ESSAYS ON INNOVATION ECOSYSTEMS IN THE ENTERPRISE SOFTWARE INDUSTRY

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ESSAYS ON INNOVATION ECOSYSTEMS IN THE ENTERPRISE SOFTWARE INDUSTRY

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SUMMARY

Innovation ecosystem strategy is often adopted by platform technology owners to seek complementary innovation from resources located outside the firm to exploit indirect network effect. In this dissertation I aim to address the issues that are related to the formation and business value of platform innovation ecosystems in the enterprise software industry. The first study explores the role of three factors – increased payoff from access to platform owner's installed base, risk of misappropriation due to knowledge transfer, and the extent of competition – in shaping the decisions of third-party complementors to join a platform ecosystem. The second study evaluates the effect of participation in a platform ecosystem on small independent software vendors' business performances, and how their appropriability strategies, such as ownership of intellectual property rights or downstream complementary capabilities, affect the returns from such partnerships. Built upon resource based view and theory of dynamic capabilities, the third study reveals that users' co-innovation in enterprise information systems, measured by their participation in online professional community networks, constitute a source of intangible organizational asset that helps to enhance firm level IT productivity.

CHAPTER 1

OVERVIEW

Whether a platform technology can generate significant economic returns often depends on complementary innovations in its related fields, as we have witnessed in the transition from mainframe computing paradigm to the client/server computing model (Bresnahan and Greenstein 1996). In recent years, platform-based competition is becoming increasingly a ubiquitous phenomenon in the information economy. The personal computer, personal digital assistant, and video game console are stylized examples of systems that consist of a core technology platform and interchangeable complementary applications built upon it (Bresnahan and Greenstein 1999). To meet the heterogeneous needs of users and to exploit indirect network effects, owners of platform often seek to encourage complementary third-party innovation from resources located outside the firm, ranging from customers, research companies and business partners to universities. This approach of complementary innovation has given rise to the model of an innovation ecosystem, where the collective power of platform users, developers, partners, and consultants is harnessed by the platform owner to achieve the shared success of the community (Adner 2006).

Although we see a growing interest among practitioners and researchers in platform ecosystems (Iansiti and Lakhani 2009), there has been little empirical work in understanding the formation of innovation ecosystems and mechanisms through which they create business value for the various parties. In addition, the few extant studies on platform ecosystems (Eisenmann et al. 2008; Gawer and Henderson 2007; Parker and Van Alstyne 2008; West 2003) almost exclusively focus on the platform owners' decisions to open or close their technology platform or platform governance strategies. In contrast, there is a lack of understanding of the incentives and concerns on the part of third-party complementors who consider joining the platform, and under what conditions platform ecosystems create values for them. Further, in the process of adopting a technology platform, users often create co-innovations by making idiosyncratic adaption, modification and customization of the technology. However, their co-innovation activities in platform ecosystems have largely been left unexamined in prior research.

I aim to bridge the gap in prior literature by modeling and empirically investigating the platform innovation ecosystems in the enterprise software industry. Wide adoption of enterprise software has contributed to the accelerated competition within the US economy and a period of intense innovation in corporate IT (McAfee and Brynjolfsson 2008). Specifically, I choose SAP, the largest enterprise software company as the focal platform owner. This setting represents a good place to begin studying this phenomenon for several reasons. First, the SAP ecosystem is large; it includes over 41,000 customers and more than 7,000 partners, and has been characterized by some as having its own economy (Pang 2007). Second, SAP has taken a series of initiatives to seed complementary innovation and foster its ecosystem, such as promoting technology and solution partnership programs, building a thriving user community of innovation, and opening co-innovation lab facilities to enable co-creation of solutions with its partners, etc (Iansiti and Lakhani 2009). For example, SAP publicly certifies independent software vendors (ISVs) in its ecosystem, which means that SAP engineers test and endorse that the ISV’s software integrates with the SAP platform. In addition, SAP actively promote the knowledge exchange and co-innovation between its customers, partners, developers and its own employees by sponsoring its online community network, which has drawn participation from more than 1.8 million registered members. Using this particular setting, I try to address two broad categories of research questions. The first category relates to the formation of innovation ecosystems, which includes questions like what attracts third party, complementary solution providers to participate in a platform ecosystem; what are the tradeoffs they face when they make such decisions; and under what conditions they can better appropriate the economic returns of their innovation in such relationships so that a successful ecosystem is more likely to emerge? The second category of questions relates to the business values that are enabled by innovation ecosystems for various innovation ecosystem participants, such as independent software vendors that become part of the ecosystem, or the technology platform adopters that invest their efforts to make platform specific co-innovations.

In the first essay of my dissertation, I extend prior research by Gans et al. (2002) to build a payoff model that examines the factors influencing the likelihood an ISV will become certified by SAP as a platform-compatible application provider. I stress three distinct features of this type of partnership. First, the major benefit for ISVs to join the ecosystem is to gain market exposure to the platform owner’s installed base instead of accessing the platform owner’s technological or marketing resources, and therefore the analysis is different from the context of technology commercialization or markets for technology[1]

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[1] Research in the markets for technology literature examines transactions for the use, diffusion, and creation of technology. These include transactions involving knowledge that may or may not be protected by

(Arora and Ceccagnoli 2006). Second, potential risk of entry by the platform owner, together with uncontrollable knowledge transfer during the partnership, brings the relevance of appropriability mechanisms such as intellectual property rights (Graham and Mowery 2003) and downstream complementary capabilities (Teece 1986). Third, the relationship often involves collaboration between competitors, characterized as co-opetition[2] (Nalebuff and Brandenburger 1997). In many cases both the platform owner and the ISV provide similar functional modules and compete in multiple product markets, and the formation of partnerships may depend critically on the intensity of competition. These three factors – increased payoffs from access to the platform owner's installed base, risk of misappropriation due to knowledge transfer, and extent of competition – form the main trade-offs to the partnering decision that I study in this essay. The model predicts that appropriability strategies based on intellectual property rights and the possession of downstream complementary capabilities by ISVs are positively related to partnership formation, and ISVs use these two mechanisms as substitutes to prevent expropriation by the platform owner. In addition, the model shows that greater competition in downstream product markets between the ISV and the platform owner is associated with a lower likelihood of partnership formation, while the platform's penetration into the ISV's target industries is positively associated with the propensity to partner. I then assemble a unique data set on the partnership decisions of 1201 ISVs over

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intellectual property and may or may not be embodied in a product. For a recent overview of the markets for technology literature see Arora and Gambardella (2010).

[2] Co-opetition is a term used to describe collaboration between competitors. It was coined by Raymond Noorda, the founder of the networking software company Novell, to characterize Novell's business strategy. For details, see Nalebuff and Brandenburger (1997).

1996 to 2004 to test these model-based predictions, and find support for the theoretical predictions.

In the second essay of my dissertation, I extend the previous payoff model to investigate the business value associated with joining a platform ecosystem and how start-up ISVs' appropriation strategies lead to differences in the returns to the partnership. I argue that such partnerships emerge as a new type of inter-organizational relationship (IOR) that is different from a number of other types of IORs that have been examined in prior research such as joint ventures, alliances, networks, trade associations, and supply chain relationship. More importantly, the value creation processes associated with such a relationship are likely to be different from those of other types of IORs. For example, the primary reason for start-up ISVs to join a platform ecosystem is to signal compatibility of software applications and to thereby gain access to the platform owner's installed base, in contrast to other inter-organizational relationships where organizational learning, risk sharing, resource pooling or strategic factors are important. I predict that the formation of such a partnership is associated with greater market access (Chellappa and Saraf forthcoming), positive product quality signal (Rao and Ruekert 1994), and social legitimate endorsement (Stuart et al. 1999), which leads to improved ISV performance after joining the platform ecosystem. In addition, I propose that due to the risk of expropriation by platform owner, the extent to which ISVs benefit from this relationship is moderated by their appropriability mechanisms. I test empirically how the business value of the ecosystem is reflected in sales, the likelihood of issuing an initial public offering (IPO) and the chances of being acquired of the ecosystem participants, and show that the positive performance impacts are greater when an ISV's innovation is protected by IP rights and downstream complementary capabilities.

In the third essay of my dissertation, I conduct a study to evaluate the value of a platform owner sponsored online co-innovation community to platform adopting firms. Drawing upon theories of resource based view of IT and firm dynamic capabilities, I argue that IT using firms' co-innovation in enterprise information systems complements their adoption of IT infrastructure and it improves the firms' IT productivity. Organizations' accumulation of co-innovation over time is likely to be heterogeneously distributed among firms due to their different strategic pursuits, and it is not easily transferred across firm boundaries due to time diseconomies, causal ambiguity and social complexities, and therefore it constitutes an important source of intangible assets that complements firms' IT investment (Barney 1991; Mata et al. 1995). Enterprise software, being the backbone of enterprise information systems, presents an exemplary context where user firms engage in extensive co-innovation. Enterprise software products are highly process-oriented and usually need to be tailored to fit business practices, where idiosyncratic local needs usually drive innovations in work practices (Hitt et al. 2002). To empirically identify the complementarities between user co-innovation in corporate information systems and IT investment, I construct a sample from fortune 1000 firms and collect data on their implementation of SAP enterprise software, their IT infrastructure, their stock of co-innovation in SAP's software platform, and their business performance. To resolve the challenge of measuring enterprise software adopters' co-innovation in the underlying software platform, I collect data on SAP user firms' participation and contribution to an SAP-sponsored online community network. Incorporating IT co-innovation into production function framework, my results suggest that firms with mean level stock of IT co-innovation extract as much as 54.5% greater productivity from their IT investment than those without IT co-innovation.

CHAPTER 2

PARTICIPATION IN A PLATFORM ECOSYSTEM: APPROPRIABILITY, COMPETITION, AND ACCESS TO THE INSTALLED BASE

2.1. Introduction

> *"We started from the point that one company cannot be the best in all areas. So the more partners that we have to innovate around our technology, the more it will be a win/win situation."*
>
> *"We have to be extremely clear with our partners about what they can expect. One rule is that we cannot protect the partner forever -- [we cannot guarantee] that there may not be a time when SAP is forced to enter his space."*
>
> Hening Kagermann, former CEO and Chairman of the Executive Board of SAP (Knowledge@Wharton 2006)

Platform-based competition is becoming increasingly a ubiquitous phenomenon in the information economy. The personal computer (Bresnahan and Greenstein 1999), personal digital assistant (Boudreau 2007), and video game console (Zhu and Iansiti 2007) are stylized examples of systems that consist of a core technology platform (Boudreau 2007) and the interchangeable complementary applications built upon it.[3] In the software industry we observe that communities of innovation networks, known as ecosystems, have been increasingly employed by platform owners to meet heterogeneous user needs (Adomavicius et al. 2007; Evans et al. 2006). Industry leaders nurture their ecosystems

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[3] In this study I follow Bresnahan and Greenstein (1999) in defining a platform as a set of interchangeable IT components so that buyers and sellers can benefit from the same technological advance.

by coordinating and harnessing the collective power of developers, partners, and others integral to the shared success of the community (Adner 2006).

While platform owners encourage the provision of complementary products in order to take advantage of indirect network effects (Rochet and Tirole 2003), there is often a tension between the developers of complementary products and the platform owners due to the risk that the latter may eventually compete in their partner's product market space (Gawer and Henderson 2007). This risk is illustrated by the quote from SAP ex-CEO Hening Kagermann above. To the extent that the platform owner may *ex post* "squeeze" complementors, the latter may have less *ex ante* incentive to join the ecosystem in the first place (Choi and Stefanadis 2001; Heeb 2003). Prior research has used analytical models or case studies to investigate this issue from the perspective of the platform owner (Farrell and Katz 2000; Gawer and Henderson 2007). However, as yet there has been no systematic empirical evidence on how the potential for platform owner entry conditions independent software vendors' (ISVs) incentives to participate in innovation ecosystems. Acquiring such evidence has important managerial implications, as it will inform when ecosystems are most likely to grow and succeed.

In this study I try to bridge this gap in evidence by examining how the risks of platform owner entry influence ISVs' decisions to join a platform in a specific setting: the enterprise software industry. Specifically, I examine the factors influencing the likelihood an ISV will become certified by SAP as a platform-compatible application provider. This setting represents a good place to begin studying this phenomenon for two reasons: (1) the SAP ecosystem is large; it includes over 41,000 customers and has been characterized by some as its own economy (Pang 2007), and (2) SAP publicly certifies vendors in its ecosystem, providing an empirically verifiable metric that I use as my dependent variable. SAP certification means that SAP engineers have tested and endorsed that the ISV’s software integrates with SAP (SAP 2009a). SAP-certified partners are the only ones who are displayed on the SAP ecosystem web site and partners prominently trumpet their certification through press releases and on their web sites as a means of signaling their compatibility with SAP (BasWare 2005).

I stress three distinct features of this setting. First, while ISVs have the option to produce software that is not certified, certification provides a signal that the software will interoperate with SAP, the largest enterprise software vendor. The major benefit of joining the ecosystem is the potential for greater sales arising from access to the platform owner’s installed base (Chellappa and Saraf forthcoming). Second, the relationship often involves collaboration between competitors, characterized as co-opetition (Hamel et al. 1989; Nalebuff and Brandenburger 1997). The platform owner and the ISV may provide similar functional modules and compete in multiple product markets. Third, the potential for entry into the ISV’s market by the platform owner, together with uncontrollable knowledge leakage during the process of partnering, brings with it the risk of expropriation of the ISV’s intellectual property (IP) over the course of the partnership. These risks will be mitigated by the effectiveness of different appropriation strategies such as intellectual property protection and ownership of downstream complementary capabilities (Teece 1986). These three factors – increased payoffs from access to the platform owner’s installed base, competition between platform owner and complementors, and risk of entry through knowledge misappropriation – are the main trade-offs to the partnering decision that I examine in this study.

I test my theoretical predictions by assembling a unique data set on the partnership decisions of 1201 ISVs over 1996 to 2004. Collecting data from a variety of sources, I measure the extent to which ISVs are formally protected by intellectual property rights and possess downstream marketing capabilities, the extent of SAP's market penetration into the ISVs' target industries, and the intensity of potential product market competition between SAP and the ISVs. Using both discrete time hazard and fixed effects regression models, I find that small ISVs utilize both intellectual property rights protection and downstream capabilities to prevent expropriation. In particular, I find that ISVs with greater stocks of copyrights or those with strong downstream marketing capabilities are more inclined to join the ecosystem. Interestingly, the two appropriation mechanisms serve as substitutes to each other and the presence of one weakens the marginal effect of the other on the likelihood of partnering. In addition, I find that the incentive of ISVs to join an ecosystem is positively influenced by the penetration of SAP platform (specifically, ERP) in the ISV's target industries, reinforcing the view that ISVs partner with the platform owner to gain access to its large installed base. Finally, I find evidence that ISVs' decisions to join a platform are strongly influenced by the extent of competition between the product offerings of the platform owner and the ISV.

The rest of the chapter is organized as follows. In the next section I present an overview of related research and discuss my contributions to the literature. In section 2.3, I introduce the research setting and briefly describe SAP's partnership program with ISVs. I present a simple payoff model to motivate the hypotheses in section 2.4. Section 2.5 presents my hypotheses. Section 2.6 describes the data and empirical models. I present the results, as well as a set of robustness checks, in section 2.7. In section 2.8, I discuss the implications of my study and conclude.

2.2. Literature Review

This study is related to three areas of the literature: recent work on technology platforms and ecosystems, research on appropriating the returns from innovation, and studies on the enterprise software industry. I discuss each of these in turn.

2.2.1. Technology Platforms and Innovation Ecosystems

A growing body of research has examined how platform owners can encourage third-party complementors to contribute to a platform to stimulate indirect network effects. For example, theory research in this literature has examined platform owner decisions to open a platform (Boudreau 2007; Eisenmann et al. 2008; Gawer and Cusumano 2002; Gawer and Henderson 2007; Parker and Van Alstyne 2008; West 2003) and vendors' strategic responses to open and closed platforms (Lee and Mendelson 2008; Mantena et al. 2007). Empirical work has sought to measure the value of network effects to end users (Brynjolfsson and Kemerer 1996; Gallaugher and Wang 2002; Gandal 1995; Liu et al. 2008; Zhu and Iansiti 2009) as well as the effects of increasing openness on competition (Boudreau 2007).

Most directly related to my own work is research on the strategies used by a platform owner to manage platform stakeholders such as end users and complementors (Gawer and Cusumano 2002; Gawer and Henderson 2007; Iansiti and Levien 2004). Of particular concern is the fine line that platform sponsors must walk between maximizing profits and leaving sufficient residual profit opportunities to encourage complementary innovation.

For example, platform sponsors like Microsoft will frequently absorb complements (e.g., a web browser or a media player) for efficiency gains (Eisenmann et al. 2007) or to avoid double marginalization (Casadesus-Masanell and Yoffie 2007). While such actions can increase ex post returns for the platform owner, they may discourage ex ante platform-specific investments by potential complementors. At present, there is little empirical work that shows how threat of potential entry conditions complementor decisions to join a platform. This chapter takes a first step towards filling this gap by examining how appropriability and competition influence the decision to partner.

2.2.2. Appropriating the Returns from Innovations

Profiting from technology innovations within a platform-based industry such as enterprise software emerges as only a special example of the more general set of innovations investigated by Teece (1986). He suggests that when an innovation is easily imitated or invented around, profits from an innovation may be appropriated by the owners of certain manufacturing, marketing, and a variety of other capabilities that are required to commercialize an innovation. These complementary capabilities are usually specialized to the innovation (i.e., they would lose value in alternative uses). They have two associated characteristics: (1) they are not easily accessible through the market, since their specificity give rises to significant transaction costs (Teece 1986), and (2) they are valuable, rare and difficult to imitate and their ownership provides a sustainable competitive advantage (Barney 1991; Rothaermel and Hill 2005; Teece 1992). Indeed, from an empirical point of view, ownership and strength of downstream capabilities required to commercialize an innovation are some of the most important appropriability mechanisms across a wide range of industries (Cohen et al. 2000).

While a stronger position in specialized complementary capabilities is beneficial to the appropriation strategy through product markets, some argue that the possession and strength of intellectual property rights is conducive to technology licensing and markets for ideas (Arora et al. 2001; Dechenaux et al. 2008; Gans and Stern 2003). Recent research has extended this literature to examine how the existence of markets for technology influences the licensing strategies and survival of entrepreneurial firms in the security software industry (Arora and Nandkumar 2008; Gambardella and Giarratana 2008). Gambardella and Giarratana (2008), in particular, find that technology markets in the security software industry thrive when product markets are fragmented and technologies have more general application, whereas ownership of patents or co-specialized complementary capabilities do not have sizable or significant impacts on the hazard rate of licensing. Arora and Ceccagnoli (2006) show however that when firms of all size are considered, whether the effectiveness of patent protection increases licensing propensity depends critically on the ownership and strength of downstream complementary capabilities.

