	Aperi Open-Source Project

Table 7.1 (cont.)

IBM	1/26/2007	Identity Mixer
IBM	8/5/2008	HPC Open Source Software Stack
Intel	8/10/2006	Linux Drivers for Gen 4 Graphics.
Intel	7/16/2007	Launches Mobile Linux Initiative – MobLin
Intel	9/13/2007	Thread Building Blocks 2.0
Intel	9/20/2007	LessWatts.org
Intel	12/18/2007	Fibre Channel over Ethernet
Intel	8/28/2008	Intel Buys OpenedHand
Sun Microsystems	6/28/2004	Project Looking Glass
Sun Microsystems	1/25/2005	OpenSolaris
Sun Microsystems	6/27/2005	Glassfish - Java System Application Server
Sun Microsystems	7/13/2005	OpenSSO
Sun Microsystems	8/22/2005	Project DReaM
Sun Microsystems	10/19/2005	Jini Technology Starter Kit
Sun Microsystems	11/4/2005	Open Source Web Services Implementations
Sun Microsystems	12/6/2005	OpenSPARC
Sun Microsystems	4/11/2006	Java Studio Enterprise
Sun Microsystems	8/23/2006	Java Mobile Edition Development Tool
Sun Microsystems	9/8/2006	Jruby sponsorship
Sun Microsystems	11/13/2006	Sun Open Sources Java Platform
Sun Microsystems	12/6/2006	NetBeans Visual Web Pack and C/C++ Pack
Sun Microsystems	1/23/2007	Fortress
Sun Microsystems	3/5/2007	Project Darkstar
Sun Microsystems	4/16/2007	Storage code to OpenSolaris.org
Sun Microsystems	6/27/2007	Solaris Cluster
Sun Microsystems	9/12/2007	Lustre File System
Sun Microsystems	10/15/2007	Project Indiana
Sun Microsystems	11/14/2007	xVM
Sun Microsystems	1/16/2008	MySQL acquisition
Sun Microsystems	2/12/2008	Buys Innotek – VirtualBox
Sun Microsystems	2/28/2008	Sun Archiving
Lattice Semiconductor	4/16/2007	Embedded MPU core is open source
Lattice Semiconductor	3/31/2008	uClinux operating system for LatticeMico32
Motorola	5/15/2006	Java test framework and sample test cases
Motorola	10/31/2006	Java Micro Edition (Java ME) software stack
Motorola	2/28/2007	OpenSAF
Motorola	8/7/2007	Motomagx
Microsoft	4/5/2004	Windows Installer XML (WiX)
Microsoft	5/12/2004	Windows Template Library (WTL)
Microsoft	9/28/2004	FlexWiki
Microsoft	1/27/2006	Microsoft sponsors IronPython
Microsoft	7/6/2006	Open XML Translator project

Table 7.1 (cont.)		
Microsoft	7/23/2007	IronRuby
Microsoft	3/13/2008	UI Accessibility Checker (AccChecker)
Microsoft	6/9/2008	Podcasting Kit for SharePoint
Novell	11/4/2003	Novell To Buy SuSE
Novell	3/22/2004	YaST
Novell	5/11/2004	Evolution 2.0 Connector for MS Exchange
Novell	6/30/2004	Mono 1.0
Novell	2/15/2005	Hula - open source collaboration server
Novell	5/10/2005	Acquires Immunix
Novell	8/9/2005	openSUSE
Novell	1/10/2006	AppArmor
Novell	6/12/2006	Bandit project
Novell	10/25/2006	SUSE Linux Enterprise Real Time (SLERT).
Novell	2/13/2008	Acquires SiteScape
Novell	3/12/2008	MonoDevelop
Oracle	6/28/2005	Eclipse JavaServer Faces (JSF) tooling project
Oracle	10/7/2005	Acquisition of Innobase OY
Oracle	2/14/2006	Oracle Buys Sleepycat - Berkeley DB
Oracle	5/16/2006	TopLink Essentials - Donated to Sun Glassfish
Oracle	10/9/2007	Oracle Call Interface database driver for PHP
Oracle	3/18/2008	XQilla XQuery Engine
Red Hat	11/6/2003	Fedora Core
Red Hat	5/24/2005	Netscape Directory technology
Red Hat	4/10/2006	Red Hat buying Jboss
Red Hat	2/14/2008	Black Tie
Red Hat	6/19/2008	Red Hat Network (RHN) Satellite - Spacewalk
Silicon Graphics	10/20/2004	SpeedShop performance analysis tool
Tibco Software	10/2/2006	TIBCO General Interface
Tibco Software	4/2/2007	TIBCO General Interface Test Automation Kit
Wind River Systems	3/8/2005	Adaptation for VxWorks to the TIPC
Yahoo	12/5/2003	DomainKeys
Yahoo	9/17/2007	Yahoo acquires Zimbra
Yahoo	7/10/2008	Search BOSS

Data source: Infotrac General Business File ASAP database

Table 7.2: Daily abnormal returns surrounding the event date of OSS announcement by publicly-traded US firms (Dates = -5 to +5, N = 114)

Event Date	Mean Abnormal Return (%)	Parametric Significance Test (Patell Z)	Non-Parametric Significance Test (Generalized Signed Z)
-5	0.04	-1.022	-0.189
-4	-0.02	0.005	0.560
-3	-0.20	-1.599+	-0.752
-2	-0.03	0.371	0.560
-1	0.35	2.176*	1.498+
0	0.52	2.485**	0.935
+1	0.04	0.608	-0.189
+2	0.17	0.707	0.186
+3	-0.22	-1.079	-1.126
+4	-0.21	-1.269	-0.564
+5	-0.07	0.113	0.186

Note:

1. Market model using equally weighted index excluding dividends
2. The symbols +,*,**, and *** denote statistical significance at the 0.10, 0.05, 0.01 and 0.001 levels, respectively, using a generic one-tail test.

Table 7.3: Comparison of cumulative abnormal returns (CARs) for different time windows surrounding the OSS announcements (N=114)

Days	Mean CAR (%)	Positive: Negative (Number of Securities)	Parametric Significance Test (Patell Z)	Non-Parametric Significance Test (Generalized Signed Z)
(-30,-2)	-0.82	55:59	-0.388	-0.002
(-1,0)	0.87	65:49	3.296***	1.872*
(-1,+1)	0.92	69:45	3.042**	2.622**
(-2,+2)	1.05	65:51	2.839**	2.060 *

Note: The symbols *, **, and *** denote statistical significance at the 0.05, 0.01 and 0.001 levels, respectively, using a generic one-tail test

Table 8.1: Step 2 – Linear regression correlation table

	CAR2	Hard-ware	Net	System	Commu-nity-origin-ated	Plat-form	AVG OSS Release	Patent Inten-sity	Asset	OSS Pure-play
CAR2	1									
Hardware	.0771	1								
Net	.0549	-.1146	1							
System	.0107	-.2681	-.2316	1						
Commu-nity-originated	.2413	-.0697	-.0395	-.0334	1					
Platform	.1282	-.1227	.0043	.2025	-.0055	1				
Average OSS Release	.0299	-.0433	.3903	-.1641	-.0355	.0714	1			
Patent Intensity	.0542	.0327	-.3041	.6017	-.1745	.0131	-.2165	1		
Asset	-.0259	.0813	-.0817	.2940	-.0653	-.1649	-.1874	.2264	1	
OSS Pure-play	.0067	-.1549	-.1338	-.3130	.1104	.0112	.1908	-.2801	-.346	1

Table 8.2: Step 2 – OLS regression results for determinants of OSS sponsorship performance (DV: 2-day CAR, days (-1, 0)) (N=111)