To the best of my knowledge there is relatively little work studying how the ownership of intellectual property and downstream capabilities shape the innovation strategies of small firms in markets characterized by software platforms such as enterprise software. My setting allows me to significantly extend the extant appropriability and markets for technology literature, in order to take into account of the fundamentally different nature of the cooperative strategies characterizing platform-based industries. Since software certification requires the disclosure of sensitive and proprietary knowledge, I show that appropriability strategies—including IP protection, ownership of downstream complementary capabilities and their interaction—are crucial drivers of the formation of such partnerships.

2.2.3. Enterprise Software

Extant IS research on enterprise software predominantly focuses on the user side of the market. For example, recent empirical research on firm-level performance suggests that adoption of enterprise systems is associated with improvements of productivity (Aral et al. 2008; Hitt et al. 2002), market value (Hendricks et al. 2007; Hitt et al. 2002), profitability (Hendricks et al. 2007) and operational performance (Cotteleer and Bendoly 2006; Hitt et al. 2002; McAfee 2002).

Despite this wealth of work, there has been a paucity of IS research that studies the supply side of enterprise systems, and there is less understanding of the economics and dynamics of the provision of enterprise software. An exception is Chellapa and Saraf (forthcoming), which investigates the strategic considerations behind alliance relationships among enterprise software vendors and how firms' performance is conditioned on their structural position in the alliance network. My study, in contrast, differentiates the roles played by platform owner and complementary application providers, and unifies theories on technology platform, innovation appropriation and collaborative competition to provide a holistic view of the formation of enterprise software ecosystem.

2.3. SAP and Its Ecosystem

Enterprise software is claimed to be the organizational operating system (Chellappa and Saraf forthcoming), which consolidates the diverse information needs of an enterprise's departments together into a single, integrated software program that operates on a shared database (Hitt et al. 2002). I follow Bresnahan and Greenstein (1999) as defining a platform as a set of interchangeable IT components so that buyers and sellers can benefit from the same technological advance. Third-party software vendor applications extend the functionality of the platform and add value to adopters.

ISVs that produce software that communicates with SAP have the option to become certified by SAP and become a member of the SAP platform ecosystem. This certification endorses the interoperability between the ISV's software and the SAP platform. The certification process begins with the ISV completing an application with the assistance of the local SAP Integration and Certification Center (ICC) or SAP partner liaison/manager. The ISV will then go through development, documentation, and testing phases to make sure the product is compliant with SAP's platform specifications. During this time, the SAP ICC will assign a consultant to work with the ISV to prepare for certification and conduct/document a certification test. Once the product successfully completes the certification test, a certification logo will be issued and the solution will be listed on SAP's web portal which is accessible by its customers. For ISVs, the primary benefit to partnering is to signal software compatibility and to give ISVs access and exposure to SAP's customer base (Chellappa and Saraf forthcoming). Further, partnership gives ISVs access to partner-only portals for product, marketing and sales information, sales/marketing assistance, and technical support.

However, such partnerships are not costless for ISVs. Besides the fixed cost of developing a platform-compliant version of the software solution, certification application fees and yearly membership fees, there are considerable appropriability issues for ISVs due to extensive knowledge sharing involved in the relationship. Knowledge transferred from the ISV to SAP may, perhaps inadvertently, lower the costs of SAP entering into the market with a competing product.

2.4. Partnering to Achieve Platform Compatibility: A Simple Model

I present a simple multi-stage decision model to formalize the payoff structure related to an ISV's decision to join a platform ecosystem and to motivate my hypotheses. The model is adapted from Gans et al. (2002) and involves a start-up ISV and a platform owner. The ISV is endowed with an invention and embeds the invention into a software product. It faces a choice of going to the market alone or forming a partnership with the platform owner, and therefore gaining access to a larger market. In order to sell to the platform owner's installed base the ISV must go through the certification process. Let θ be the strength of IPR protection for the ISV. That is, in case the invention is imitated or invented around by a competitor, the ISV has probability θ of enforcing its IPR successfully (that is, deterring entry). Let T denote the ISV's downstream complementary capabilities, C denote the intensity of competition between the platform owner and the ISV in the application product market, and P denote the platform owner's penetration into the ISV's target industries.

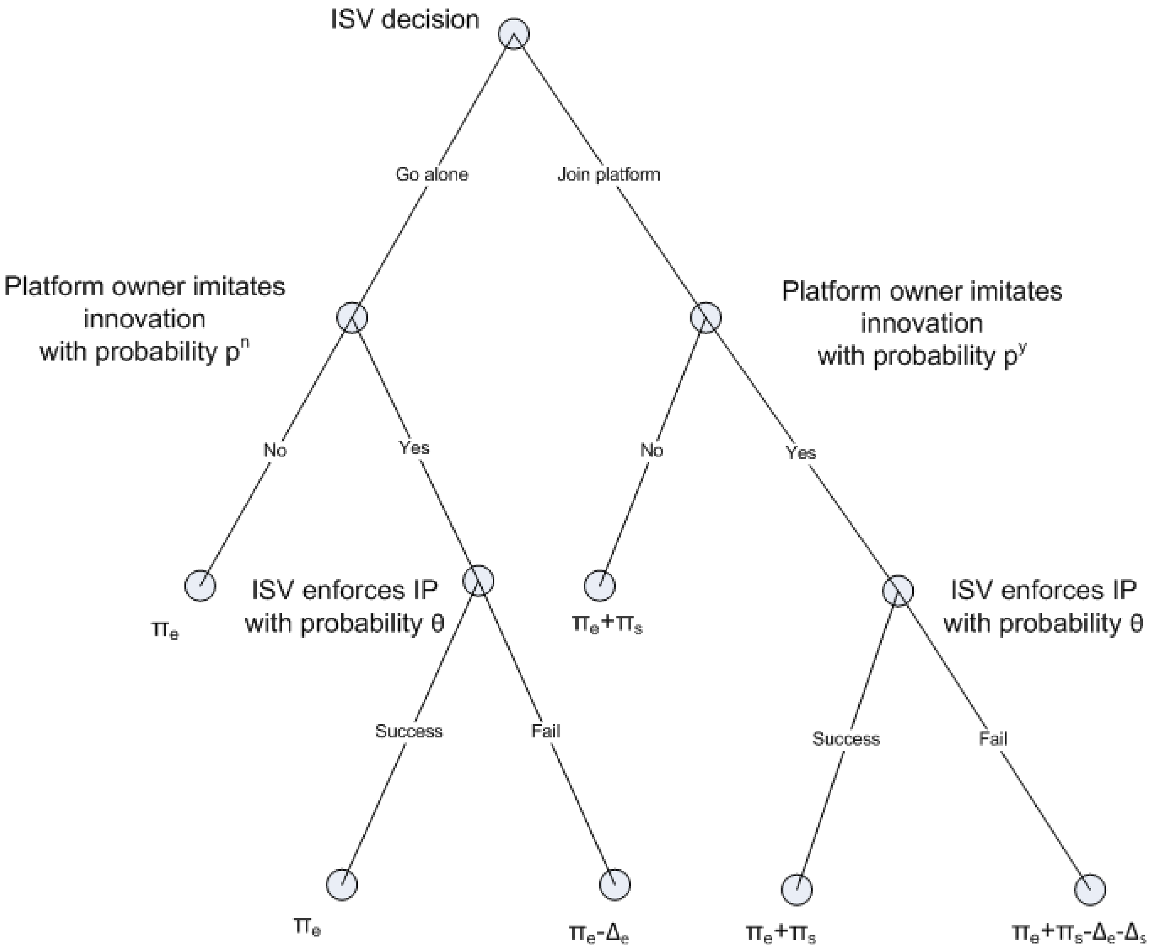

Figure 2.1 The ISV's Payoffs

Figure 2.1 illustrates the sequence of the game. If the ISV goes to market alone (i.e., does not join the platform), it enjoys a profit π_e in a relatively small market. However there is a probability p^n that the platform owner imitates its innovation (e.g., by reverse engineering) and enters the ISV's application market. If the ISV is unsuccessful in defending its IPR, the ISV incurs a profit loss $\Delta_e(C,T)$ with probability (1− θ) from its current market. Otherwise the ISV maintains its current position with probability θ. Therefore the expected profit of the ISV if it chooses not to join the platform is

$$\pi^n = \pi_e - \Delta_e p^n (1-\theta) \tag{2.1}$$

The ISV can also partner with the platform owner to tap into the customer base of the latter. Denote the additional profit the ISV enjoys from accessing the platform owner's installed base by $\pi_s(C,P,T)$. I assume π_s is decreasing in the intensity of product market competition between the platform owner and the ISV ($\frac{\partial \pi_s}{\partial C} < 0$), increasing in the platform's penetration into the ISV's target industries ($\frac{\partial \pi_s}{\partial P} > 0$), and an ISV with strong downstream capabilities is more successful in extracting additional profits from the platform owner's installed base ($\frac{\partial \pi_s}{\partial T} > 0$). By going through the product certification process, an ISV may have to disclose product design information to the platform owner. Therefore the platform owner has a higher probability, $p^y > p^n$, of successfully imitating the innovation. Similarly the ISV has a probability θ of successfully enforcing its IPR in this case. In addition, if the platform owner imitates the innovation and the ISV is unsuccessful in defending its IPR, the ISV suffers a profit loss from both the platform owner's installed base $\Delta_s(C,T)$ and its own market $\Delta_e(C,T)$. I assume the ISV's losses from both its own market and the platform owner's installed base are decreasing in the strength of the ISV's downstream complementary capabilities, while they are increasing in the intensity of product market competition between the platform owner and the ISV. That is, $\frac{\partial \Delta_e}{\partial T} < 0$, $\frac{\partial \Delta_s}{\partial T} < 0$, $\frac{\partial \Delta_e}{\partial C} > 0$, $\frac{\partial \Delta_s}{\partial C} > 0$. The expected profit of the ISV by joining the platform is

$$\pi^y = \pi_e + \pi_s - (\Delta_e + \Delta_s) p^y (1 - \theta) \tag{2.2}$$

The ISV chooses to partner as long as $\pi^y - \pi^n > 0$. Let the relative benefit of joining the platform ecosystem be

$$S = \pi^y - \pi^n = \pi_s - \Delta_e (p^y - p^n)(1 - \theta) - \Delta_s p^y (1 - \theta) \tag{2.3}$$

Taking partial derivatives of S with respect to the ISV's IPR strength, downstream complementary capabilities, their interactions, the platform's penetration into the ISV's target industries, and intensity of product market competition between the ISV and the platform owner, it is straightforward to see that

$$\frac{\partial S}{\partial \theta} = \Delta_e (p^y - p^n) + \Delta_s p^y > 0 \tag{2.4}$$

$$\frac{\partial S}{\partial T} = \frac{\partial \pi_s}{\partial T} - \frac{\partial \Delta_e}{\partial T} (p^y - p^n)(1 - \theta) - \frac{\partial \Delta_s}{\partial T} p^y (1 - \theta) > 0 \tag{2.5}$$

$$\frac{\partial^2 S}{\partial \theta \partial T} = \frac{\partial \Delta_e}{\partial T} (p^y - p^n) + \frac{\partial \Delta_s}{\partial T} p^y < 0 \tag{2.6}$$

$$\frac{\partial S}{\partial P} = \frac{\partial \pi_s}{\partial P} > 0 \tag{2.7}$$

$$\frac{\partial S}{\partial C} = \frac{\partial \pi_s}{\partial C} - \frac{\partial \Delta_e}{\partial C}(p^y - p^n)(1-\theta) - \frac{\partial \Delta_s}{\partial C} p^y (1-\theta) < 0 \tag{2.8}$$

(2.4) – (2.8) correspond to the five hypotheses H1 – H5, respectively, that I propose in the next section.

Further, it is straightforward to show that these results continue to hold or are strengthened if downstream complementary capabilities or intensity of product market competition between the ISV and the platform owner also affect the probability that the platform owner imitates the ISV's innovation by assuming $\frac{\partial p^y}{\partial T} \leq \frac{\partial p^n}{\partial T} \leq 0$, $\frac{\partial p^y}{\partial C} \geq \frac{\partial p^n}{\partial C} \geq 0$. Essentially, these assumptions state that: (1) the additional risk of imitation $(p^y - p^n)$ due to partnering is (1) non-increasing in T, and (2) non-decreasing in C, both are reasonable. Specifically, I have

$$\begin{aligned} \frac{\partial S}{\partial T} &= \frac{\partial \pi_s}{\partial T} - \frac{\partial \Delta_e}{\partial T}(p^y - p^n)(1-\theta) - \frac{\partial \Delta_s}{\partial T} p^y (1-\theta) \\ &\quad - \Delta_e \left(\frac{\partial p^y}{\partial T} - \frac{\partial p^n}{\partial T} \right) (1-\theta) - \Delta_s \frac{\partial p^y}{\partial T}(1-\theta) > 0 \end{aligned} \tag{2.5'}$$

$$\frac{\partial^2 S}{\partial \theta \partial T} = \frac{\partial \Delta_e}{\partial T}(p^y - p^n) + \frac{\partial \Delta_s}{\partial T} p^y + \Delta_e \left(\frac{\partial p^y}{\partial T} - \frac{\partial p^n}{\partial T} \right) + \Delta_s \frac{\partial p^y}{\partial T} < 0 \tag{2.6'}$$

$$\begin{aligned} \frac{\partial S}{\partial C} &= \frac{\partial \pi_s}{\partial C} - \frac{\partial \Delta_e}{\partial C}(p^y - p^n)(1-\theta) - \frac{\partial \Delta_s}{\partial C} p^y (1-\theta) \\ &\quad - \Delta_e \left(\frac{\partial p^y}{\partial C} - \frac{\partial p^n}{\partial C} \right) (1-\theta) - \Delta_s \frac{\partial p^y}{\partial C}(1-\theta) < 0 \end{aligned} \tag{2.8'}$$

2.5. Theory and Hypotheses

In this section I detail my theory and hypotheses. The simple model of the last section describes how the payoffs to partnering with a software platform owner are conditioned by factors such as IP protection, downstream capabilities, the platform's market penetration, and the extent of product competition between the platform owner and an ISV. Below I describe a set of hypotheses that map to the comparative statics in the model.

2.5.1. Intellectual Property Protection

Inter-firm collaborative relationships that involve a technology component are often characterized by extensive knowledge sharing and exchange (Khanna et al. 1998; Mowery et al. 1996). To the extent that one party in the alliance relationship is unaware of the other's knowledge acquisition intentions, or unable to define or control the extent of knowledge leakage, inter-firm collaboration may result in the loss of core competencies and expropriation of its innovation by collaborators if the transferred knowledge is not protected by any appropriation mechanism (Bresser 1988; Heiman and Nickerson 2004).

Such knowledge transfer is likely to occur in partnerships between an ISV and a software platform owner. For example, during the course of certification in the enterprise software industry the ISV may reveal sensitive information on its proprietary technology, its codification of business processes or best practices that embody industry-specific knowledge, or a particular design interface. A platform owner who acquires such knowledge may replicate or invent around the innovations of the ISV, absorb the distinct features of the ISV’s application programs into its own software product suite, and compete directly with the ISV by invading its product markets.

ISVs can employ several mechanisms to protect their inventions, including legal mechanisms (patents, copyrights, and trade secrets), first mover advantages, and the ownership of complementary marketing and manufacturing capabilities (Cohen et al. 2000). While surveys suggest that the exploitation of first mover advantages is the most effective appropriation mechanism in the software industry (Graham et al. 2009), this mechanism may be less effective among firms who partner. Historically, copyrights have been commonly regarded as an effective legal form of protection for computer software (Graham and Mowery 2003; Graham et al. 2009; Menell 1989); however a series of legal decisions throughout the 1980s and 1990s has recently strengthened the intellectual property protection afforded by patents, especially for “business methods” (Cockburn and MacGarvie 2006; Graham and Mowery 2003; Lerner and Zhu 2007). As a result, both patents and copyrights can be used by the ISV to defend its intellectual property (Graham et al. 2009). While knowledge leakage may increase the risk of imitation associated with partnering, I expect stronger IP protection to decrease the potential loss of revenues arising from a platform owner’s market invasion. Therefore, other things equal, increases in IP protection will be associated with greater expected payoffs to partnering. I hypothesize

HYPOTHESIS 1 (H1). *The better an ISV’s innovations are protected by intellectual property rights, the more likely that it will partner with the software platform owner.*

2.5.2. Downstream Complementary Capabilities

Since Teece's (1986) seminal work, strategy research on innovation appropriation has emphasized the importance of the ownership of specialized downstream capabilities (Arora and Ceccagnoli 2006; Ceccagnoli and Rothaermel 2008; Gambardella and Giarratana 2006). ISVs with downstream capabilities will be more successful in appropriating returns from their innovations, even when potential competitors such as the platform owner successfully enter their product space (Graham et al. 2009). For one, in the case of the partnership between ISVs and SAP, strong downstream marketing capability will enhance the returns to access to SAP's large installed base. In particular, the success of converting the platform owner's extant users into an ISV's customers will depend on downstream capabilities such as brand image, downstream marketing, distribution and service capability.

For similar reasons, the losses from imitation of the ISV's innovation will be lower in the presence of downstream capabilities. An ISV with brand image and marketing capability will be better able to defend their market than firms without such capabilities. Further, these capabilities may be difficult to replicate by the platform owner. While knowledge embedded in products can be codified by physical, formal or formulaic means, knowledge embedded in business practices or downstream service and consulting activities is often stored in human's head and is less susceptible to unintended leakage (Heiman and Nickerson 2004). For example, implementation of enterprise software often requires idiosyncratic adaptations to user needs that will be embedded in the implementation and configuration of the software products, and related consulting and service activities (Hitt et al. 2002). Such downstream knowledge and capabilities are more costly to transfer across firm boundaries (Brown and Duguid 2001; Von Hippel 1994b) and may also act as a barrier to entry. Therefore, I propose

HYPOTHESIS 2 (H2). *The stronger an ISV's downstream capabilities, the more likely that it will partner with the software platform owner.*

2.5.3. IP Protection and Downstream Capabilities

Researchers have examined and recognized the substitution effect among different types of IP strategies (Graham and Somaya 2006). For example, filing a patent necessitates information disclosure which makes maintaining the secrecy of an innovation difficult; thus, the use of patents and trade secrecy tend to be substitutes in IPR protection (Friedman and Landes 1991; Horstmann et al. 1985; Teece 1986). In this study I argue that formal IP protection is less crucial to the expected payoff from partnering in the presence of strong complementary downstream capabilities. While the exact payoffs and marginal effects are described in my model in the previous section, here I sketch an intuitive argument. As noted in Hypothesis 1, patents and copyrights reduce the likelihood of knowledge expropriation. However, Hypothesis 2 suggests that the negative effect of potential knowledge expropriation will be weaker in the presence of complementary downstream capabilities. It follows immediately that the benefits of patents and copyrights as a means to protect knowledge when partnering (and, consequently the expected payoff to partnership) will be weaker in the presence of strong complementary downstream capabilities. Therefore, I propose

HYPOTHESIS 3 (H3). *The impact of an ISV's IP protection on the likelihood that it will partner with the software platform owner is lower when the ISV has strong downstream capabilities.*

2.5.4. Platform Penetration into the ISVs' Target Industries

Despite the risks of IPR expropriation, ISVs will partner with the platform owner to gain access to its installed base. Depending upon the software market, ISVs may still be able to market stand-alone application programs and make sales even in the absence of association with a platform. However, partnership with the platform owner signals compatibility of the ISV's product with the platform, increasing the expected utility of purchasing the ISV's product for platform customers and thereby increasing the ISV's sales to the platform's installed base. Thus, the payoff to partnership will be increasing in the size of the platform's installed base.