	(1)	(2)	(3)
	CAR2	CAR2	CAR2
HW	0.0103	0.0083	0.0092
	(1.13)	(0.88)	(0.98)
NET	0.0078**	0.0093*	0.0108*
	(2.82)	(2.54)	(2.53)
SYS	0.0025	-0.0027	-0.0020
	(0.79)	(-0.65)	(-0.43)
Platform Knowledge	0.0072	0.0079+	0.0079+
	(1.62)	(1.75)	(1.69)
Community-originated	0.0179+	0.0197+	0.0195+
	(1.88)	(1.94)	(1.90)
Avg OSS Release Rate		0.0007	0.0003
		(0.33)	(0.15)
Patent Intensity		0.3850*	0.3953*
		(2.13)	(2.12)
Asset			5.36e-09
			(0.12)
OSS Pure-play			0.0032
			(0.47)
Constant	-0.0035	-0.0080	-0.0085
	(-0.96)	(-1.28)	(-1.17)
Observations	111	111	111
R-squared	0.09	0.11	0.11

t statistics in parentheses
+ p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Table 9.1: Rationales for external knowledge sharing

Theoretical Lens	Rationale for External Knowledge Sharing	Strategic Focus	Explanation
Technology Evolution	Shaping Standards	Institutional Environment	External knowledge sharing can influence technological and evaluation standards to favor the firm's own technology trajectory in dominant design competition
	Attracting Collaborators	Value Network	External knowledge sharing can reduce barrier to entry into the firm's technological trajectory, thus creating a critical mass necessary for improving the technology and attracting complementary products
Industry Structure	Credible commitments	Barriers to Substitution	Knowledge sharing with key stakeholders of the firm such as employees, customers and suppliers can gain their cooperation in creating barriers to substitution including: continuous improvement, lock-in and market deterrence
Open Innovation	Knowledge pool access	Innovation Experimentation	External knowledge sharing meets the expectation of generalized reciprocity, thus allowing the firm to access common knowledge pool, which facilitates experimentation and improves its flexibility in dealing with uncertainties
	Knowledge base adaptation	Dynamic Learning	External knowledge sharing with partners and customers creates feedbacks necessary for knowledge adaptation, which is a key source of sustainable competitive advantage

Figure 3.1: Closed Innovation Model (From Chesbrough et al, 2006)

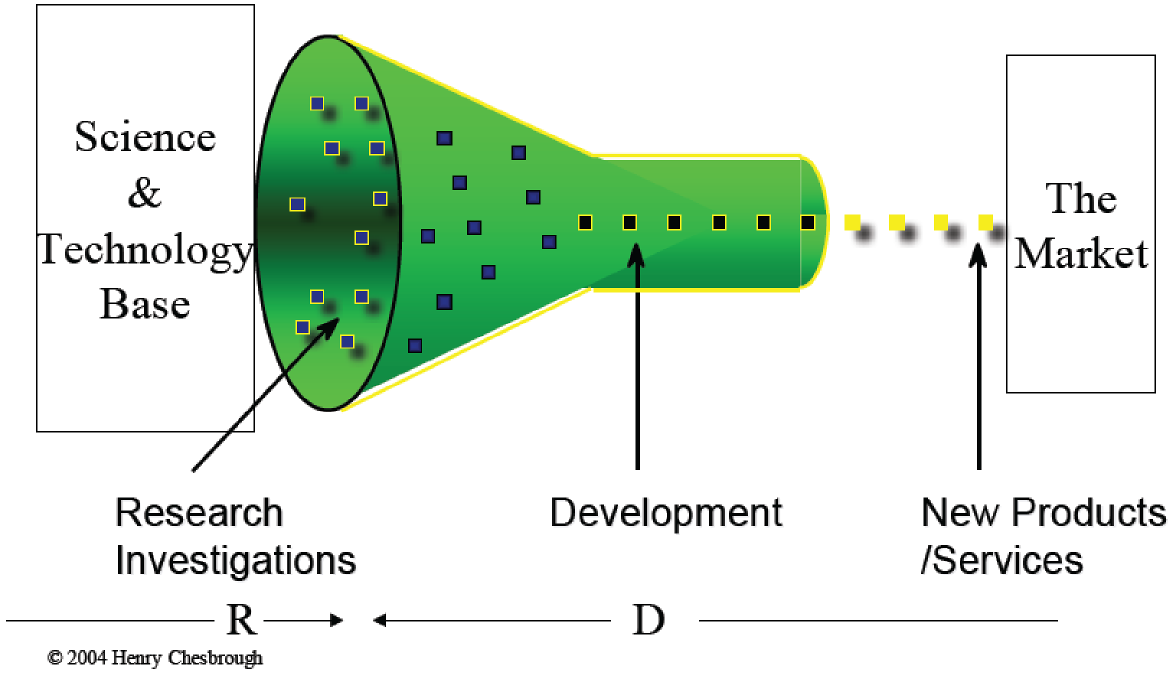


Figure 3.2: Open Innovation Model (From Chesbrough et al, 2006)

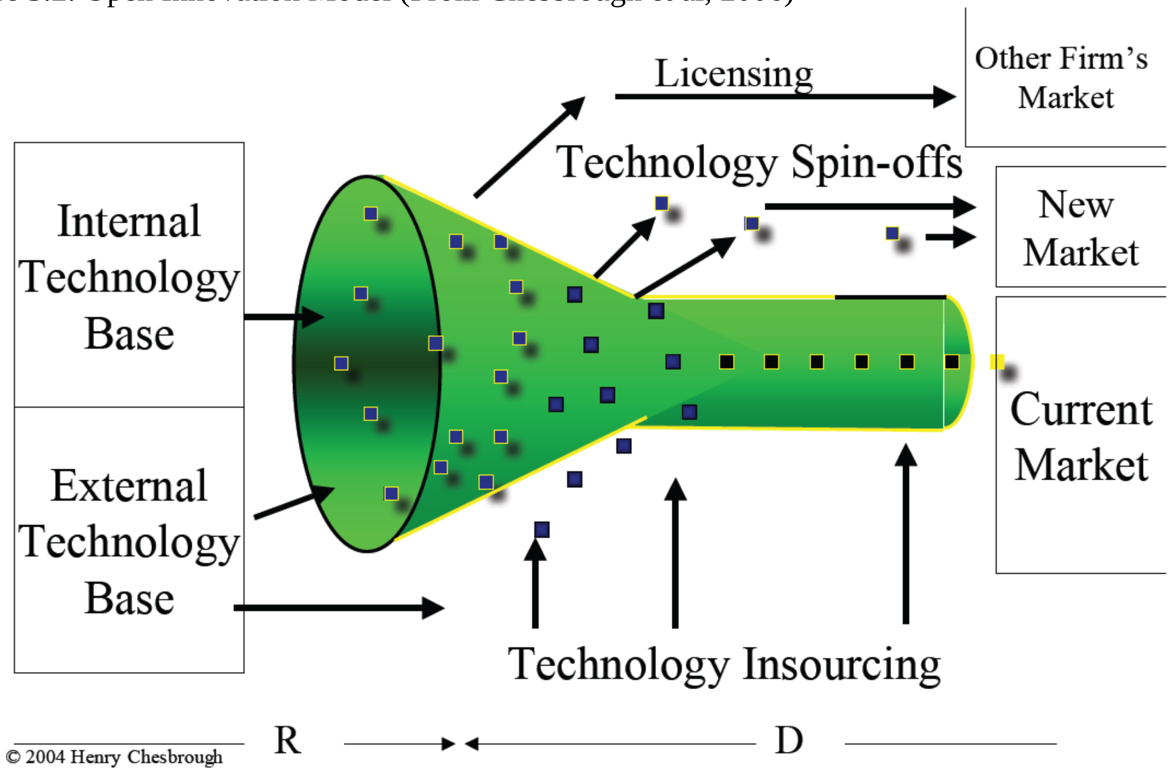


Figure 6.1: Hypotheses

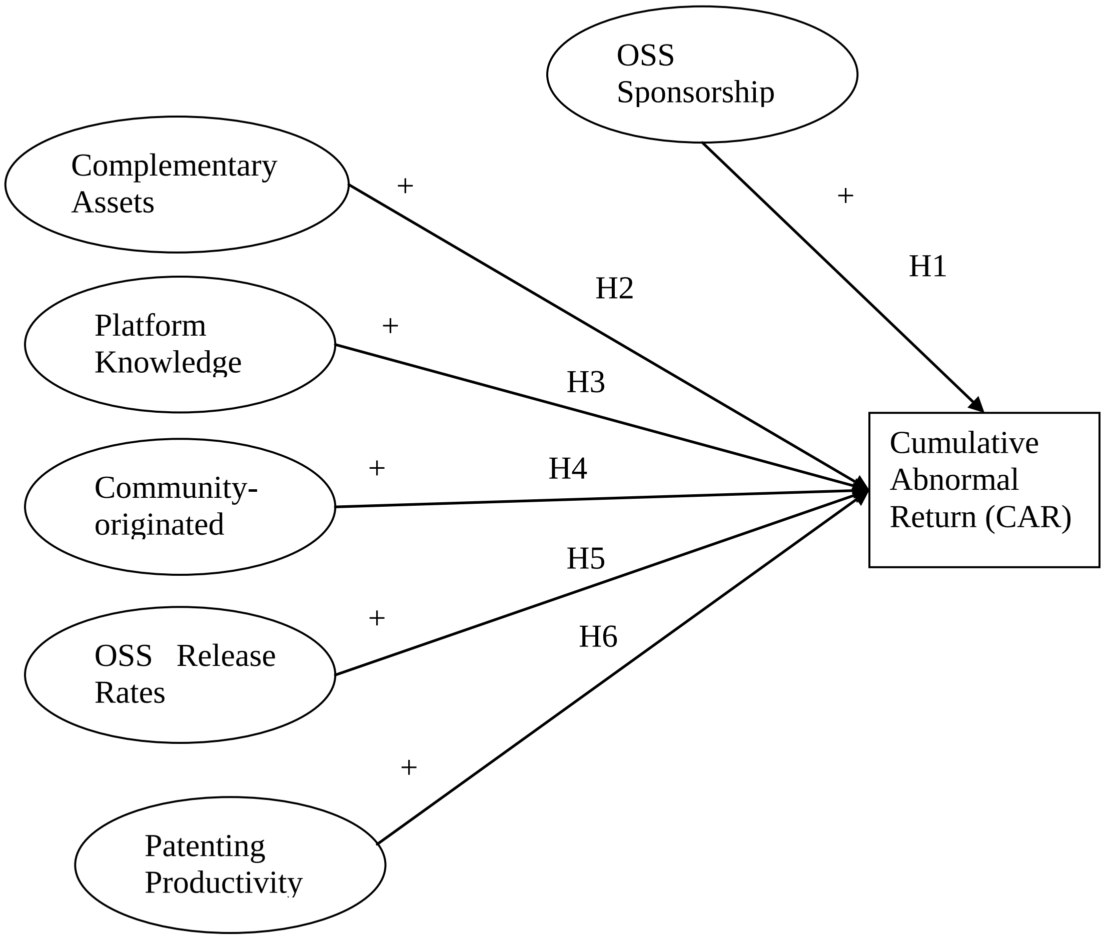


Figure 7.1: Two-day cumulative abnormal return (CAR2) of open source software sponsorship events - close to normal distribution (N=114)