Increases in the platform's installed base will increase the payoff to partnership with the platform owner for other reasons if there are significant (direct or indirect) network effects associated with the platform owner's product. For one, buyers may be willing to pay more for products that are compatible with a larger network (Besen and Farrell 1994; Brynjolfsson and Kemerer 1996; Liu et al. 2008). Further, in industries that are characterized by network effects or complementary products, an industry standard often emerges (Besen and Farrell 1994; David and Greenstein 1990; Gandal 1995; Metcalfe and Miles 1994). In those industries, being associated with the industry standard is critical for the survival and success of producers of complementary products that are based on the chosen standard or platform (Suárez and Utterback 1995). The ISV's prediction of which platform will become dominant critically depends on the platform's installed base. Therefore, I propose

HYPOTHESIS 4 (H4). *Greater market penetration by the software platform owner into an ISV's target industries is associated with higher likelihood that the ISV will partner with the software platform owner*.

2.5.5. Competition between the Platform Owner and the ISV

The effect of competition on partnership success is well documented in the strategy literature (Gimeno 2004). Although competitive collaboration, or co-opetition, could generate mutual benefits and result in a win-win situation through sharing complementary resources or acquiring new skills and capabilities by organizational learning (Hamel et al. 1989), empirical evidence often suggests the fragility of such inter-firm relationship between rivals. For example, Kogut (1989) argues that competitive conflicts impair the stability of cooperative agreements due to imitation of partners' technology and competition in the downstream market, and cooperative incentives could be offset by industry structural conditions that may promote rivalry among the partners.

In this study, I examine one facet of competition between the ISV and the platform owner: closeness in product market space. Competition between the ISV and the platform owner will be greater when the products of the two vendors are more similar. Further, the losses from imitation of the ISV's product will be higher when the two vendors offer more similar products. Since partnering increases the probability of imitation by the platform owner, these losses will in expectation be higher with partnering. That is, the expected costs from increased competition with the platform owner will be higher under partnering.

Anticipating these effects, an ISV with a more similar product portfolio to the platform owner will have an attenuated incentive to join the ecosystem. Therefore, I propose

HYPOTHESIS 5 (H5). *The greater the similarity of products with the platform owner, the less likely that the ISV will partner with the software platform owner.*

2.6. Methods and Measures

2.6.1. Sample

I test my theoretical predictions using a longitudinal data set of 1201 ISVs over the period of 1996-2004. My sample begins in 1996 since I observe no such partnerships in my sample prior to 1996 (more details will be provided later in the section of variable definition).

A study of partnerships within the enterprise software industry based solely on publicly traded firms in the COMPUSTAT universe is likely to suffer from a serious selection bias: well-established public software firms may have starkly different incentives to form inter-firm linkages from those of privately held new ventures or start-ups (Cockburn and MacGarvie 2006; Shan 1990); moreover, the majority of ISVs are privately owned. However, collecting comprehensive, reliable information on small, private firms over an extended time period is extremely difficult. In this study I use the CorpTech directory of technology companies. The dataset has detailed information on 100,000 public and private firms, including information on geography, sales and employees, product offerings, industry classification, ownership, funding sources and executives.

To construct a representative sample of ISVs in enterprise software industry that are likely to form partnerships with SAP, I compare the product characteristics between existing SAP partners and those in the CorpTech data set. The first step involves retrieving a complete list of SAP's current software partners. SAP publishes the directory of all its certified partners as well as their solution offerings on its Internet portal,[4] and a searching using the terms "*Country: United States*" and "*Partner Category: Independent Software Vendor*" yields a list of 411 software firms that are existing SAP partners. Comparing this list with the CorpTech directory generates 206 matching records. One of the key advantages of the CorpTech database is that it records the product portfolio of each company and assigns each product into 3-digit product classes.[5] I retrieve distinct 2-digit level product classification codes of the 206 existing SAP software partners, and try to find the most frequent software product codes in the product portfolio of the partnering firms. Two product codes, SOF-MA (manufacturing software, 61 firms) and SOF-WD (warehousing/distribution software, 44 firms), emerge as the leading products that partnering firms produce. I subsequently define my sample as firms that operate in the United States, with primary industry of computer software (identified by CorpTech company primary industry code "SOF"), and that have ever produced SOF-MA or SOF-WD products during the sampling period. The query generates 2175 ISVs from the CorpTech database. As I am primarily interested in the drivers of alliance formation for small, entrepreneurial software companies, I further remove established incumbents from my sample firms. Consistent with prior literature (Petersen and Rajan 1994; Puranam et

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[4] http://www.sap.com/ecosystem/customers/directories/searchpartner.epx

[5] CorpTech uses a proprietary, 3-digit level product classification system. For example, a product coded as "AUT-AT-DA" means "Factory automation"-"Automatic test equipment"-"Analog/digital component".

al. 2006), I refine the ISV firms to those established after 1980, with sales less than $500 million and number of employees less than 1000 throughout the sampling period. As an additional check, I manually go through the business description field in the CorpTech data set for each company, and visit the website of each firm (if the company no longer exists, I visit the archival web site from www.archive.org instead) to confirm that the ISVs indeed produce enterprise software applications, and delete those that do not fit the profile. My final sample consists of 1201 ISV firms.

2.6.2. Dependent Variable

The dependent variable is whether an ISV firm enters into partnership with SAP and develops platform compliant application software for the first time in a particular year. As my study is longitudinal in nature, using the list of partnering ISV firms retrieved from SAP's web portal as the dependent variable is problematic for several reasons. First, the list of partnering ISVs reflects only the current snapshot but fails to capture historical partnering events. SAP's policy requires that partnering ISVs to recertify their products for compatibility and renew their partnerships every 3 years. Failure to recertify would result in removal of the company from the SAP's web portal. Second, the enterprise software industry experiences considerable entry and exit during the sampling period, with some of the once partnering firms being acquired by or merged with other companies. Third, information about the exact date on which the partnership is formed is missing from SAP's web portal, which makes the determination of the year of partnership formation impossible.

As an alternative to overcome the aforementioned difficulties, I identify the alliance formation events with SAP through press releases. To test the viability of this approach, I experiment with the existing partner list retrieved from SAP web portal to see whether a matching press release could be found for each firm. I use the search term "*COMPANY(SAP) and COMPANY(XYZ) and BODY(certification or certify or certified or partner or partnership or alliance)*" to search against the Lexis/Nexis news wire services database, where "*XYZ*" is replaced by the ISV's name. For a random sample (60 firms) of the 411 existing SAP partners, I am able to find a matching news release for over 98% of the firms, which confirms the validity of using press releases to determine the formation of alliances. I subsequently apply the same algorithm to my sample universe and retrieve 148 alliance events between sample ISVs and SAP. It is notable that there has been no such alliance activity prior to 1996. I further exclude pure joint development, marketing or distribution alliances and alliances after 2005 from the list. In addition, for ISVs that have multiple SAP alliance press releases (due to certification for multiple products, new versions of same product, or different interface certifications), I use the first such event as the time the ISV joins SAP's platform ecosystem. I identify a total of 39 first-time alliance events for the sample ISVs.

The observation unit for the dependent variable is firm-year, with the variable set to 1 if a first-time alliance is formed in that year; 0 otherwise. I treat partnering with SAP as an absorbing state, as there are no obvious reasons for a partnering ISV to make its certified product incompatible with SAP's platform thus quitting from the platform ecosystem. Post-alliance observations are deleted as the firms are no longer exposed to the hazard of forming partnership with SAP. The 1201 sample ISV firms generate 6381 firm-year observations. The data is structured as an unbalanced panel.

2.6.3. Independent Variables

Patents. I generate the ISV patent stock variable by using the U.S. Patent and Trademark Office (USPTO) CASSIS Patents BIB database. While the decision to partner will be influenced by a vendor's stock of *software* patents, some vendors may have inventions in related areas such as manufacturing control or data acquisition equipment. Accordingly, I restrict my patent measure to software patents only (however my results are similar if I include both software and non-software patents). To identify software patents, prior research has used USPTO class-subclass combinations (Graham and Mowery 2006; Hall and MacGarvie 2006) while others have used a Boolean query that searches for keywords in patent text (Bessen and Hunt 2004). I follow Hall and MacGarvie (2006) in using the intersection of these two methods to identify software patents.[6] As a robustness check, I also use the union of the software patent sets identified by the two methods and derive alternative measures; my empirical results are robust to the different measures of patents stock. To account for the heterogeneity in the impact and importance of innovation, I use Hall-Jaffe-Trajtenberg weighted stock of patent grants by incorporating forward patent citations (Hall et al. 2001).

Patent effectiveness. An ISV's stock of patents is partly determined by its patent propensity, which may in turn be influenced by variations in the effectiveness of patent protection in the different sub-segments in the software industry in which the ISV participates (Arora and Ceccagnoli 2006). To examine whether variance in *patents* does indeed capture sub-segment variation in the strength of patent protection, I construct the

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[6] For a survey of various methods of identifying software patents in USPTO patent data, see Layne-Farrar (2005).

variable *patent effectiveness* obtained from the patent inventor survey jointly conducted by Georgia Tech and the Japanese Research Institute of Economy, Trade and Industry (RIETI).[7] The survey asks patent inventors to assess the importance of patents in protecting their firm's competitive advantage for the commercial product/process/service based on the patented invention in a 5-point Likert scale. I computed averages of the Likert responses at the 5-digit international patent class (IPC) level and linked to my data by the corresponding IPC class of the patents owned by ISVs in my sample. The resulting firm-level patent effectiveness score represents the average of patent effectiveness scores of all patents owned by the focal firm. A similar measure has been frequently used in the literature on innovation and appropriability as a summary indicator of the net benefits from patenting (Arora and Ceccagnoli 2006; Cohen et al. 2000; Gans et al. 2002).

Copyrights. The cumulative number of software copyrights for each firm-year is obtained from the United States Copyright Office. I retrieve the complete set of copyrights that are described as "computer files" within that office's classification scheme.

Downstream capability. One important measure of a firm's marketing capability is trademarks (Gao and Hitt 2004), which is a word, phrase, symbol or design, or combination of words, phrases, symbols or designs that identifies and distinguishes the source of the goods or services of one party from those of others. In this study I use the total number of software trademarks as a proxy for downstream marketing capabilities (Fosfuri et al. 2008), and obtain the data from the USPTO CASSIS Trademarks BIB

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[7] The survey was conducted in 2008 and was directed to the inventors of a random sample of the granted U.S. patents filed between 2000 and 2003 and included in the OECD's Triadic Patent Families, e.g., filed with both the Japanese Patent Office (JPO) and the European Patent Office (EPO) and granted in the United States Patent and Trademark Office (USPTO). More information on the survey can be found in Jung (2009) and Walsh and Nagaoka (2009).

database. For each trademark listed on USPTO, a Live/Dead indicator is assigned, which could be Registered, Pending or Dead. Dead marks may have been abandoned, cancelled, or expired. Application abandonment usually happens as a result of failure to respond to an Office Action or a Notice of Allowance. Canceled trademarks are due to the registrant's failure to file the required continued use affidavit under Section 8 of the Trademark Act. An expired trademark results from the registrant’s failure to renew the trademark registration at the end of the registration period. To construct the trademark variable, I first retrieve all the trademark records for the sample ISVs, including pending and dead records. The next step involves devising a search term to be applied to the “goods and services” description of trademark records to retain only those software trademarks.[8] Afterwards, I determine the life span of each trademark to derive the active trademarks for each firm-year. Pending and abandoned trademarks are removed as a formal trademark registration is never granted. For canceled trademarks, registration date and cancelation date are used to determine the life span. For expired trademarks, I calculate the expiration date as 10 years after the registration date, or 10 years after the latest renew date if there has been any renewal record for the trademark.

Target industry penetration. In order to construct a valid measure of SAP’s market penetration in the ISV’s target industries, I obtain SAP installation data in the United States from Harte-Hanks CI Technology Database, and calculate SAP’s penetration rate in the companies of the CI database by each industry-year. Harte Hanks surveys over 300,000 establishments in the United States per year on their use of information

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[8] After conducting thorough content analysis of 100 software trademarks, I construct the key words as: “computer application” or “computer software” or “computer program” or “operating software” or “business application” or “software application” or “application software” or “enterprise system” or “accounting system” or “application program”.

technology; my sample of data from the CI database includes all establishments with over 100 employees.[9] For each company in the CI database, I treat it as penetrated by SAP after its first installation of any module of SAP's enterprise software suite. To define the industries of SAP's user firms, I find that SAP uses a "master code" system to classify its customers, which is composed of indicators for 33 vertical industries, such as aerospace & defense, banking, and chemical, to mention a few. I match the SAP master codes with Standard Industrial Classification (SIC) codes (the match table is available upon request), and determine the master code for each company in the CI database by referencing the table. I then calculate employee-weighted penetration rate in the CI universe of firms for each master code-year as a measure of the size of SAP's network.[10] Next, I read the target industries description of the 1201 sample ISV firms and create master code dummies for each of them (CorpTech data has a field that describes the industries that a firm sells its product and service to). Variable *Target industry penetration* is defined as the average of SAP penetration rate across all the industries that a particular ISV serves. However, for a small portion of the ISV firms, the CorpTech database does not give an explicit target industry description, but rather describe the firm as "selling products and services to multiple industries". In that case, I use the average SAP penetration rate across all 33 industries as the value of the penetration variable. I also create an indicator variable *multiple industry* to control for potential bias introduced by this coding. The

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[9] The CI database has been extensively used in the information systems and economics fields to measure IT investment (Brynjolfsson and Hitt 2003; Dewan et al. 2007), including investment in enterprise software (Hitt et al. 2002). Prior work has shown that this database is quite representative of the distribution of large establishments (the ones most likely to use SAP) in the U.S. economy (Forman et al. 2005).

[10] As software license subscription is usually based on the number of concurrent users (Hitt et al. 2002), I use employee-weighted penetration rate instead of sales-weighted.

variable is set to 1 if a firm's precise target industry is not given in the CorpTech database.

Competition. The variety of its product portfolio is indicative of a software firm's scope of economic activity (Cottrell and Nault 2004), and the similarity in product market space between the ISV and SAP (and similarly, the intensity of competition) can be measured by how much their application product offerings overlap. Product portfolio information is obtained from the CorpTech database. The CorpTech database has an internal "2-digit" classification system that indicates the products produced by software firms (for example, Software-Accounting and Software-Warehousing/Distribution are examples of "2-digit" classes). I retrieve the distinct 2-digit product codes for each ISV in each year, and compare those with SAP's 2-digit product portfolio in the same year. 2-digit product codes are used as a proxy for product lines because they correspond very well to the functional modules of enterprise software. The variable *product overlap* is defined as the ratio of the number of common product lines (produced by both an ISV and SAP) to the number of ISV's product lines for each firm-year. As a robustness check, I also construct alternative measures of product overlap by dividing the number of common product lines by the number of SAP's product lines for each firm-year and the results are similar. Note *product overlap* is a time-varying covariate as an ISV may have entered into a related software market segment, introduced new software product lines, or exited from certain product markets.

2.6.4. Control Variables

I control for various firm level drivers that could influence an ISV's decision to join the SAP ecosystem. Firm size is measured by an ISV's annual *sales*, obtained directly from the CorpTech database. Firm *age* is derived by referencing the year that an ISV was established. To allow for nonlinear effect of age, I add both linear and quadratic terms of age. I also add an ownership indicator variable to allow for different propensities for alliance formation between public and privately held companies. The variable *public* is set to 1 if an ISV is a publicly traded company; 0 otherwise.

I also include controls for firm funding sources. Software firms' source of capital is likely to affect their decision to form partnership for several reasons. First, software firms backed by corporate investment or venture capital are more likely to accumulate social capital that is unavailable to other start-ups. In addition, bargaining intermediaries such as venture capitalists can reduce the cost of forging a contract between the parties and so increase the likelihood of partnership (Colombo et al. 2006; Gans et al. 2002). The CorpTech database classifies the funding sources into corporate investment, private investment or venture capital investment. I create 3 dummy variables, *cinvest*, *pinvest* and *vinvest*, respectively, to control for the effect of firms' source of funding on alliance formation.

As a control for ISVs' innovative capability, I obtain the ISVs' cumulative number of *publications* in academic journals or conferences in each year via the Web of Science database. To account for the importance of publications, I also retrieve forward citation data for all the publications and construct citation weighted publications.

2.6.5. Model Specification

I use hazard models to study the decisions of ISVs to partner with SAP. The hazard model (also referred to in various literatures as survival, duration or event history model) is appropriate since it relaxes normality assumption in most linear regressions and allows corrections for right censoring, truncation, late entry, time-varying covariates and duration dependence (Cameron and Trivedi 2005). Hazard analysis models the underlying and unobserved hazard rate, which is the instantaneous rate at which hazard events occur at time *t*, given that the subject under study has survived until time *t*.

I chose the Cox proportional hazard model as a starting point for empirical analysis. The Cox proportional hazard model is a semi-parametric specification that makes no assumption about the shape of the baseline hazard over time, and assumes that covariates multiplicatively shift the baseline hazard function. Applying the hazard model to my specification, I have $h_i\left(t\middle|\boldsymbol{x}_{i,t-1}\right) = h_0(t)\ exp\left(x_{i,t-1}\boldsymbol{\beta}\right)$, and

$$\begin{aligned} x_{i,t-1}\boldsymbol{\beta} = \beta_0 patent_{i,t-1} + \beta_1 coppyright_{i,t-1} + \beta_2 trademark_{i,t-1} \\ + \beta_3 patent \times trademark_{i,t-1} + \beta_4 copyright_{i,t-1} \\ \times trademark_{i,t-1} + \beta_5 SAP\_penetration_{i,t-1} \\ + \beta_6 product\_overlap_{i,t-1} + \beta_7 sales_{i,t-1} + \beta_8 age_{i,t-1} \\ + \beta_9 age_{i,t-1}^2 + \beta_{10} public_{i,t-1} + \beta_{11} cinvest_{i,t-1} \\ + \beta_{12} pinvest_{i,t-1} + \beta_{13} vinest_{i,t-1} + \beta_{14} publication_{i,t-1} \end{aligned} \tag{2.9}$$

Where $h_i\left(t\middle|\boldsymbol{x}_{i,t-1}\right)$ is the conditional instantaneous hazard rate for ISV i in year *t*, and $h_0(t)$ is the unspecified baseline hazard in year *t*. I lag all independent variables by one year to allow for causal interpretation. Note there is no intercept in the Cox model as it is subsumed into the baseline hazard function and unidentified.

As an alternative estimation method, I use a (firm) fixed effects linear probability model to study the event history (Wooldridge 2001), allowing for firm-level unobserved heterogeneity. I follow prior literature in using the fixed effects linear probability model to study outcomes with limited dependent variables (Forman et al. 2009; Gowrisankaran and Stavins 2004; Miller and Tucker 2009) due to the known difficulties of controlling for panel-level unobservables using fixed effects in nonlinear models such as the probit or logit.[11] In order to estimate the linear probability model, the data are arranged into cross-sectional time series format. The unit of observation is a firm-year, and the event is the binary decision that an ISV joins the platform ecosystem of SAP. If the event happens for an ISV in a particular year, all post-event observations are removed from the sample as I assume partnering is an absorbing state. Otherwise the observation for the ISV is right censored (event does not occur during the sampling years) and all years of data are included.

2.7. Results

2.7.1. Findings

Table 2.1 provides summary statistics of the variables and controls, as well as the correlation matrix. The descriptive statistics indicate that ISVs are characterized by significant heterogeneity along key dimensions, such as ownership of IPRs (*copyrights* range from 0 to 498), downstream capability (*trademarks* range from 0 to 23), SAP penetration (ranges from 0% to 93%), and product portfolio overlap (ranges from 0% to 100%). It is worth noting that *patents* are far less frequently used by start-up ISVs in the enterprise software industry (with mean of .14 patent per firm) than *copyrights* (mean

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[11] For a full discussion of these issues, see Wooldridge (2001). Unconditional fixed effects provide inconsistent estimates using probit or logit models because of the well-known incidental parameters problem. Further, conditional fixed effects models drop panels where there is no variation in the dependent variable—in my setting, this would include any ISV that does not eventually become a partner.

2.03 per firm), consistent with prior literature suggesting that copyrights remain an important source of IP protection for enterprise software since most innovations are in business processes, routines and best practices that may not be amenable to patenting (Mann and Sager 2007; Menell 1989).

Results from Cox proportional hazard survival models are presented in Table 2.2. In all regressions I use the log transformation of patents, patent effectiveness, copyrights, trademarks and sales (that is, *log(1+x)* to avoid taking log of zeros except for patent effectiveness, which is strictly positive) to control for over dispersion and skewness in these variables. Variables are entered into the regression sequentially with the log likelihood reported for each model. Column 1 presents the baseline model where only variables for IP protection, downstream capabilities and publications are included. In column 2 I add interactions between IP protection and downstream capability. Column 3 includes the measurement of SAP's penetration rate in the ISV's target industries, as well as product portfolio overlap between SAP and ISVs. I add the full set of control variables in Column 4. Finally, in column 5 I add patent effectiveness to control for potential differences in patent propensities among firms.

Table 2.1 Summary Statistics and Correlation Matrix

	Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Partner$_{i,t}$	0.006	0.078	0	1	1.000													
2	Patents$_{i,t-1}$	0.138	0.682	0	13	0.028	1.000												
3	Patent effectiveness$_{i,t-1}$	1.028	0.239	1	5	0.047	0.472	1.000											
4	Copyrights$_{i,t-1}$	2.031	13.187	0	498	0.010	0.009	0.003	1.000										
5	Trademarks$_{i,t-1}$	0.806	2.009	0	23	0.061	0.334	0.126	0.279	1.000									
6	SAP penetration$_{i,t-1}$	0.226	0.153	0	0.932	0.023	0.092	0.027	0.007	0.089	1.000								
7	Product overlap$_{i,t-1}$	0.418	0.327	0	1	-0.026	-0.046	-0.024	-0.014	-0.073	-0.115	1.000							
8	Age$_{i,t-1}$	12.947	5.680	0	24	-0.049	-0.111	-0.096	0.069	0.005	0.045	0.022	1.000						
9	Sales$_{i,t-1}$ (millions)	6.967	13.980	0	169	0.077	0.213	0.124	0.292	0.356	0.032	-0.032	-0.044	1.000					
10	Public$_{i,t-1}$	0.058	0.233	0	1	0.032	0.227	0.122	0.062	0.213	0.022	-0.031	-0.047	0.403	1.000				
11	Cinvest$_{i,t-1}$	0.041	0.198	0	1	0.014	0.042	0.003	-0.021	0.045	0.023	0.015	-0.115	0.113	0.054	1.000			
12	Pinvest$_{i,t-1}$	0.520	0.500	0	1	-0.037	-0.042	-0.039	-0.011	-0.050	0.024	0.029	-0.146	-0.095	-0.027	-0.061	1.000		
13	Vinvest$_{i,t-1}$	0.114	0.318	0	1	0.079	0.121	0.071	-0.008	0.104	0.109	0.017	-0.332	0.152	0.138	0.073	-0.070	1.000	
14	Publication$_{i,t-1}$	0.616	5.532	0	137	0.000	-0.003	-0.004	0.000	0.032	0.039	0.005	0.045	0.052	0.079	-0.015	-0.018	0.040	1.000

Notes.
Number of firms: 1201; Number of observations: 6381.

Table 2.2 Survival Analysis, Cox Proportional Hazard Model

Variables	(1)	(2)	(3)	(4)	(5)
Patent	0.158	0.279*	0.226	0.124	-0.0217
	(0.104)	(0.153)	(0.157)	(0.169)	(0.204)
Patent effectiveness					1.826*
					(1.103)
Copyrights	0.142	0.569***	0.607***	0.658***	0.663***
	(0.156)	(0.208)	(0.212)	(0.219)	(0.219)
Trademarks	0.803***	1.276***	1.205***	0.922***	0.929***
	(0.213)	(0.256)	(0.257)	(0.294)	(0.292)
Patents × Trademarks		-0.121	-0.107	-0.0755	-0.0463
		(0.0997)	(0.0992)	(0.109)	(0.110)
Copyrights × Trademarks		-0.465**	-0.485**	-0.567***	-0.571***
		(0.200)	(0.200)	(0.211)	(0.208)
SAP penetration			3.417***	2.709**	2.790**
			(1.212)	(1.322)	(1.342)
Multiple industry			0.880**	0.825**	0.832**
			(0.393)	(0.384)	(0.386)
Product overlap			-0.601	-0.941*	-0.970*
			(0.531)	(0.547)	(0.550)
Public				-0.595	-0.570
				(0.540)	(0.539)
Age				-0.106	-0.110
				(0.119)	(0.120)
Age^2				0.00245	0.00259
				(0.00539)	(0.00539)
Sales				0.650***	0.648***
				(0.174)	(0.172)
Corporate invest				0.110	0.111
				(0.627)	(0.627)
Private invest				-0.702*	-0.731*
				(0.373)	(0.375)
VC invest				0.945**	0.924**
				(0.374)	(0.376)
Publication	0.259	0.157	0.111	0.140	0.173
	(0.327)	(0.341)	(0.367)	(0.384)	(0.379)
No. of firms	1201	1201	1201	1201	1201
Observations	6381	6381	6381	6381	6381
Log likelihood	-250.99388	-247.01567	-240.66373	-221.04926	-219.83565

Notes.

Standard errors in parentheses.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Examining the results of the final model, I find support for H1. Increases in the stock of copyrights are positively associated with an ISV's hazard of partnering with SAP, indicating that copyrights are an important mechanism employed by ISVs to prevent knowledge expropriation. Although the stock of patents is not found to be significantly related to the decision of an ISV to join the partnership, I do find evidence that the effectiveness of patent protection increases an ISV's propensity to partner. This is not surprising since the stock of patents granted to a particular firm is driven by multiple factors such as patent propensity (itself driven by patent strength), technological opportunities, and R&D productivity (Griliches 1990). Patent effectiveness is a more direct, albeit survey-based, measure of the strength of patent protection. ISVs with few or no patents should have a low propensity to patent because this legal mechanism may not be effective for appropriating innovation rents. However, my theory implies that firms with stronger patents are expected to enforce their patents with a greater probability of success. Consistent with expectations, I find that ISVs holding patents in technological sub-classes where patent protection is considered more effective have greater incentives to partner due to greater abilities to safeguard themselves against the potential imitation by the platform owner. The results clearly show that the effect of *patents* is significantly reduced when patent effectiveness is included, suggesting that this variable is indeed capturing, albeit imperfectly, variations in the underlying strength of patent protection within segments of the enterprise software industry. I also find a strong positive effect of trademark stock on the partnership formation across specification and models, confirming hypothesis H2. Consistent with my expectation, I also find evidence that IP protection and downstream capabilities act as substitutes for one other in their influence on partnership formation, and the effect is more pronounced for copyrights than for patents, partially confirming H3.

A numerical example would illustrate the main effects and interaction effects of IPR protection and trademarks. To examine the marginal effects, I consider a log transformed variables x_i in the Cox proportional hazard model. Suppose I increase x_i by 100%, while holding other variables constant, the hazard ratio is

$$\frac{h(t|2x_i, \boldsymbol{x_{-i}})}{h(t|x_i, \boldsymbol{x_{-i}})} = \frac{\exp[\beta_i \ln(2x_i)]}{\exp(\beta_i ln x_i)} = \exp(\beta_i ln2) = 2^{\beta_i}$$

For example, if the effectiveness of patent protection is doubled while everything else remains unchanged, the likelihood of partnering with SAP will be increased by $2^{1.826} - 1 = 255\%$.

Now consider a firm that has the mean value of log transformed copyright (.378, correspond to copyright=.46) and the mean value of log transformed trademarks (.333, correspond to trademark=.40). If the firm doubles its stock of copyrights while holding other variables constant, the hazard ratio becomes $2^{[.663+(-.571)\times.333]} = 2^{.473} = 1.388$, which means a 39% increase in the hazard. Similarly, if the firm doubles its stock of trademarks while holding other conditions unchanged, the hazard ratio becomes $2^{[.929+(-.571)\times.378]} = 2^{.713} = 1.639$, which translates into a 64% increase in the hazard rate. However, if the firm doubles both its copyrights and trademarks, the hazard ratio becomes

$$
\begin{aligned}
\frac{h(t|2x_1, 2x_2, \boldsymbol{x}_{-1,2})}{h(t|x_1, x_2, \boldsymbol{x}_{-1,2})}
&= \frac{\exp[\beta_1 \ln(2x_1) + \beta_2 \ln(2x_2) + \beta_3 \ln(2x_1) \times \ln(2x_2)]}{\exp(\beta_1 lnx_1 + \beta_2 lnx_2 + \beta_3 lnx_1 \times lnx_2)} \\
&= \exp\{[ln2 + \beta_2 ln2 + \beta_3[(ln2)^2 + ln2 \times lnx_1 + ln2 \\
&\quad \times lnx_2]]\} \\
&= 2^{.663} \times 2^{.929} \\
&\quad \times \exp\{(-.571) \times [(.693)^2 + .693 \times .378 + .693 \times .333]\} \\
&= 1.730
\end{aligned}
$$

which implies a 73% increase in the hazard rate. This is considerably lower than the combination of the direct effect of copyrights and the direct effect of trademarks, 1.388×1.639-1=127% increase, due to the substitution effect (negative interaction) between copyrights and trademarks.

Hypothesis H4 suggests that as SAP's penetration into an ISV's target industries increases, the ISV is more inclined to partner with SAP. This hypothesis is confirmed by my empirical results. A one percent increase in SAP's penetration into ISV's industries is associated with a $\exp(.01 \times 2.790) - 1 = 2.83\%$ increase in the likelihood of partnering.

Hypothesis H5 states that the higher product portfolio overlap with SAP that an ISV has, the less likely that the ISV will join the SAP's platform ecosystem. I find that hypothesis H5 is supported. As an ISV's product overlap with SAP increases by 1%, its likelihood of partnering with SAP decreases by $1 - \exp[.01 \times (-.97)] = .96\%$.

Among the controls, the results suggest the funding sources of ISVs do influence their inter-firm linkage activities. Consistent with prior literature, ISVs that are backed by venture capital are more inclined to partner with SAP, due to their greater access to social capital, stronger bargaining power and lower contract cost. In contrast, ISVs funded by private investment are less likely to access those resources, and therefore have lower chance of partnering with SAP.

2.7.2. Tests for Robustness

Although survival analysis is suitable for modeling event history and my specification of Cox proportional hazard model does not impose restrictions on the baseline hazard function, there are two possible concerns associated with my prior analyses. First, there might be firm-specific unobserved heterogeneity that is correlated with the dependent variable which could lead to inconsistent estimates. For example, better managed or more innovative firms could both have more copyrights and trademarks and also be more likely to partner. Second, my measurements of IP protection using patents and copyrights stocks may be correlated with unobserved drivers of a firm's innovative capability and propensity for adopting formal IP protection strategies. Using a fixed effects model could effectively remove any bias caused by any source of time-invariant unobserved firm-specific heterogeneity.

Table 2.3 presents the results of estimating a standard fixed effects ('within firm') model. Comparing the results with those of Table 2.2, I actually find stronger support for Hypothesis 1, as a significant positive effect is identified for patent stocks after controlling for time-invariant innovation capabilities and patent propensities. I also observe that the positive effect of *patents* is mainly driven by the strength of patent protection. Indeed, when *patent effectiveness* is added to the model, the patent stock itself becomes insignificant. Hypotheses 2 and 3 also hold as before.

While the results for all of my variables measuring IP appropriation are robust to the use of fixed effects, estimates for the effects of penetration and product overlap are weaker. I speculate that this result is driven by the fact that variation in these measures are primarily cross-sectional, while fixed effects models only utilize the within-firm, longitudinal variation to perform the estimation. As it is well known, this can lead to significant loss of efficiency in estimation (Greene 2002). Indeed, a between-firm panel estimation using cross-sectional variations confirms my conjecture and demonstrates a much stronger and significant effect of penetration and product overlap (between estimation results are available upon request).

Table 2.3 Linear Probability Model, Fixed Effects Estimation

Variables	(1)	(2)	(3)	(4)	(5)
Patents	0.00859***	0.00910***	0.00872***	0.00717**	0.00485
	(0.00295)	(0.00331)	(0.00331)	(0.00335)	(0.00350)
Patent effectiveness					0.0291**
					(0.0129)
Copyrights	0.0120***	0.0199***	0.0197***	0.0184***	0.0184***
	(0.00414)	(0.00503)	(0.00503)	(0.00505)	(0.00504)
Trademarks	0.00620*	0.0118***	0.0115***	0.0102**	0.0104***
	(0.00322)	(0.00392)	(0.00393)	(0.00399)	(0.00399)
Patents × Trademarks		-0.000771	-0.000748	-0.00165	-0.000822
		(0.00177)	(0.00177)	(0.00178)	(0.00181)
Copyrights × Trademarks		-0.00675***	-0.00660***	-0.00608**	-0.00645**
		(0.00254)	(0.00254)	(0.00255)	(0.00255)
SAP penetration			0.0149	0.0145	0.0149
			(0.0144)	(0.0144)	(0.0144)
Multiple industry			--	--	--
Product overlap			0.0118	0.0106	0.0103
			(0.00738)	(0.00749)	(0.00748)
Public				0.0506***	0.0499***
				(0.0130)	(0.0130)
Age				0.00323*	0.00337**
				(0.00167)	(0.00167)
Age^2				-9.09e-05**	-9.45e-05**
				(4.27e-05)	(4.27e-05)
Sales				-0.000844	-0.000648
				(0.00266)	(0.00266)
Corporate invest				-0.0167	-0.0149
				(0.0131)	(0.0131)
Private invest				-0.00249	-0.00255
				(0.00638)	(0.00638)
VC invest				0.00228	0.00335
				(0.00994)	(0.00994)
Publication	0.0242***	0.0235***	0.0234**	0.0244***	0.0242***
	(0.00910)	(0.00910)	(0.00910)	(0.00918)	(0.00918)
Constant	0.00501	0.00158	-0.00835	-0.0317	-0.0531**
	(0.00350)	(0.00372)	(0.00671)	(0.0240)	(0.0258)
Year dummies	yes	yes	yes	yes	yes
No. of firms	1201	1201	1201	1201	1201
Observations	6381	6381	6381	6381	6381
R^2 (with fixed effects)	0.5018	0.5026	0.5029	0.5052	0.5057

Notes.
Standard errors in parentheses.
*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

I further explore the robustness of my findings through several alternative models and measurements of the independent variables. In column 1 of Table 2.4 I present results of my baseline Cox hazard model using raw counts of stocks of patents and scientific publications that are unweighted by forward citations. While the measurement of product overlap is normalized by ISVs' product portfolios in Table 2.2 and 2.3, the variable may not capture the extent to which SAP perceives the ISV as a competitor. I replace the variable by normalizing it using SAP's product portfolio and present the results in Column 2 of Table 2.4. In both cases I find the set of results is similar to those in Table 2.2.

Although Cox hazard model has been commonly used in the literature because of its flexibility, the estimates are not always efficient when compared with full parametric models, if the underlining baseline hazard function is known (Cameron and Trivedi 2005). In column 3 of Table 2.4 I present the results from the most commonly used parametric model, the exponential hazard model. Similar results are found as in the Cox proportional hazard model. I also extend the exponential model to account for unobserved heterogeneity, as there could be potential omitted variables that influence alliance formation and which are correlated with the independent variables. Empirically this amounts to the inclusion of a multiplicative idiosyncratic factor, known as a *frailty*, to the hazard function specification (Bruce et al. 2004; Cameron and Trivedi 2005). The unobserved heterogeneity is usually assumed to be gamma or inverse-Gaussian distributed. I present the results of an exponential hazard model with inverse-Gaussian *frailty* in column 4 of Table 2.4. The likelihood ratio test for heterogeneity does not reject the null of no heterogeneity (p=.304), indicating that my set of explanatory variables is sufficiently inclusive. The different models listed in Table 2.4 provide further evidence of the robustness of my results.

2.8. Discussion and Conclusion

2.8.1. Summary of Results and Managerial Implications

Innovation ecosystems have long existed in the computer software industry. Surprisingly, there has been a paucity of empirical studies that examine the incentives of participation and antecedents of the formation of such ecosystems from the perspective of its participants. My study uses a simple model to illustrate the facilitators of and barriers to an ISV's partnering with a platform owner in the enterprise software industry. I present robust empirical evidence that ISVs with better legal protections through intellectual property rights and those with stronger downstream marketing capabilities are more likely to partner. Interestingly, protection of upstream capabilities using formal IPRs and downstream appropriation protection through marketing capabilities substitute for each other in shaping the payoff to partnering. Increases in the size of the platform owner's installed base also increase the payoff to partnering. Further, when the ISV and the platform owner compete in similar markets, the risks of platform owner's entry discourage such partnership.