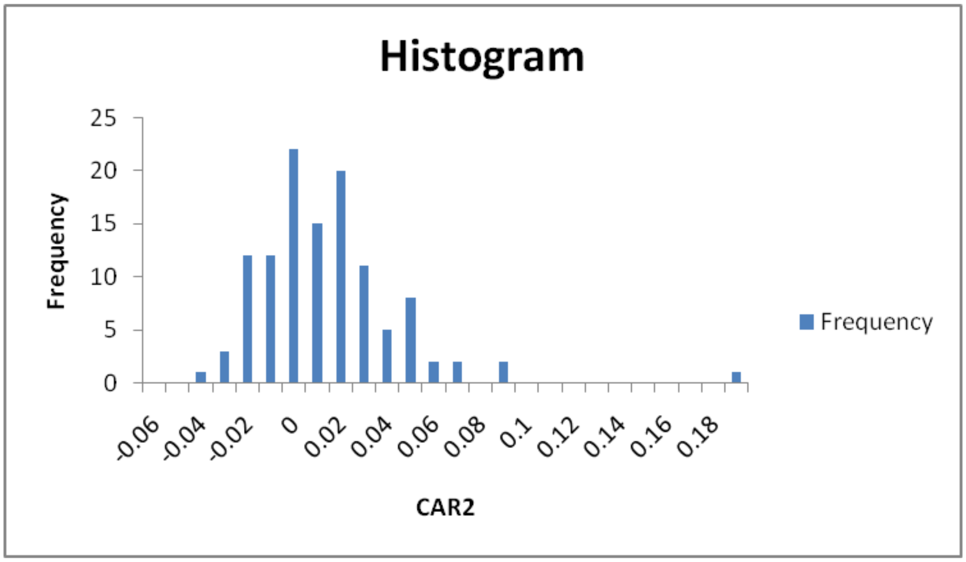
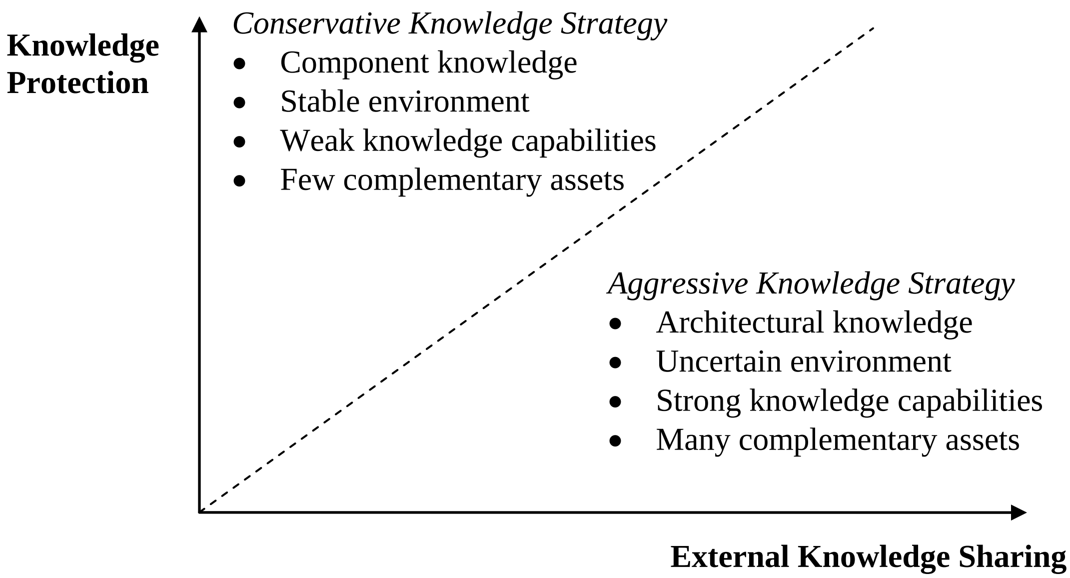


Figure 9.1: Balance between knowledge protection and external knowledge sharing



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APPENDIX A: SAMPLE OSS ANNOUNCEMENT

Google Programs Android as Next Mobile Operating System.

eWeek (Nov 5, 2007)(566 words)
Hide details
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Document Type: Magazine/Journal
Bookmark: Bookmark this Document

Full Text :

There is no Google phone, but what Google revealed Nov. 5 could be even bigger.

Google unveiled a complete mobile phone stack under an open-source license as an alternative to proprietary platforms from Microsoft and Symbian.

Aimed at the roughly 3 billion mobile phone users around the world, Android, as it is called, is a Linux-based mobile software stack, including an operating system, HTML Web browser, middleware and applications. Google will make a software developer kit for Android available within a week to allow programmers to begin testing it.

The stack was created under the aegis of the Open Handset Alliance, an alliance of technology and wireless carriers that includes Google, T-Mobile, eBay, Qualcomm and Motorola as just a handful of the 34 founding members.

Google CEO Eric Schmidt joined by the CEOs of Deutsche Telekom, the parent company of T-Mobile, HTC, Qualcomm, and Motorola, said on a conference call that alliance was created to make it easier for software developers to build applications on top of a mobile platform.

Schmidt noted that the lack of a collaborative effort has made it a challenge for developers, wireless operators and handset manufacturers to work together and build better mobile products.

To read more about the alleged Google phone, click here [link omitted].

This has resulted in poor, often unwieldy user interfaces that make accessing the Web via mobile phones a chore; a mobile software stack that assuages the usability problem, combined with Google's search capabilities and applications, has the potential to be extremely successful.

Andy Rubin, Google's director of mobile platforms, said on the call that the browser-based user interface for Android will be no different in quality to that of a desktop Web browser.

Fostering Android under the alliance, Schmidt said, will give consumers better user experiences than what they get from today's mobile platforms, which include the market-leading Symbian OS and Microsoft Windows Mobile OS.

Android, which is expected to appear on handsets in the second half of 2008, will pave the way for Google to optimize applications such Google Maps and Gmail on Web-enabled devices such as smartphones.

Programmers will be able to access it through the Apache version 2.0 open source license, which has no restrictions. Handset manufacturers and wireless operators will be able to customize Android to create new mobile gadgets faster and at a lower cost.

Read more here about why people say they would buy a Google phone.

"The Android platform is being made available under the most liberal open source license given to mobile operators or anyone ever," Schmidt said.

Schmidt, citing Google's policy of not pre-announcing products, repeatedly refused to admit that Google was developing a phone, but said that Android would be the perfect platform for a Google phone if one were to be built.

Moreover, while the questions focused on the notion of a single Google phone, Schmidt said he envisioned "many, many different types of mobile devices" that are very different from what's on the market today.

Responding to a question about how Google's applications, services and advertising will work with Android, Rubin said that contrary to the speculation "you won't see a completely ad-driven cell phone based on this platform for some time."

Rubin also declined to answer whether or not Google asked Nokia (which uses Symbian), Microsoft, Apple and Research in Motion, which make competing mobile operating systems, to join the Handset Alliance.
Source Citation
"Google Programs Android as Next Mobile Operating System." eWeek (2007). Academic OneFile. Web. 27 June 2010.

APPENDIX B: DYNAMIC CORPORATE PATENT PORTFOLIO

In most corporations, the corporate structures constantly undergo transformations through mergers and acquisitions. Accordingly, the knowledge profiles of these corporations should reflect these corporate structural changes over time. In management studies, the knowledge base of a corporation is often proxied by its patent portfolio (Ahuja & Katila, 2001). Nevertheless, few studies have taken into account this dynamic nature of corporate patent portfolios, partly due to lack of information about how corporate patent portfolios change along with corporate structure changes. Though critically important and necessary, the difficulty for constructing a dynamic snapshot of corporate patent portfolio is exacerbated by the fact that most patent databases do not provide a dynamic picture of corporate history. Rather, patent databases like Delphion only keeps track of the most recent corporate structure. As a result, studies of historical corporate events relying on current corporate patent portfolios may not accurately capture the corporate knowledge base at the time of the events. To address this inconsistency between time of event and time of measurement, this study took a brand-new approach of corporate patent profile measurement, by taking into account the corporate merger and acquisition history and patent attributes. The result is a much more accurate snapshot of the knowledge base of the corporation at the historical event time.

This study retrieves USPTO patents from the Delphion patent database. Under the assumption that target patents become part of the acquirer firm knowledge base after the effective date of a merger, this study adopts the following steps to capture historical snapshots of the patent portfolio of a corporation:

(1) Use USPTO assignee codes to determine CUSIP.