Table 2.4 Alternative Measures and Models

Variables	(1) Alternative measure of patent and publications (unweighted)	(2) Alternative measure of product overlap (normalized by SAP)	(3) Exponential hazard model	(4) Exponential hazard with unobserved heterogeneity
Patents	0.0549	0.119	0.103	0.113
	(0.666)	(0.171)	(0.169)	(0.183)
Copyrights	0.660***	0.683***	0.693***	0.764***
	(0.221)	(0.222)	(0.216)	(0.283)
Trademarks	0.925***	0.909***	0.903***	0.987***
	(0.289)	(0.296)	(0.297)	(0.352)
Patents × Trademarks	-0.156	-0.0812	-0.0892	-0.101
	(0.403)	(0.109)	(0.109)	(0.124)
Copyrights × Trademarks	-0.570***	-0.567***	-0.619***	-0.654***
	(0.210)	(0.211)	(0.215)	(0.245)
SAP penetration	2.778**	2.638**	1.983*	2.191*
	(1.319)	(1.329)	(1.135)	(1.297)
Multiple industry	0.841**	0.807**	0.748**	0.800**
	(0.383)	(0.384)	(0.368)	(0.406)
Product overlap	-0.900*	-2.323**	-1.002*	-1.088*
	(0.546)	(0.975)	(0.534)	(0.602)
Public	-0.541	-0.530	-0.538	-0.540
	(0.527)	(0.543)	(0.537)	(0.616)
Age	-0.118	-0.0989	-0.163	-0.167
	(0.119)	(0.120)	(0.114)	(0.125)
Age^2	0.00270	0.00216	0.00358	0.00331
	(0.00539)	(0.00545)	(0.00502)	(0.00559)
Sales	0.632***	0.683***	0.634***	0.673***
	(0.173)	(0.177)	(0.173)	(0.198)
Corporate invest	0.140	0.0565	-0.0134	0.0136
	(0.626)	(0.628)	(0.631)	(0.707)
Private invest	-0.749**	-0.717*	-0.773**	-0.830**
	(0.375)	(0.374)	(0.375)	(0.411)
VC invest	0.903**	0.926**	0.876**	0.902**
	(0.371)	(0.373)	(0.381)	(0.417)
Publication	0.225	0.138	0.140	0.142
	(0.255)	(0.379)	(0.371)	(0.421)
Constant			-6.360***	-6.455***
			(0.874)	(0.955)
No. of firms	1201	1201	1201	1201
Observations	6381	6381	6381	6381
Log likelihood	-220.90356	-219.36468	-157.44985	-157.31881

Notes.

Standard errors in parentheses.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

I envision several broad implications of my empirical findings for platform sponsors as well as participants in the platform ecosystem. First, while certification from a major platform owner may provide the ISV with a larger market access, endorsement effect and enhance its social and technical legitimacy (Chellappa and Saraf forthcoming), the ISV may bear considerable knowledge expropriation risks during the process if both IP protection is weak and if the ISV does not possess strong downstream capabilities. In addition, ISVs that compete with the platform owner in multiple product markets should be cautious about proceeding with such a partnership. Finally, for a platform owner that focuses on fostering the rapid growth of its ecosystem to capture the indirect network effect and promoting the platform as de facto industry standard, understanding the incentives and reservations of its complementary product providers is of paramount importance, and building proper governance mechanisms that alleviates its partners' expropriation concerns could be conducive to the shared success of the community (Gawer and Henderson 2007). Surprisingly, my findings suggest that a strong, well-functioning IPR regime not only protects complementors from expropriation risks, but also work to the benefit of platform owner in that it encourages the provision of complementary innovation that is based on the platform.

My results also have implications for where ecosystems are most likely to arise. Ecosystems will be less likely to arise among firms with little formal means of IPR protection and, in particular, will be less likely where the protection afforded by patents is weak. They will be relatively more common when complementors are more effectively able to secure their innovations through copyrights, patents, and downstream capabilities, and when the products of platform owner and complementor do not directly compete.

Although my research is set in the enterprise software industry, I note that the implications could be applied to more general contexts which involve the relationship between a technology platform and complementary application provision. For example, in the media player software market, WINAMP was among the first to release Windows-based mp3 players, and RealPlayer was the first Windows-based media player capable of streaming media over the Internet. However, with their innovation unprotected, Microsoft eventually invaded their product space with its introduction of built-in Windows Media Player, and squeezed both into oblivion. In contrast, Windows-based iTunes, released by Apple at a later stage, enjoyed great success, largely due to Apple's ownership of downstream complementary capabilities: a dominant position in content provision and a large, loyal customer base of its mobile media device, iPod.

2.8.2. Limitations and Future Research

Although patents and copyrights appear as effective measures of IP protection, I acknowledge my limited ability to disentangle the effects of innovation from IPR protection on partnership formation, as firms in different industry segments may face different levels of strength of legal IPR mechanisms and have different propensities for employing patents, copyrights, trade secrecy, lead time advantage and other informal innovation protection alternatives (Cohen et al. 2000). For example, prior studies have documented that the patent propensity rate varies dramatically across industries, with firms in textiles on average patenting less than 10% of their innovations while pharmaceutical firms have a patent rate of more than 80% (Arundel and Kabla 1998). Although firms in the industry of interest in this study, enterprise software, are relatively homogeneous, it is possible that patent and copyright propensity varies according to firm size (Brouwer and Kleinknecht 1999), relative effectiveness of patents and copyrights within software submarkets (Arora et al. 2008a; Mann and Sager 2007), or characteristics of the technology (Hall and Ziedonis 2001). I address this issue by including scientific publications of ISVs as a measure of (unprotected) innovation, by using fixed effects models to remove time-invariant factors that may contribute to patent filing, and by explicitly controlling for the strength of patent protection using a survey-based measure.

Another limitation of this study is that I focus on the dyadic relationship between an ISV and the platform owner, while theory and research have advanced to analyze conduct and performance of firms by examining the network relationships in which they are embedded (Bae and Gargiulo 2004; Goerzen and Beamish 2005). In cases that multiple platforms and standards coexist in certain industries, firms face substitutable alliance partners from which they can draw complementary resources from (Bae and Gargiulo 2004). Particularly in enterprise software, studies of what determines small ISVs to choose or join different platforms sponsored by dominant incumbents such as SAP or Oracle, and how firm performances are conditioned on their structural positions inside the partnership network would provide a much richer understanding of the ecosystem evolution than treating the partnership decision as binary choices.

There is plenty of room for further research on the topic of ecosystem of enterprise software. Particularly, it is unclear through what mechanisms the partnering ISVs extract relational rent from such inter-firm exchange and how their post-partnership financial performance and exit strategies differ from non-participants. In addition, the roles of other ecosystem constituents such as customers, implementation partners and consulting companies remain largely unexplored and call for further investigation.

CHAPTER 3

CO-CREATION OF VALUE IN A PLATFORM ECOSYSTEM: THE CASE OF ENTERPRISE SOFTWARE

3.1. Introduction

Platform-based technologies such as personal computers, PDAs, and video game consoles are becoming increasingly important in the information economy (Evans et al. 2006). As noted by Boudreau (2007), such platforms are defined as the set of components used in common across a product family whose functionality can be extended by applications. To meet the needs of heterogeneous users and to exploit indirect network effects, owners of a platform often seek to encourage complementary third-party innovation from resources located outside the firm, ranging from customers, research companies and business partners to universities (Linder et al. 2003). This approach of complementary innovation has given rise to the model of an innovation ecosystem. A burgeoning body of research has started to theorize about how such ecosystems are formed and their implications for platform owners, complementary providers, and users (Adomavicius et al. 2007; Adomavicius et al. 2008; Eisenmann et al. 2008; Gawer and Henderson 2007; Lee and Mendelson 2008; Mantena et al. 2007; Parker and Van Alstyne 2008; West 2003).

To encourage complementary innovation, owners of IT hardware and software platforms such as Microsoft, IBM, and SAP often have partnership programs for members of their innovation ecosystems. Members of these partnership programs co-create value with the platform owner by developing applications and solutions to be used on the platform. Such partnerships have also drawn interest as examples of co-opetition (Hamel et al. 1989) that inevitably involve competition and conflict of interest. However, despite increasing interest among practitioners and researchers on ecosystems there has been little work in understanding the value of these partnership programs, and under what conditions they are most beneficial to their participants. This is a surprising gap in understanding. For researchers, this means that there is little systematic measurement of the extent to which partnership programs facilitate the co-creation of value. For example, recent theoretical work on how platform owners can encourage the development of ecosystems (Eisenmann et al. 2008; Parker and Van Alstyne 2008; West 2003) would benefit from empirical evidence on the value of these programs. For practitioners, platform owners and their complementors currently have no systematic means to determine how much to invest in them. In addition, efforts of start-up software vendors to use ecosystem participation as a growth strategy will have meaning only if vendors know who is most likely to benefit from such relationship. In short, measurement of the (co-created) value from ecosystem partnership programs has important implications for both researchers and practitioners.

A related question is the issue of value appropriation in IT innovation networks. Recent studies on inter-firm alliances have emphasized the role of partners' resources and capabilities in value creation (Ahuja 2000; Lane and Lubatkin 1998; Mowery et al. 1996). However, they have generally tended to overlook the effect of appropriation hazards on the co-creation of value by alliance partners. The misappropriation issue is particularly important in the case of platform ecosystem partnerships,[12] as such relationships are often characterized by a conflict between the developers of complementary products and the platform owner due to the risks that the latter may eventually compete in the former's product market space (Gawer and Henderson 2007). The question of how these risks of misappropriation affect the returns to partnership has yet to be answered. Acquiring empirical evidence on these issues has important managerial implications, as it will inform when ecosystems are most likely to grow and succeed.

In this chapter I take one step toward addressing these gaps in prior research. To do this, I develop a set of hypotheses building upon a rich literature on the commercialization of new technologies and markets for technology (e.g., Arora et al. 2001; Gans et al. 2002; Gans and Stern 2003). Following one stream of this literature (e.g., Gans et al. 2002; Gans and Stern 2003), I explore the decisions of small firms to pursue a cooperative or competitive strategy with incumbents. Focusing in this way allows me to isolate a key tradeoff to potential partners in my setting—the benefits of partnership from accessing a larger installed base versus the potential risks of intellectual property expropriation from the platform owner.

Building on this central tradeoff, I develop a set of hypotheses that predict the relationship between platform ecosystem participation, appropriation strategies and firm performance. I then test these hypotheses in the context of the enterprise software industry. Specifically, using a unique data set on the partnering activities of 1210

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[12] For example, over the last decade SAP has resolved a number of disputes with its ecosystem partner ISVs, whose claims include infringement of patents and copyrights as well as misappropriation of confidential information and trade secrets (SAP annual report 1998 – 2008).

independent software vendors (ISVs) over the period of 1996-2004, I evaluate the effects of joining the SAP ecosystem on two critical performance measures for entrepreneurial ISVs: sales and the likelihood of obtaining an initial public offering (IPO). I analyze the former because it is strongly correlated with the profitability and overall financial performance of the firm, due to the high fixed cost/low variable cost structure of software firms. I analyze the latter because it is both a measure of the future sales prospects for the firm and a common measure of small firm performance (Cockburn and MacGarvie 2009; Shane and Stuart 2002). I present robust empirical evidence showing that the decision to partner is associated with both an increase in sales and a greater likelihood of an IPO.

I next investigate how appropriability strategies, such as ownership of intellectual property rights (IPR) and downstream complementary capabilities by the ISV, moderate the effects of partnership on ISV performance. A rich literature on appropriating the returns to innovation show that both are conducive to appropriating returns through product markets (Teece 1986) or the markets for technology (Arora and Ceccagnoli 2006; Arora et al. 2001; Gans and Stern 2003) and have a significant effect on firm performance (Ceccagnoli 2009), though as yet there is less understanding of how these may condition the value of partnerships in a platform ecosystem. In particular, I find that the impact of partnership on sales and the likelihood of an IPO is greatest for those ISVs who are protected by IPR and who have strong downstream capabilities.

My study contributes to the extant literature on several fronts. First, although prior research on alliance relationships has examined their impact on firm performance (Bae and Gargiulo 2004; Baum and Oliver 1991; Goerzen and Beamish 2005; Mitchell and Singh 1996; Zaheer and Bell 2005), the focus in much of that literature has been on the value of alliances as a mechanism to facilitate learning and access to specialized resources (Porter and Fuller 1986). My analysis and theory differs from this extant literature in significant ways: in my setting, partnerships are valuable primarily as a way of signaling compatibility with the platform rather than a mechanism of sharing critical information that will improve the innovative productivity of the partnering organizations (Colombo et al. 2006; Khanna et al. 1998; Mowery et al. 1996). In that way, my study shares similarities with Chellappa and Saraf (forthcoming), who also argue that compatibility signaling is a primary benefit of partnership in enterprise software. However, while Chellappa and Saraf are primarily interested in how a firm's position in the social network of large enterprise software firms influences firm performance, I examine the impact of ecosystem partnership on ISV performance.

My research differs from prior alliance literature (including Chellappa and Saraf) in another significant way. With the exception of Lavie (2007), few authors have simultaneously studied value creation and value appropriation mechanisms in alliance relationships. I bridge this gap by applying theory on innovation commercialization to inter-firm alliance studies. While Lavie (2007) emphasizes the role of bilateral and multilateral competition on value appropriation in alliance relationships, I examine how the benefits of participation in a platform ecosystem vary according to different appropriation strategies. Specifically, my findings imply that appropriability, in particular intellectual property protection, is a critical determinant of the returns to ISVs from the co-creation of value in the software industry, and that successful and sustainable ecosystems will be found in environments where appropriability mechanisms are strong. In such environments, strong ISV participation in the ecosystem will engender a rich supply of innovative solutions to meet heterogeneous customer needs, igniting a virtuous cycle of indirect network effects that will in turn lead to further value co-creation.

More broadly, while a growing body of literature has examined how platform owners can encourage third-party complementors to stimulate indirect network effects, the current literature on platform technology focuses primarily on the management issues and strategies from the perspective of the platform owners (Eisenmann et al. 2008; Gawer and Cusumano 2002). There is at present little work examining the perspective of the platform participants. In this way, my research builds upon the previous chapter where I study the decisions of ISVs to participate in a partnership program.

The rest of the chapter is organized as follows. In the next section I present an overview of literature in related research areas and propose hypotheses regarding value creation and appropriation in a platform ecosystem. In section 3.3 I describe the research setting, the data, and methods used in the empirical investigation. I present the results, as well as a set of robustness checks, in section 3.4. In section 3.5 I discuss the implications of my findings and conclude.

3.2. Relevant Literature and Hypotheses

In this section I propose hypotheses regarding value creation and appropriation in platform ecosystems. My hypotheses are grounded in the literature on innovation commercialization, appropriability, and markets for technology (e.g., Arora et al. 2001; Gans et al. 2002; Gans and Stern 2003). This line of work suggests that the decision of start-ups to partner with established firms in order to commercialize their innovations is critically conditioned by ownership of IPR and downstream commercialization capabilities. I apply and extend these ideas to analyze the impact of an ISV decision to join a platform ecosystem on its financial performance. Later, in section 3.5, I discuss the generalizability of my findings to other platform environments.

3.2.1. Appropriating the Returns from Innovation

Technology entrepreneurs such as small enterprise software vendors often face a critical challenge when attempting to translate their innovation into a steady stream of economic returns. When start-ups commercialize their innovations, they often face a choice between (1) embedding the innovation into a product and competing with established firms versus (2) earning returns through cooperation with incumbents (Gans and Stern 2003). A key determinant of this choice is the ownership of costly-to-build downstream manufacturing, marketing, distribution and other complementary capabilities that are essential to a firm's value chain and required for successfully launching a product or service (Teece 1986). These complementary capabilities are often a choke point for innovation commercialization, since they cannot be easily contracted for through the market on competitive terms and are therefore rare, path-dependent and difficult to imitate (Teece 1986). Their ownership may constitute a barrier to entry and provide a sustainable competitive advantage (Barney 1991; Rothaermel and Hill 2005; Teece 1992). Indeed, large scale empirical studies suggest that ownership of downstream capabilities required to commercialize an innovation is one of the most effective means of securing returns from innovation across a wide range of industries (Cohen et al. 2000).

While the ownership of downstream complementary assets is typically conducive to an appropriation strategy through vertical integration into the product market, securing returns from innovation by commercialization through the market for technology depends critically on the possession and strength of IPR (Arora et al. 2001; Gans and Stern 2003; Oxley 1999). For example, Gambardella and Giarratana (2008) find a positive relationship between the effectiveness of patent protection and technology licensing in the security software industry, while the ownership of downstream complementary capabilities increases the likelihood that firms will launch new products. Recent research has also extended this literature to examine the role of markets for technology in affecting the survival of entrepreneurial firms in the security software industry (Arora and Nandkumar 2008).

In what follows, I develop a set of hypotheses based on some of the key ideas outlined above.

3.2.2. Participation in the Ecosystem and Sales

In technology industries where network effects are important and a dominant standard has yet to be established, small technology firms may initiate an alliance or join a platform ecosystem to achieve technology compatibility with a platform. The literature on standards competition suggests that technology compatibility is often a prerequisite to gaining access to the user base of the platform owner (Brynjolfsson and Kemerer 1996; Katz and Shapiro 1994; Kauffman et al. 2000; Matutes and Regibeau 1988; Tassey 2000).

Since the key objective of partnerships in this industry is to achieve compatibility between innovative software solutions of the complementors and the platform, cooperation is a way to access a key complementary asset, certification of software compatibility, that increases a startup’s ability to appropriate the returns from its innovation (Arora et al. 2001; Gans et al. 2002; Gans and Stern 2003; Teece 1986). This kind of alliance therefore *co-creates value* by avoiding investments in hard-to-duplicate complementary assets (e.g., investments needed to integrate complementary products with the platform and gain a reputation for quality and reliability). They also increase the *value captured* by the complementors, by allowing the ISV to achieve a more reliable integration with the platform, as well as reach the installed base faster and more effectively.

Indeed, since platform owners are usually established incumbents with a large installed base, partnership exposes an ISV to a greater potential market that is not served or is underserved by the platform owner. Successful exploitation of the platform owner's user base is therefore expected to boost the sales of a partnering ISV. In addition, in order to become a certified complementary solution provider to a platform, an ISV may have to conform to a series of quality specifications in product design and pass a rigorous certification process conducted by the platform owner. As a result, obtaining certification from an industry leader may be perceived by users as a quality signal (Rao and Ruekert 1994), which may enhance the willingness-to-pay of the ISV's potential customers, and in turn have a positive impact on sales revenue. Indeed, prior research has shown that obtaining quality certification such as ISO (International Organization for Standardization) 9001 enhances software companies' revenue and is associated with higher price per unit of output (Arora and Asundi 1999).

Therefore, I propose

Hypothesis 1 (H1). *An ISV's participation in an enterprise software platform's innovation ecosystem is associated with an increase in sales.*

A few words are in order about the statement of my hypothesis. As I will discuss in section 3.2.4, while platform participation may be associated with an increase in sales on average, the relationship between participation and sales may vary significantly with ISV characteristics (in particular the appropriation strategies of the ISV) and the market conditions under which the ISV operates. In other words, there may exist considerable heterogeneity in value co-creation—and for the ISV, value appropriation—across partnerships. Further, ISVs may choose to partner with incomplete knowledge about the future values of these variables that will moderate the effects of partnership. I discuss these variables in detail in section 3.2.4.