Patents from the same firm may bear different assignee codes, which keeps track of the original assignee of the patent. This is the starting point of our history tracking. The purpose of this step is to clean up the assignee codes in the patents and keep track of unique acquired firms within the corporate tree. I would go though each USPTO assignee code, identify each corresponding acquired firm which appears in the merger and acquisition (M&A) history of the corporate parent, then assign a unique code to each firm. After all the unique assignees have been identified, I would go through each patent and assign it to one of the unique acquired firm or the corporate parent. This task is accomplished in Excel with the following VBA script:

```
Option Explicit

Public Function SetCUSIP(ByVal Y As Range) As String

    'Lookup range - USPTO codes mapped to CUSIPs
    Dim X  As Range
    Set X = Worksheets("Sheet2").Range("C2:C100")

    Dim offsetCUSIP As Integer
    offsetCUSIP = -9          'offset from USPTO Assignee Code column J

    '-----------------------------------
    Dim c As Range

    Dim currCode As String
```

```
    Dim codeList As String
    Dim CUSIP As String

    CUSIP = ""

    currCode = Y.Value

    Dim d As Range
    For Each d In X
        codeList = d.Value

        If InStr(codeList, currCode) > 0 Then
            CUSIP = d.Offset(0, -2).Value

            Exit For
        End If

    Next d

    SetCUSIP = CUSIP

End Function
```

(2) Create M&A history for each corporation during the relevant time window

The SDC database does a good job in keeping track of the merger and acquisition history of public firms. Using the M&A information from SDC, I construct an M&A history table in the Microsoft Access, with the following data structure:

Field	Acquirer Name	Acquirer CUSIP	Target Name	Target CUSIP	Date Announced	Date Effective	Date Exited	Derived
Data Type	Text	Text	Text	Text	Date/Time	Date/Time	Date/Time	Yes/No

After importing the M&A history from SDC database, I would run another VBA script within Access database to determine the relationship between each pair of firms in the same corporate tree, based on the M&A history. For example, Compaq acquired DEC in 6/1998, and HP acquired Compaq in 5/2002 (effective dates). While there is no direct historical record of HP acquiring DEC, the DEC patents indirectly became part of HP's knowledge base through the HP-Compaq merger. Therefore, the VBA script would create an additional linkage from DEC to HP based on the M&A effective dates of the two M&A deals above. All such indirect linkages are marked as "Derived" in this table.

(3) Create "ultimate parent" CUSIP based on M&A history

Based on the unique firm codes obtained in step (1) and M&A history constructed in step (2), I can now examine each patent and determine its true owner at the time the patent application is filed. For this step I would create a "PatentAttr" table parallel to the patents table, with the following fields:

Field	CUSIP	Publication Number	UltimateOwnerCUSIP	Application Date
Data Type	Text	Text	Text	Date/Time

In this table, each patent's ultimate corporate parent is identified using VBA script, based on the date of patent application and the corporate M&A history. Essentially, all patents filed after the effective date of a merger would now ultimately belong to the acquirer firm. Following the example in (2), a patent filed by Compaq in 2001 would have ultimate owner as Compaq, while a Compaq patent filed in 2003 would have ultimate owner as HP.

(4) For each event date, create a list of CUSIPs representing the corporate tree at that time

Using the M&A history information constructed from (2), we may identify all firms belonging to a particular corporation at any event date. The result will be a list of CUSIPs corresponding to the corporate parent and the event date specified. Again, this is an important intermediate step, done by VBA code.

(5) Dynamic patent portfolio

Finally, using the dynamically constructed CUSIP list obtained in (4) and the patent ultimate owner obtained in (3), we may retrieve all patents with ultimate owner in this CUSIP list. This would be the desired snapshot of the patent portfolio for the focal corporation at the event date, including each subsidiary firm at the event time included in the CUSIP list, and excluding subsidiary firms acquired after the event date specified.

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Sai Lan graduated from Tongji University in Shanghai, China in 1995 with a Bachelor's Degree in Computer Engineering. He went on to earn his Master's Degree in Computer Science from Peking University in Beijing, China in 1998. He graduated from both universities summa cum laude. After graduating from Peking University, Sai came to study in the US on scholarship, which led to his second Master's Degree in Electrical Engineering and Computer Science from University of Illinois at Chicago in 1999.

Sai started his job career in 1999 as a software engineer at Motorola Inc. in Arlington Heights, Illinois, working on 3G telecommunication core network development. Later he has held job positions as software architect and business analyst in the healthcare IT industry in the Chicago area, before relocating to Champaign, Illinois in 2006 to pursue his Ph.D. in Strategic Management. Following the completion of his Ph.D. in 2011, Sai will return to his home country of China to work as an Assistant Professor at Peking University, HSBC School of Business.