3.2.3. Participation in the Ecosystem and IPO

For young entrepreneurial software companies, a crucial dimension of long term performance is the speed at which the company issues an initial sale of securities in the financial market (Hsu 2006; Stuart et al. 1999). An IPO is a critical milestone which marks the transition of a privately held venture into a publicly owned company. From the perspective of a new venture, selling securities to the public is a less expensive way to raise working capital that is required for future growth and expansion, and it presents an opportunity to the equity holders to exchange their stake in the company for cash.

However, the IPO market is a context in which investors need to assess the quality of relatively new companies with a short track-record and about which investors will have limited information (Pollock and Rindova 2003). I argue that given the significant uncertainty surrounding a new venture’s viability and future profit generating capabilities, an ISV’s decision to join a platform ecosystem will be an effective way of mitigating uncertainties in the eyes of third party investors. First, the market’s evaluation of the firm is based on its expected future cash flow (Kaplan and Ruback 1995), which will be correlated with its current market penetration and sales. Since joining the platform ecosystem facilitates a faster and more effective penetration of the installed base by the ISV, as argued above, such partnerships should be interpreted favorably by the financial markets and boost investors’ confidence in the future profitability of the new venture, resulting in a greater likelihood of IPO.

Second, institutional theory (DiMaggio and Powell 1983) suggests that organizations are under the pressure of institutional environments to conform to prevailing social norms and demonstrate legitimacy. Third parties such as investors will be more willing to engage in exchange relationships with firms that have proven social legitimacy (Sine et al. 2007). To the extent that small ventures have limited history of demonstrating their conformance to prevailing rules, practices and social norms, partnering with large, well-established companies can significantly increase their visibility, reputation, image and prestige. Indeed, studies have examined how endorsements from venture capitalists (Gulati and Higgins 2003; Shane and Stuart 2002), investment banks (Gulati and Higgins 2003; Stuart et al. 1999), alliance partners (Stuart et al. 1999) and media coverage (Pollock and Rindova 2003) can affect impression formation and impart legitimacy to entrepreneurial ventures, and increase the likelihood of raising capital through an IPO. Therefore, I propose

Hypothesis 2 (H2). *An ISV's participation in an enterprise software platform's innovation ecosystem is associated with an increase in the likelihood of issuing an IPO.*

3.2.4. Participation in the Innovation Ecosystem and Appropriation Strategies

As is widely noted in the markets for technology literature, cooperative strategies like ecosystem partnerships often occur in the shadow of competition (Arora and Ceccagnoli 2006; Arora et al. 2001; Gans et al. 2002; Gans and Stern 2003). The above literature has highlighted the *paradox of disclosure* that occurs when start-ups explore potential licensing strategies with established firms: when trading in ideas, the willingness to pay for potential buyers depends upon their knowledge of the idea, however disclosure of the idea implies that the potential buyer need not pay for it (Gans and Stern 2003).

Similar appropriability risks arise for small ISVs who consider joining a platform ecosystem. Although joining a platform ecosystem may improve an ISV's sales and likelihood of IPO *on average*, there may be considerable risks associated with such relationships that may lead to variance in the returns to partnership. One particular risk is that the platform owner may replicate the technology of the ISV and begin to offer a competing product, a risk that is likely to increase with partnership. Inter-firm collaborative relationships often lead to unintended knowledge transfer (Khanna et al. 1998; Mowery et al. 1996). Knowledge that is not protected by any appropriation mechanism can therefore be profitably used by collaborators (Bresser 1988; Heiman and Nickerson 2004). As noted above, the potential risk that platform owners may enter a complementor's product space has been acknowledged by theoretical and case study work on software platforms (Gawer and Cusumano 2002; Gawer and Henderson 2007; Iansiti and Levien 2004), but has not been empirically tested.

The partnership between an ISV and a software platform owner is likely to facilitate such knowledge spillovers. Software certification may require the ISV to disclose proprietary knowledge, the codification of business processes or its best practices that the platform owner could imitate. In this way, the costs of entry for the platform owner into the ISV's product market are reduced. In other words, by joining a platform ecosystem an ISV is exposed to a greater expropriation risk.

Prior research has noted that the disclosure problem can be ameliorated if IPR are available (Arora and Ceccagnoli 2006; Gans and Stern 2003; Oxley 1999). Both patents and copyrights have been shown as common methods of IPR protection in the software industry (Bessen and Hunt 2007; Graham et al. 2009). In particular, in the presence of patents and copyrights, a start-up may be able to deter imitation or exercise its IPR and prevent entry once imitation has occurred (Gans et al. 2002). I expect that stronger IP protection from patents and copyrights will increase the payoff to partnering by decreasing the risks of imitation. As a result, the effect of partnership on sales and the likelihood of issuing an IPO will be higher in the presence of IP-based appropriability strategies.

Appropriability risks will also be affected by the ownership and strength of specialized downstream capabilities (Arora and Ceccagnoli 2006; Ceccagnoli and Rothaermel 2008; Gans and Stern 2003; Rothaermel and Hill 2005; Teece 1986). These are specialized downstream assets necessary to manufacture, market, and distribute products, e.g., assets that lose value when redeployed to other classes of products. For example, sales forces that specialize in a particular product may have accumulated specialized skills that are not easily transferred and would require time and costly retraining to be exploited in selling different classes of products. Specialized complementary assets are difficult to imitate since they are built over long periods of time, are not easily codified, and often result from the interaction of people from different parts of a firm’s organization (Teece 1992).

The effect of partnering on the ISVs’ returns will be higher in the presence of specialized downstream capabilities for two reasons. First, the returns to accessing the platform owner’s installed base will be greater if the ISV has an established brand image or strong marketing, distribution and service capabilities, as it is able to convert platform adopters into its own customers more effectively. Second, an ISV with strong downstream capabilities will be better able to defend its “territory” in the presence of platform owner entry than firms without such capabilities. Knowledge embedded in business practices or downstream service and consulting activities is difficult to codify and therefore will be more difficult for the platform owner to imitate (Barney 1991; Dierickx and Cool 1989). For example, implementation of enterprise software often requires extensive effort to configure it to meet the user’s idiosyncratic needs (Hitt et al. 2002; Ko et al. 2005). Knowledge of how to conduct such configurations will typically reside in the consulting and service activities of the ISV. Such downstream knowledge and capabilities are difficult to transfer across firm boundaries (Brown and Duguid 2001; Von Hippel 1994b) and may also act as a barrier to entry.

In summary, I argue that the extent to which an ISV may benefit from joining a platform ecosystem is likely to vary according to the ISV’s ownership of IPR and downstream capabilities. Particularly, I propose

Hypothesis 3 (H3). *The positive effect of an ISV's participation in an ecosystem on sales is greater when a) the ISV is better protected by intellectual property rights such as patents and copyrights, and b) the ISV has stronger downstream capabilities.*

Hypothesis 4 (H4). *The positive effect of an ISV's participation in an ecosystem on the likelihood of issuing an IPO is greater when a) the ISV is better protected by intellectual property rights such as patents and copyrights, and b) the ISV has stronger downstream capabilities.*

Figure 3.1 schematically represents the research model and the hypotheses.

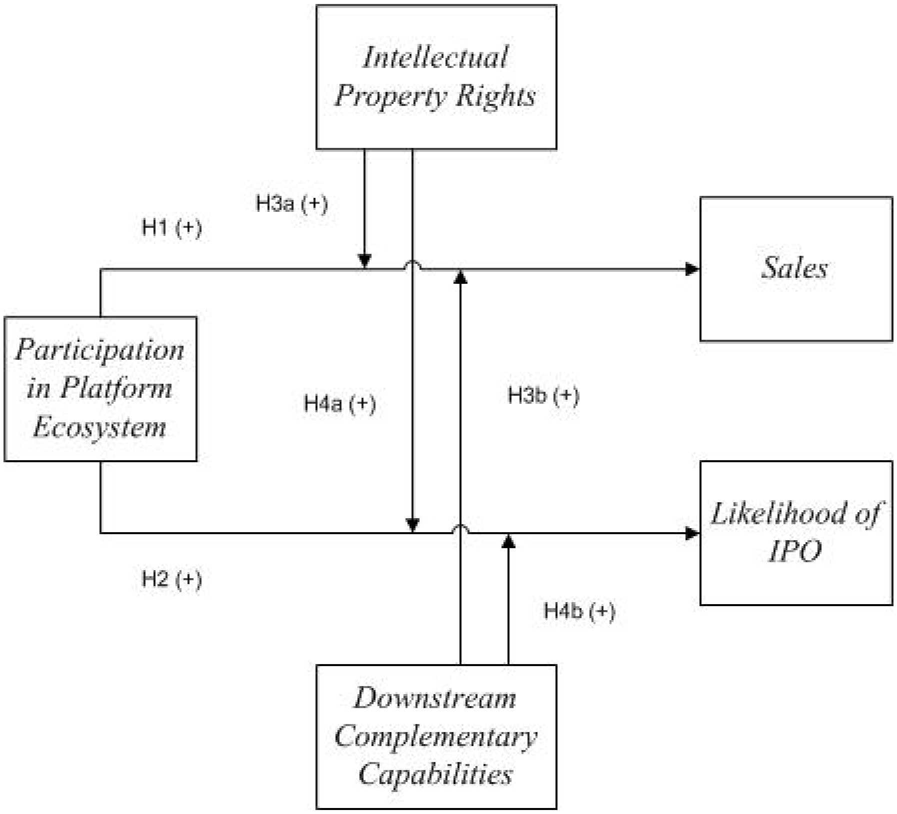

Figure 3.1 Research Framework

3.3. Methods and Measures

3.3.1. Research Context

Enterprise software is often considered to be the organizational operating system (Chellappa and Saraf forthcoming; Cotteleer and Bendoly 2006), which consolidates the diverse information needs of an enterprise's departments together into a single, integrated software that operates on a shared database. In this study I am interested in the partnership between an enterprise software platform owner and the ISVs that develop complementary applications that are integrated with the owner's platform. As noted above, I adopt the definition of Boudreau (2007) and define a platform as the components used in common across a product family whose functionality can be extended by applications and is subject to network effects. ISV applications extend the functionality of the platform and co-create value for customers who adopt the platform. SAP AG, the business software company, is chosen as the focal enterprise software platform owner for several reasons. First, SAP's enterprise computing platform is economically significant. Partnerships are core to SAP's platform strategy and its network of software solution providers, value-added resellers, distributors, technology and services partners (numbering over 7,000 as of 2009) is among the industry's largest (SAP 2009b). Second, many core features of SAP's platform are common to other settings where platform owners co-create value with their partners. For example, partnership with SAP signals compatibility with SAP's platform (Chellappa and Saraf forthcoming), enabling ISVs to more easily sell to SAP's installed base. Similar motivations are behind the decisions of firms to join platforms such as Cisco's Internetwork Operating System (IOS) platform for computer networking (Gawer and Cusumano 2002). Further, platform participants in other industries face similar expropriation risks, as platform owners have entered complementary markets for efficiency gains or strategic advantage (Casadesus-Masanell and Yoffie 2007; Eisenmann et al. 2007; Gawer and Cusumano 2002; Gawer and Henderson 2007).

To join SAP's partner program, ISVs develop a product and then obtain a certification from SAP which endorses the interoperability between the product and the SAP platform. In particular, ISVs that plan to achieve software integration with the SAP solutions work with one of the local SAP integration and certification centers (ICCs) to have their product certified. The process typically involves a feasibility study, service offer processing, and extensive testing by SAP. If successful, SAP issues a formal SAP ICC contract for the ISV to sign and applicable fees are paid by the ISV and the now-certified integration is publicly listed online in the SAP partner information center.

By making its product SAP-certified, the ISV effectively signals its compatibility with the SAP platform. This will strengthen the ISV's ability to sell to SAP's large customer base. In addition, by teaming up with a prestigious industry leader, ISVs gain endorsements, enhance their social legitimacy, and signal their technological excellence (Stuart et al. 1999). The reputation consequences of strategic partnership are particularly important in high-technology industries, which are noted for pervasive uncertainty (Tushman and Rosenkopf 1992).

A couple of examples will help to place my research context in perspective. LogicTools Inc. is a software company that provides an integrated suite of strategic supply chain planning solutions that optimize the supply chain by simultaneously optimizing account production, warehousing, transportation and inventory costs, as well as service level requirements. It became an SAP software partner in January 2004 (Simchi-Levi et al. 2006). Since then, LogicTools' customer base has been growing rapidly, adding 30 new clients in 2005 alone, with its sales growing by over 50% in 2005 (Business Wire Inc. 2006). According to the press release, "LogicTools' software partnership with SAP and certified integrations make LogicTools' solutions an easy choice for many companies". As yet another example, TIBCO Software Inc. (www.tibco.com), an ISV that provides enterprise application integration solutions, certified its interface for SAP R/3 solutions and became a member of the SAP Complementary Software Partner program in 1998 (Business Wire Inc. 1998). Since then it became the de facto standard for event-driven computing and enterprise application integration in finance, manufacturing, construction, electronic commerce and other industries, and obtained an initial public offering at NASDAQ one year later (Business Wire Inc. 1999). This IPO was highly successful with a strong first day of trading, when its stock price increased from $15 to $32.375.

On the other hand, joining SAP's platform ecosystem is not costless for ISVs. Besides the fixed cost of developing a platform-compliant version of the software solution, certification application fees and yearly membership fees, there are considerable misappropriation risks for ISVs due to the extensive knowledge sharing involved in the relationship. For example, AMC Technology, a leading provider of multi-channel integration solutions that allows contact centers to more efficiently manage all types of customer interactions, has been a certified SAP software partner since 1998. With its introduction of the product suite mySAP CRM 5.0 in 2005, SAP folded the multi-channel integration functionality into its platform and entered into AMC's product territory with a

"CRM Interaction Center" module, which allegedly contained copyrighted AMC code from AMC's "Multi-Channel Management Suite" product. AMC soon filed a lawsuit that claimed vicarious copyright infringement, breach of contract, and misappropriation of trade secrets by SAP (Shapiro 2005).

3.3.2. Data

I test my theoretical predictions using a longitudinal data set of 1210 small independent software vendors over the period of 1996 - 2004. I collect information on both the ISVs' decisions to join SAP's innovation ecosystem and information on their business performance. The sampling period starts from 1996 as I find no such partnership activities between SAP and small ISVs in the sample before then (more details will be provided later in the section on variable definitions).

My primary data source is the CorpTech database, which has detailed information on over 100,000 public and private firms, including information on sales, employees, product offerings, source of funding and company executives.[13] It is well known that studies related to firm performance solely based on public firms may suffer from severe sample selection bias (Cockburn and MacGarvie 2006; Shan 1990), and will be particularly problematic for my study given my focus on small firms.

To construct a representative sample of entrepreneurial ISVs that could potentially form partnerships with SAP, I first identify within CorpTech the set of firms operating in the United States and who list computer software as their primary industry. To further

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[13] These data have been used frequently to study firm behavior in technology industries. For examples of recent studies using the CorpTech database to study the software industry, see Lerner and Zhu (2007) and Cockburn and MacGarvie (2009).

identify firms in the enterprise software industry I examine the product portfolios of current SAP software partners, and then find all software firms in CorpTech that produce similar products. The first step involves retrieving a complete list of SAP's current software partners. SAP publishes the directory of all its certified partners as well as their solution offerings on its Internet portal,[14] and a search using the terms "*Country: United States*" and "*Partner Category: Independent Software Vendor*" yields a list of 411 software firms that are current SAP partners. Comparing this list with software firms within CorpTech generates 206 matching records.

I use these matching records to identify the set of potential partners. One of the key advantages of the CorpTech database is that it records the product portfolio of each company and assigns each product to a 3-digit product class.[15] I retrieve the distinct 2-digit product classification codes of the 206 current SAP software partners, and find that SOF-MA (manufacturing software, 61 firms) and SOF-WD (warehousing/distribution software, 44 firms), are the most frequent software product codes in the product portfolios of the matched partnering firms. To verify that the unmatched partners are not systematically different from those matched to CorpTech, I collect information on the unmatched ISVs from Company Insight Center (CIC), a database launched by BusinessWeek and Capital IQ. A short business profile is obtained from CIC for each of the remaining ISVs, which is complemented by a description of their business and products I collect from the ISVs' websites. Then I manually examine the product portfolio of these ISVs by reading their business profiles and product descriptions. I find

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[14] http://www.sap.com/ecosystem/customers/directories/searchpartner.epx.

[15] CorpTech uses a proprietary, 3-digit product classification system. For example, a product coded as "AUT-AT-DA" means "factory automation"-"automatic test equipment"-"analog/digital component".

that manufacturing software and warehouse/distribution software are also the two most frequently produced by the unmatched ISVs, similar to the ISVs that are matched in the CorpTech database. I subsequently define my sample as firms that have produced SOF-MA or SOF-WD products during the sample period.[16] The final query retrieves 2175 ISVs from the CorpTech database.

I further exclude established incumbents and restrict my sample to startup ISVs. Consistent with prior literature (Petersen and Rajan 1994; Puranam et al. 2006) that has focused on small, entrepreneurial businesses, I restrict my sample to firms with less than $500 million in sales and 1000 employees, and those established after 1980. I exclude established incumbents because of my research focus on small ISV behaviors and because the partnering incentives and payoffs of large firms are likely to be quite different from those of small firms. For example, to the extent that large firms sponsor platforms of their own, partnership may increase the value of a large firm's own platform. Also the misappropriation risks that large firms face after partnering may be quite different than those of small firms due to the latter's strong IPRs and/or downstream capabilities. My final sample consists of 1210 ISVs with 6578 observations over the 1996 - 2004 time period. The typical ISV in the final sample is about 12 years old, with 56 employees and average sales of $7 million.

It should be noted that in my setting ISVs produce software products that can be sold both as a stand-alone product and as platform compliant software. Once the product is

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[16] As an additional check, I manually go through the business description field in the CorpTech data set for each company, and visit the website of each firm (if the company no longer exists, I visit the archival web site from www.archive.org instead) to confirm that the ISVs produce enterprise software applications, and delete those that do not fit the profile.

developed, the cost of making it compatible with a platform (technical cost, to be specific) is considerably lower than product development cost. As a result, ISVs rarely make products that are dedicated to one specific platform from the beginning; in most cases a stand-alone product is first developed, then is made compatible with the platforms of incumbents. In addition, many ISVs certify their product for multiple platforms to gain access to as many customers as possible.[17]

3.3.3. Dependent Variables

Sales. Sales data for each company-year are retrieved directly from the CorpTech database, and are measured in millions of US dollars. I take the log form of the sales variable (that is, log (1+x) to avoid taking log of zeroes) as the dependent variable in the regressions because this variable is highly skewed to the right. When the distribution of dependent variable is skewed, models using logged dependent variable often satisfy the classical linear model assumptions more closely than models using the level of the dependent variable (Verbeek 2008; Wooldridge 2008).

IPO. I search the Securities Data Company (SDC) platinum database to retrieve the list of ISVs in my sample that issued an initial public offering in the US market during the

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[17] As an additional check, I examined the history of SAP partners in my sample to check whether their certified products were new, exclusive add-ons for only one platform. If this is true, it may suggest alternative explanations for the proposed hypotheses, especially H1. I found that all the partners fell into one of three cases: (1) they had already produced multiple versions of the software prior to partnering with SAP; (2) they had already used trademarks related to the product in commerce at least two years prior to partnering (and so were not new); or (3) the product has been certified by multiple other enterprise software platforms such as Oracle, Siebel, J.D. Edwards, Infor, PeopleSoft, etc. I further note that ISVs in my sample had been around for several years prior to partnering; the average age of the ISVs in the year prior to patenting is 9.4 (with the youngest being 1 in the year prior to partnering (that is, 2 in the year when a partnership was formed) and oldest being 23), and the average sales of these firms at one year prior to partnering is $20.7 million (with the lowest being $.33 million).

sample period. I also obtain the date of IPO. The variable is set to 1 if an IPO is issued for a firm during a year, 0 otherwise.

3.3.4. Independent Variables

Partnership. The independent variable of interest is whether an ISV is an SAP-certified software solution provider in a particular year. As my study is longitudinal in nature, using the list of partnering ISVs retrieved from SAP's web portal as the dependent variable is problematic for several reasons. First, the list of partnering ISVs reflects only the current snapshot but fails to capture historical partnering events. Second, the enterprise software industry experiences considerable entry and exit during the sampling period; many partnering firms are eventually acquired by or merged with other companies. Third, information about the exact partnering date is missing from SAP's web portal, which makes determination of the year of partnership formation difficult.

As an alternative to overcome the aforementioned difficulties, I identify the partnership formation events through press releases. To test the viability of this approach, I examined the existing partner list retrieved from the SAP web portal to see whether a matching press release could be found in the Lexis/Nexis database for each firm. For a random sample (60 firms) of the 411 existing SAP partners, I am able to find a matching news release for over 98% of the firms, which confirms the validity of using press releases to determine the formation of partnerships. I subsequently apply the same algorithm to my sample universe and retrieve 148 alliance events between sample ISVs and SAP. It is notable that there has been no such alliance activity prior to 1996. I further exclude pure joint development, marketing or distribution alliances and alliances after 2004 from the list. In addition, for ISVs that have multiple SAP alliance press releases (due to certification for multiple products, new versions of same product, or different interface certifications), I use the first instance of such events to indicate the time that the ISV joins SAP's platform ecosystem.

The *partnership* variable is set equal to 1 in the first year that a partnership is formed and remains 1 for the rest of the years, and is 0 otherwise. I treat partnering with SAP as an absorbing state, as there are no obvious reasons for a partnering ISV to make its certified product incompatible with SAP's platform. In order to verify that partnering with SAP is indeed an absorbing state, I collect information on the ISVs' status after the partnering events. I find that partnering ISVs fall into the following three categories. (1) 31% of the ISVs are partners with SAP as of April 2010 (they are listed on SAP's current ecosystem website) and their products remain certified. (2) 46% of the ISVs were acquired or merged with other companies since they partnered with SAP. By reading the press releases of these merger and acquisition events, I find that the certified product existed at the acquisition/merger event in all cases, and note that such firms are dropped from my sample subsequently. (3) 23% of the ISVs are no longer listed on SAP's website as certified partners, but their most recent SAP certification occurs after 2004, the end of my sample period. To summarize, these efforts reassure me that partnering is an absorbing state for all the ISVs during my sample period (1996 - 2004).

Patents. I measure the patent stock of ISVs by using the USPTO CASSIS patent BIB database. Although diversified software vendors may have patented innovations in related areas (e.g., manufacturing control or data acquisition equipment), I am primarily interested in their software patents. I follow Hall and MacGarvie (2006) by defining the universe of software patents as the intersection of the two sets of criteria: the patents in the software-related U.S. Patent Office technology classes defined by Graham and Mowery (2005), and those that are found in the results of a Boolean queries that searches for key words in the text of issued patents (as defined by Bessen and Hunt (2007))[18]. For a survey of different ways to identify software-related inventive activities see Arora et al. (2008b). I also weight the resulting stock of software patents using each patent's forward citations, to account for the heterogeneity in the value of an innovation protected by the patent (Hall et al. 2001).[19]

Copyrights. The cumulative number of registered software copyrights for each firm-year is obtained from the United States Copyright Office.[20] To indicate copyright type, the US Copyright Office assigns a prefix to each copyright it issues. As I am interested in software copyrights, I retrieve only those copyrights that are described as "computer file" within the TX (monograph including books, maps and software) class.

Downstream Capabilities. Following prior literature, I use the stock of software trademarks registered in the U.S. as a proxy of the ISV's effort to build brand, reputation, and distribution channels (Gao and Hitt 2004). According to the USPTO definition, a trademark is "a word, phrase, symbol or design, or combination of words, phrases, symbols or designs, that identifies and distinguishes the source of the goods or services of one party from those of others." While trademarks may not directly protect a

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[18] As a robustness check, I also use the union of the two software patent sets and derive alternative measures, and find that all the empirical results are robust to this alternative measure.

[19] Use of patent data is becoming increasingly common in IS research. For one example, see Kleis et al. (2009).

[20] A copyright protects the original expression of an idea fixed in a medium and does not need to be registered to be obtained. However, registration of a copyright in the US Copyright Office provides evidence of validity of the claim and enables the right holder to file an infringement suit in court and to file for statutory damages as well as recover attorneys' fees if claims are litigated (http://www.copyright.gov/circs/circ01.pdf).

firm against the imitation of its products by its rivals per se, they enhance a firm's appropriability by legally protecting its investments in marketing and other intangibles such as brand and reputation (Fosfuri et al. 2008). It is important to note that trademarks not only protect the brand and logo of a firm's products, but also the broader marketing and promotional investments. For example, "The Best-Run Businesses Run SAP" is a registered trademark of SAP AG, as well as Microsoft's slogan "Global Access to Local Knowledge". I follow prior research where trademarks have been used as a proxy for the stock of marketing-specific downstream assets and a firm's brand capital (Fosfuri et al. 2008; Gambardella and Giarratana 2006). Brand capital represents a hard to imitate capability since it is not easily contracted for through the market on competitive terms and is hard to be redeployed to alternative uses and alternative users (Williamson 1991). The data have been obtained from the USPTO CASSIS Trademarks BIB database. I use only software trademarks that are active for the firm-year.

3.3.5. Control Variables

I control for a number of firm characteristics that could potentially influence operational performance. In particular, I control for an ISV's basic R&D capabilities by including its yearly stock of *publications* in academic journals or conferences in both the sales and IPO regressions. I obtain this variable from the ISI Web of Knowledge database, by searching for the ISV's name as organization and ("article" or "proceedings paper") as document type. I weight the number of publications by the number of forward citations obtained by each article, to account for heterogeneity in their importance.

Software firms' funding sources are likely to impact their operations. I therefore control for the effect of firms' source of funding. I create three dummy variables, *cinvest*, *pinvest* and *vinvest* following the CorpTech database classification of funding sources into corporate investment, private investment or venture capital investment.

I also control for firm *age* in both performance equations based on the year in which an ISV was established, as well as its quadratic term, to account for nonlinear effects. As typically done for IPO equations, I control for firm size by incorporating the number of *employees*, which is obtained directly from the CorpTech database. Due to the high correlation (> 0.9) between *sales* and *employees* I exclude *sales* in IPO equation to avoid multicollinearity (Hsu 2006). The variable *employees* is not included in the sales equation due to endogeneity concerns. To control for performance differences between public and privately held companies I instead add an ownership indicator variable in the sales equation.

Investments in product and process innovations are driven in part by expectations about the potential size of the market and its growth potential (Acemoglu and Linn 2004; Cohen 1995; Schmookler 1966). In other words, ecosystem partnership may be associated with unobserved industry-level features such as expected industry growth that may influence a firm's success. To control for these industry-level features, I obtain the target industries that each ISV serves from the CorpTech database and classify them into 40 categories (such as banking, chemical, oil and gas). Next, I calculate the industry growth rate by averaging the sales growth rates of all the ISVs that serve the industry. I then map the industry growth to individual ISVs and derive the variable *industryGrowth* as a control. Table 3.1 presents the summary statistics of all of my variables, as well as the correlation among them[21].

3.3.6. Methods

Main Effect of Partnering. Cross-sectional analysis of the effect of partnering on an ISV's performance is likely to suffer from unobserved firm heterogeneity which may be correlated with partnering decisions, resulting in inconsistent estimates. I choose panel data methods with fixed effects as a starting point for the empirical analysis. Specifically, for firm sales I estimate the following equation:

$$\begin{aligned} Log(sales_{it}) = \alpha &+ \beta_1 partner_{it} + \beta_2 patent_{it} + \beta_3 copyright_{it} \\ &+ \beta_4 trademark_{it} + \beta_5 age_{it} + \beta_6 {age_{it}}^2 \\ &+ \beta_7 public_{it} + \beta_8 cinvest_{it} + \beta_9 pinvest_{it} \\ &+ \beta_{10} vinest_{it} + \beta_{11} publication_{it} \\ &+ \beta_{12} industryGrowth_{it} + year_t + c_i + u_{it} \end{aligned} \tag{3.1}$$

where $year_t$ is a set of year dummies, and c_i denotes firm fixed effects. The variables patent, copyright, trademark and publication are entered in log form (that is, log (1+x) to avoid taking log of zeroes) because their distributions are highly skewed.

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[21] Notice that the correlations need to be interpreted with caution due to the panel structure of the data. For example, the correlation coefficient between partner and IPO is 0.06. If the data are collapsed at the firm level the correlation increases to 0.24, which reflect variation *between* firms. Similarly, the correlation between trademarks and IPO is 0.005 overall, but jumps to 0.11 in the between sample. It is difficult to describe the correlation between variables *within* firms.

Table 3.1 Summary Statistics and Correlation Matrix

	Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Sales$_{i,t}$	7.539	16.219	0.000	206.400	1.000													
2	IPO$_{i,t+1}$	0.004	0.064	0.000	1.000	0.035	1.000												
3	Partner$_{i,t}$	0.017	0.129	0.000	1.000	0.295	0.063	1.000											
4	Copyright$_{i,t}$	1.988	12.841	0.000	498.000	0.253	0.029	0.044	1.000										
5	Patent$_{i,t}$	0.145	0.722	0.000	13.000	0.303	0.038	0.129	0.016	1.000									
6	Trademark$_{i,t}$	0.835	2.011	0.000	23.000	0.377	0.005	0.154	0.282	0.338	1.000								
7	Age$_{i,t}$	12.566	5.830	0.000	24.000	-0.052	-0.059	-0.058	0.069	-0.114	0.004	1.000							
8	Publication$_{i,t}$	0.600	5.259	0.000	137.000	0.044	-0.005	0.003	0.001	-0.005	0.030	0.045	1.000						
9	Corporate invest$_{i,t}$	0.046	0.210	0.000	1.000	0.102	0.010	0.101	-0.019	0.031	0.062	-0.118	-0.016	1.000					
10	Private invest$_{i,t}$	0.501	0.500	0.000	1.000	-0.087	-0.029	-0.039	-0.007	-0.048	-0.053	-0.144	-0.017	-0.068	1.000				
11	VC invest$_{i,t}$	0.122	0.327	0.000	1.000	0.176	0.108	0.171	-0.008	0.155	0.106	-0.339	0.039	0.071	-0.073	1.000			
12	Employee$_{i,t}$	56.248	104.904	1.000	997.000	0.901	0.071	0.283	0.240	0.286	0.385	-0.075	0.049	0.108	-0.100	0.199	1.000		
13	Industry growth$_{i,t}$	1.261	0.342	0.873	6.322	0.007	0.006	0.012	-0.001	-0.012	-0.023	-0.051	0.013	-0.019	-0.015	-0.019	0.011	1.000	
14	Public$_{i,t}$	0.061	0.239	0.000	1.000	0.447	-0.017	0.230	0.059	0.248	0.243	-0.058	0.072	0.075	-0.040	0.157	0.477	0.013	1.000

Notes.

Number of firms: 1210; Number of observations: 6578.

Following prior studies (Forman et al. 2009; Gowrisankaran and Stavins 2004; Tucker 2008) with binary dependent variables, I estimate the IPO regression using a linear probability model with firm fixed effects, due to the known difficulty of controlling for time-invariant unobserved heterogeneity using panel data probit or logit models. In particular, I estimate:

$$\begin{aligned} 1(IPO_{it+1} = 1) \\ &= \alpha + \beta_1 partner_{it} + \beta_2 patent_{it} + \beta_3 copyright_{it} \\ &+ \beta_4 trademark_{it} + \beta_5 age_{it} + \ \beta_6 {age_{it}}^2 \\ &+ \beta_7 cinvest_{it} + \beta_8 pinvest_{it} + \beta_9 vinest_{it} \\ &+ \beta_{10} publication_{it} + \beta_{11} industryGrowth_{it} \\ &+ \beta_{12}\, employee_{it} + year_{t+1} + \ c_i + u_{it+1} \end{aligned} \tag{3.2}$$

where $1(IPO_{it+1} = 1)$ represents a binary variable indicating whether an IPO has been issued in year t+1. Note that only private firms are included in the IPO regression. The observations after a firm goes public are dropped from the sample as the firm is no longer exposed to the hazard of issuing an IPO. I lag all the independent variables by one year to further mitigate for potential endogeneity of the right-hand-side variables. Number of employees is entered into the regression equation in log form.

Moderating Effects of Appropriation Mechanisms. In order to evaluate Hypotheses 3 and 4, I add interactions between an ISV’s partnering status and its IPR and downstream capabilities. To enable a more intuitive interpretation of my regression results, I create discrete measures of IPR and downstream capabilities. Particularly, the variables *highCopyright* and *highTrademark* are set to 1 if an ISV’s cumulative number of copyrights and trademarks are in the top quartile of the distribution[22]. Because less than 15% of the observations have patents, the variable *highPatent* is set to 1 if an ISV has at least one patent during the year, 0 otherwise.

To summarize, I estimate the following two equations to test if the effects of partnering on an ISV's sales and likelihood of issuing an IPO are moderated by appropriation mechanisms.

$$\begin{aligned} Log(sales_{it}) = {} & \alpha + \beta_1 partner_{it} + \beta_2 highPatent_{it} \\ & + \beta_3 highCopyright_{it} + \beta_4 highTrademark_{it} \\ & + \beta_5 age_{it} + \beta_6 {age_{it}}^2 + \beta_7 public_{it} + \beta_8 cinvest_{it} \\ & + \beta_9 pinvest_{it} + \beta_{10} vinest_{it} + \beta_{11} publication_{it} \\ & + \beta_{12} industryGrowth_{it} + \beta_{13} partner_{it} \\ & \times highPatent_{it} + \beta_{14} partner_{it} \times highCopyright_{it} \\ & + \beta_{15} partner_{it} \times highTrademark_{it} + year_t + c_i \\ & + u_{it} \end{aligned} \tag{3.3}$$

$$\begin{aligned} 1(IPO_{it+1} = 1) & \\ = {} & \alpha + \beta_1 partner_{it} + \beta_2 highPatent_{it} \\ & + \beta_3 highCopyright_{it} + \beta_4 HighTrademark_{it} \\ & + \beta_5 age_{it} + \beta_6 {age_{it}}^2 + \beta_7 cinvest_{it} + \beta_8 pinvest_{it} \\ & + \beta_9 vinest_{it} + \beta_{10} publication_{it} \\ & + \beta_{11} industryGrowth_{it} + \beta_{12}\, employee_{it} \\ & + \beta_{13} partner_{it} \times highPatent_{it} + \beta_{14} partner_{it} \\ & \times highCopyright_{it} + \beta_{15} partner_{it} \\ & \times highTrademark_{it} + year_{t+1} + c_i + u_{it+1} \end{aligned} \tag{3.4}$$

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[22] As a robustness check, I test the models using an alternative threshold, the 50th percentile, to define the variables *highpatent*, *highcopyright* and *hightrademark*. I conduct further robustness checks using continuous values for patents, copyrights and trademarks. All my findings reported in the main text are robust to these alternative specifications.

3.4. Results

3.4.1. Effect of Joining Platform Ecosystem on Sales

The results of fixed effects models that use *log(sales)* as the dependent variable are presented in Table 3.2. Variables are entered into the regressions sequentially. In column 1 I present the baseline model in which only the variables partnering status, IPR and downstream capabilities are included. In column 2 I add the other control variables. In column 3 I include year dummies.

Examining the results from the final model, I find support for Hypothesis 1, suggesting that joining a platform ecosystem is associated with greater sales. The variable *partner* is significant at the 5% level in all of the models. On average, ISVs enjoy a 26% ($=e^{.23}-1$) increase in sales after they become SAP certified. Interestingly, I also find that ISVs' annual sales are strongly correlated with their appropriability mechanisms, as the coefficients of patent, copyright and trademark are positive and highly significant.[23]

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[23] Note that I present two sets of R-squared values in all of my tables. First, I present "within" R-squares that do not include the explanatory power of the fixed effects on the explained sum of squares, and are computed based on the fraction of variance explained within firms. These within R-square values are lower than my R-squared with fixed effects, which are based on the total (within and between) sum of squares and incorporate the explanatory power of the fixed effects. Note that in my IPO regressions, my dependent variable is binary, not continuous, and regressions with binary dependent variables typically have lower R-squared values than continuous variables. For further examples, see Forman et al. (2009).

Table 3.2 Effect of Partnering on Sales

Variables	(1) Baseline model	(2) With firm level controls	(3) With year dummies
Partner	0.484***	0.254**	0.231**
	(0.115)	(0.105)	(0.105)
Patent	0.179***	0.121***	0.111***
	(0.032)	(0.026)	(0.027)
Copyright	0.233***	0.167***	0.156***
	(0.034)	(0.031)	(0.031)
Trademark	0.204***	0.102***	0.085***
	(0.025)	(0.024)	(0.024)
Age		0.079***	0.037***
		(0.009)	(0.011)
Age^2		-0.002***	-0.002***
		(0.000)	(0.000)
Publication		0.062	0.048
		(0.065)	(0.065)
Cinvest		0.339***	0.327***
		(0.119)	(0.117)
Pinvest		0.040	0.027
		(0.045)	(0.045)
Vinvest		0.172**	0.171**
		(0.085)	(0.085)
IndustryGrowth		0.048***	0.055***
		(0.015)	(0.016)
Public		0.715***	0.704***
		(0.136)	(0.136)
Year dummies	No	No	Yes
Constant	1.232***	0.476***	0.848***
	(0.019)	(0.071)	(0.090)
Observations	6578	6578	6578
Number of firms	1210	1210	1210
R-squared (within)	0.103	0.183	0.192
R-squared (with fixed effects)	0.906	0.914	0.915

Notes.
Fixed effects panel data models with robust standard errors in parentheses.
*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

3.4.2. Effect of Joining Platform Ecosystem on IPO

Hypothesis 2 suggests that joining a platform innovation ecosystem is associated with a greater likelihood of issuing an IPO. The hypothesis is supported by the results in Table 3.3. As I did for the sales models, I present the baseline model in column 1, the one with the full set of control variables in column 2, and include year dummies in column 3. The variable *partner* is significant at the 5% or 10% level in all of the models. Using the results of the full model in column 3, I find that joining SAP's platform ecosystem is associated with a 5.9 percentage point increase in the likelihood of obtaining an IPO, supporting Hypothesis 2.

Table 3.3 Effect of Partnering on IPO

Variables	(1) Baseline model	(2) With firm level controls	(3) With year dummies
Partner	0.066**	0.060*	0.059*
	(0.033)	(0.034)	(0.034)
Patent	0.004	0.005	0.004
	(0.004)	(0.004)	(0.004)
Copyright	0.019**	0.016**	0.016*
	(0.008)	(0.008)	(0.008)
Trademark	0.002	-0.000	-0.000
	(0.003)	(0.003)	(0.003)
Age		0.000	-0.001
		(0.001)	(0.001)
Age^2		-0.000	-0.000
		(0.000)	(0.000)
Publication		-0.006*	-0.006*
		(0.003)	(0.003)
Employee		0.004***	0.004**
		(0.002)	(0.002)
Cinvest		0.043	0.044
		(0.028)	(0.028)
Pinvest		0.004	0.004
		(0.005)	(0.005)
Vinvest		0.027	0.028
		(0.021)	(0.021)
IndustryGrowth		0.002	-0.001
		(0.002)	(0.002)
Year dummies	No	No	Yes
Constant	-0.005	-0.025***	-0.003
	(0.003)	(0.009)	(0.022)
Observations	6266[1]	6266[1]	6266[1]
Number of firms	1175[1]	1175[1]	1175[1]
R-squared (within)	0.020	0.032	0.037
R-squared (with fixed effects)	0.654	0.662	0.664

Notes.

Fixed effects panel data models with robust standard errors in parentheses.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

[1]: only private companies are included. Post IPO observations are dropped.

3.4.3. Robustness Checks

I test a number of alternative models and use different variable definitions to demonstrate the robustness of my findings. The results are presented in Table 3.4 (sales results) and Table 3.5 (IPO results).

First, in the benchmark models I use forward-citation-weighted patents and publications as independent variables. In column 1 of Table 3.4 and Table 3.5 I present a similar specification using a fixed effects model and raw counts of patent stocks and scientific publications that are unweighted by forward citations. Second, although fixed effects models are robust to unobserved heterogeneity and require weaker model assumptions, they are more susceptible to attenuation bias arising from measurement error (Griliches and Hausman 1986). In column 2 of Tables 3.4 and 3.5 I present the results from a random effects model. I observe that the estimates of the marginal effects of partnering are very similar to that of the fixed effects model.

Table 3.4 Robustness Check, Sales

Variables	(1) Unweighted patent and publication	(2) Random effects	(3) Years before partner	(4) Instrumental variables
Partner	0.230**	0.232**	0.298***	1.995**
	(0.102)	(0.096)	(0.115)	(0.822)
Patent	0.443***	0.097***	0.110***	0.100***
	(0.091)	(0.022)	(0.027)	(0.029)
Copyright	0.128***	0.173***	0.156***	0.136***
	(0.031)	(0.022)	(0.031)	(0.032)
Trademark	0.080***	0.136***	0.084***	0.057**
	(0.023)	(0.021)	(0.023)	(0.028)
Age	0.035***	0.032***	0.036***	0.037***
	(0.011)	(0.008)	(0.011)	(0.011)
Age^2	-0.002***	-0.002***	-0.002***	-0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
Publication	0.062	0.014	0.049	0.089
	(0.060)	(0.044)	(0.065)	(0.068)
Cinvest	0.321***	0.301***	0.328***	0.347***
	(0.118)	(0.082)	(0.117)	(0.125)
Pinvest	0.024	-0.058*	0.028	0.036
	(0.044)	(0.033)	(0.045)	(0.048)
Vinvest	0.166*	0.290***	0.168**	0.033
	(0.086)	(0.059)	(0.086)	(0.108)
IndustryGrowth	0.054***	0.059***	0.055***	0.057***
	(0.016)	(0.016)	(0.016)	(0.017)
Public	0.626***	0.791***	0.705***	0.426**
	(0.137)	(0.105)	(0.136)	(0.217)
One year before partnering			0.070	
			(0.102)	
Two years before partnering			0.122	
			(0.123)	
Year dummies	Yes	Yes	Yes	Yes
Constant	0.868***	0.941***	0.850***	
	(0.090)	(0.067)	(0.090)	
Observations	6578	6578	6578	6578
Number of firms	1210	1210	1210	1210
R-squared (within)	0.197	.	0.193	0.069
R-squared (with fixed effects)	0.915		0.915	

Notes.

Robust standard errors in parentheses.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 3.5 Robustness Check, IPO

Variables	(1) Unweighted patent and publication	(2) Random effects	(3) Years before partner	(4) Instrumental variables
Partner	0.059*	0.058*	0.063*	0.242*
	(0.034)	(0.035)	(0.035)	(0.132)
Patent	0.018	0.006	0.004	0.002
	(0.016)	(0.004)	(0.004)	(0.005)
Copyright	0.015*	0.014**	0.016**	0.014*
	(0.008)	(0.006)	(0.008)	(0.008)
Trademark	-0.000	-0.001	-0.000	-0.003
	(0.003)	(0.003)	(0.003)	(0.004)
Age	-0.001	0.000	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Age^2	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Publication	-0.010**	-0.005	-0.005*	-0.002
	(0.004)	(0.003)	(0.003)	(0.002)
Employee	0.004**	0.006***	0.004**	0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Cinvest	0.044	0.028	0.044	0.041
	(0.028)	(0.021)	(0.028)	(0.028)
Pinvest	0.004	-0.002	0.004	0.006
	(0.005)	(0.004)	(0.005)	(0.005)
Vinvest	0.029	0.035**	0.028	0.014
	(0.021)	(0.015)	(0.021)	(0.018)
IndustryGrowth	-0.001	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
One year before partnering			-0.009	
			(0.030)	
Two years before partnering			0.032	
			(0.050)	
Year dummies	Yes	Yes	Yes	Yes
Constant	-0.002	-0.021*	-0.003	
	(0.022)	(0.011)	(0.022)	
Observations	6266[1]	6266[1]	6266[1]	6266[1]
Number of firms	1175[1]	1175[1]	1175[1]	1175[1]
R-squared (within)	0.038	.	0.040	0.041
R-squared (with fixed effects)	0.664		0.665	

Notes.

Robust standard errors in parentheses.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

[1]: only private companies are included. Post IPO observations are dropped.

It is possible that there exist time-varying omitted variables that affect both the ISV's decision to join SAP's platform ecosystem and its performance, which are not fully accounted for in the fixed effects models in Tables 3.2 and 3.3. For example, it is possible that ISVs with superior performance choose to join the SAP's platform ecosystem. I address these endogeneity concerns in several ways. First, as a falsification test I verify that the measured positive impacts of partnering on ISV performances do not occur before the partnering year (Agrawal and Goldfarb 2008). If we expect firms with better financial status will join SAP's ecosystem, it is likely that I will observe an increase in sales or the likelihood of an IPO in the years preceding their partnership with SAP. To investigate this possibility, I add as additional controls two dummy variables that are equal to one in the two years prior to the first partnering event. I present the results in column 3 of Tables 4 and 5. The results show no significant preexisting trend on sales or the likelihood of an IPO for partnering ISVs. The effect only takes place *after* partnering with SAP.

Second, I use instrumental variables (IV) methods to address potential endogeneity concerns. In particular, I use two candidate variables that should be correlated with the partnering decision but not with financial performance. The first variable describes how many executives of an ISV have personal connections with SAP. From the CorpTech database I retrieve the complete list of executives for every firm-year. I then look up the working experience of each executive on the business-oriented social network website, LinkedIn, to find if he/she has ever worked for SAP as an employee. I then aggregate the number of executive links to SAP at the firm-year level. The rationale for using this variable as an instrument is that an executive's past working experience at SAP is likely to establish personal connections that would increase the propensity to partner with SAP. However, it is unlikely to be correlated with unobserved firm-level factors that would increase the performance of the firm where he/she serves as an executive. The second variable describes the propensity to partner with SAP among ISVs that serve markets similar to those of the focal ISV. The CorpTech database has data on the target industries within which each company sells its products and services, which I broadly classify into 40 categories. I calculate the fraction of ISVs that partner with SAP in each industry-year, and use this to approximate the partnering propensity at the industry level. I then calculate the partnering propensity for each ISV, by weighting these data by the set of industries served by the ISV. If an ISV serves multiple industries, the industry level propensities are averaged to derive the ISV's propensity. The logic for this variable is that it will capture cross-industry differences in the value of partnership. However, conditional on my controls for industry growth, it should be uncorrelated with factors influencing ISV performance. Following prior literature on instrumental variables under binary endogenous variables, I use these instruments to run a probit model of the propensity of a firm-year to be an SAP partner.[24] I then use the predicted probability of partnership from this probit model, and the square of this predicted probability, as my instruments. Using nonlinear fitted values of instruments in this way has been shown under some cases to have superior efficiency properties than a traditional linear first stage but still provides consistent estimates (Angrist 2001; Newey 1990).

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[24] That is, I run the probit model of partnership on my two instruments: social connections and industry propensity to partner.

I present the results from the instrumental variable model in column 4 of Tables 4 and 5. My results are robust to the use of these models.[25]

Since acquisition by another firm is often considered a successful exit strategy for small start-up firms, an alternative measure of forward-looking performance in the literature is whether the firm issues an IPO or has been acquired (Cockburn and MacGarvie 2009). I also examine how partnership influenced the likelihood of obtaining an IPO or acquisition,[26] and the results were qualitatively similar to my IPO models.[27]

3.4.4. Moderating Effect of Appropriability Mechanisms for Sales

Hypothesis 3 suggests that the positive effect of joining a platform ecosystem on an ISV's sales is greater when the ISV enjoys greater IPR protection or stronger downstream capabilities. In other words, the effect of partnering on ISV sales is moderated by their appropriability mechanisms. I present the results for the moderating effects in Table 3.6. As usual, fixed effects panel data models are used. Column 1 presents the baseline model where only partnering status, appropriability mechanisms and their interactions are included. In column 2 I add the control variables, while in column 3 I include year dummies. The results in column 3 suggest that ISVs who partner with SAP on average experience a 43.6% sales increase provided that they have high patent stocks, a 32% increase provided that they have high copyright stocks, or a 26.9% increase provided that

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[25] All the instrumental variable results presented in the study are supported by tests of instruments validity (available from the author upon request). Indeed, the p-value related to the tests of the joint null hypothesis of no effect of the instruments on partnership is always lower than 0.001. In addition, the tests of the overidentifying restrictions (Hansen J tests) always suggest that the instruments used are exogenous in all the IV specifications presented in the study.

[26] I define acquisitions as majority share acquisitions, and I exclude bankrupt acquisitions and liquidation acquisitions. Data are collected from the SDC Platinum database.

[27] Due to space constraints, the results of these models are not reported, but are available upon request.

they have high trademark stocks. The upper panel of Figure 3.2, which is based on column 3 of Table 3.6, visually illustrates the moderating effect of IPR and downstream capabilities on the relationship between partnership and ISV sales. Surprisingly, my results indicate that ISVs whose innovations are not protected by any means of appropriation do not experience any significant improvement in sales. If anything, their sales performance is poorer (though not significantly so) than if they did not partner.

While a firm's stock of trademarks is a good measure of its marketing and distribution capabilities, I acknowledge that the downstream capabilities of an ISV may encompass other equally important dimensions that may not be entirely captured by the firm's stock of trademarks, such as its consulting and other professional service capabilities. As a robustness check of my measure of downstream capabilities, I construct a variable that measures the extent of software services that are offered by an ISV. The CorpTech database provides information on my sample firms' portfolio of software service offerings, which are classified into categories such as software consulting services, business intelligence services, custom software programming services and artificial intelligence R&D services.[28] From this information I derive the variable anyService, which indicates that the ISV offers services to its clients (about 22% of the sample has anyService equal to 1). After sales service and support is an important part of the service offerings of many ISVs, and in many cases will be required by potential buyers to purchase the software. Thus, it is an alternative measure of downstream capabilities.

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[28] The complete list of service categories is as follows: artificial intelligence (AI) services, AI software programming, AI R&D services, other R&D services not elsewhere classified, software consulting services, custom software programming services, applications software services, systems software services, other custom programming services, and other software services.

I present the results with this new measure in columns 4 and 5 of Table 3.6. When *anyService* is substituted for *highTrademark* it behaves very similar to the latter variable; the interaction term of Partner and *anyService* is positive and significant in column 4. However, when both *highTrademark* and *anyService* are included in the same regression (in column 5) I find that the latter variable is statistically insignificant. I take this as evidence that while both *highTrademark* and *anyService* capture downstream capabilities, *highTrademark* is more important than *anyService* in appropriating the returns from partnership. There may be several reasons for this result: trademarks may be a stronger appropriability mechanism because they are more difficult to imitate; further, in the case of a sales increase the stock of trademarks can be scaled up at a much lower cost than services. Regardless of the measure used, I find that the interactions between *partner* and *highPatent* and *highCopyright* are all positive and significant at conventional levels. The results lend support to Hypothesis 3a and 3b.

Table 3.6 Moderating Effect of IPR and Downstream Capabilities, Sales

Variables	(1) Baseline model	(2) With firm level controls	(3) With year dummies	(4) With service only	(5) With service and trademarks	(6) Instrumental Variables
Partner	0.057	-0.084	-0.149	-0.043	-0.185	-0.543
	(0.136)	(0.129)	(0.129)	(0.107)	(0.132)	(1.398)
HighPatent	0.616***	0.383***	0.346***	0.356***	0.344***	
	(0.058)	(0.057)	(0.056)	(0.056)	(0.056)	
HighCopyright	0.456***	0.339***	0.310***	0.315***	0.310***	
	(0.045)	(0.043)	(0.043)	(0.043)	(0.043)	
HighTrademark	0.199***	0.104***	0.088***		0.089***	0.070*
	(0.021)	(0.021)	(0.021)		(0.021)	(0.031)
AnyService				0.009	0.017	
				(0.043)	(0.043)	
HighIPR						0.285***
						(0.063)
Partner × HighPatent	0.392***	0.323**	0.362**	0.466***	0.426***	
	(0.149)	(0.143)	(0.142)	(0.148)	(0.149)	
Partner × HighCopyright	0.251**	0.262**	0.278**	0.265**	0.295**	
	(0.127)	(0.121)	(0.121)	(0.121)	(0.121)	
Partner × HighTrademark	0.385***	0.214**	0.238**		0.199*	1.175
	(0.112)	(0.107)	(0.106)		(0.110)	(0.765)
Partner × AnyService				0.230*	0.161	
				(0.121)	(0.124)	
Partner X HighIPR						2.498*
						(1.323)
Age		0.081***	0.035***	0.038***	0.035***	0.029***
		(0.007)	(0.009)	(0.009)	(0.009)	(0.011)
Age^2		-0.002***	-0.002***	-0.002***	-0.002***	-0.002***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Publication		0.083*	0.066	0.064	0.062	0.120*
		(0.050)	(0.050)	(0.050)	(0.050)	(0.068)
Cinvest		0.357***	0.339***	0.354***	0.342***	0.329**
		(0.069)	(0.068)	(0.068)	(0.068)	(0.136)
Pinvest		0.049	0.035	0.042	0.036	0.059
		(0.034)	(0.034)	(0.034)	(0.034)	(0.050)
Vinvest		0.165***	0.164***	0.158***	0.159***	-0.035
		(0.051)	(0.051)	(0.051)	(0.051)	(0.125)
Public		0.749***	0.730***	0.754***	0.732***	0.484*
		(0.061)	(0.061)	(0.061)	(0.061)	(0.225)
IndustryGrowth		0.048***	0.055***	0.055***	0.056***	0.058***
		(0.013)	(0.015)	(0.015)	(0.015)	(0.018)
Year dummies	No	No	Yes	Yes	Yes	Yes
Constant	1.220***	0.430***	0.839***	0.838***	0.835***	
	(0.014)	(0.053)	(0.076)	(0.077)	(0.077)	
Observations	6578	6578	6578	6578	6578	6477
Number of firms	1210	1210	1210	1210	1210	1109
R-squared (within)	0.091	0.182	0.192	0.189	0.193	0.012
R-squared (with fixed effects)	0.904	0.913	0.915	0.914	0.915	

Notes.

Fixed effects panel data models with robust standard errors in parentheses.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

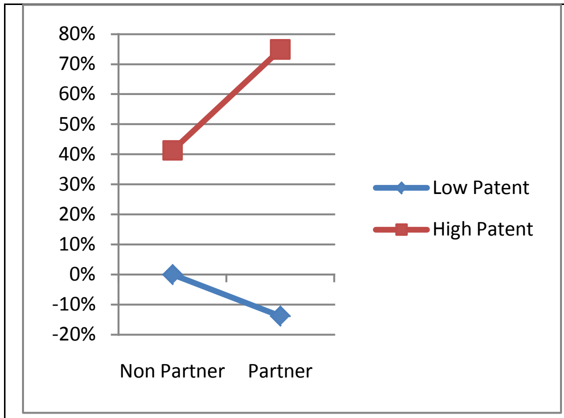

Figure 3.2a: Marginal Effect of Partnership on Growth in Sales by Patent Stock

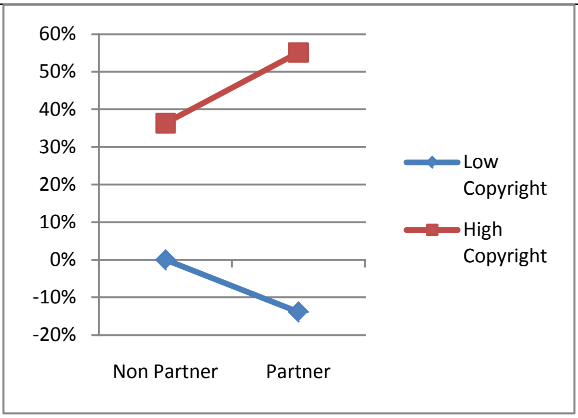

Figure 3.2b: Marginal Effect of Partnership on Growth in Sales by Copyright Stock

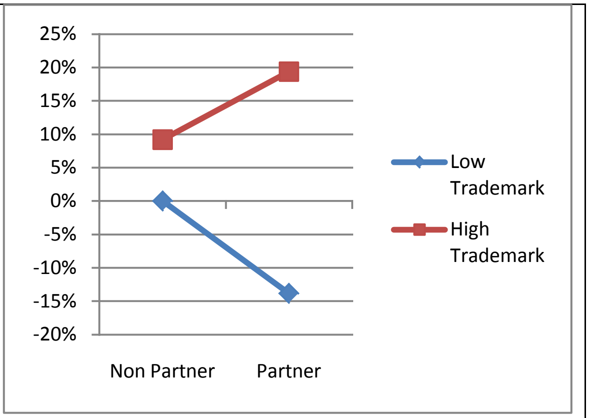

Figure 3.2c: Marginal Effect of Partnership on Growth in Sales by Trademark Stock

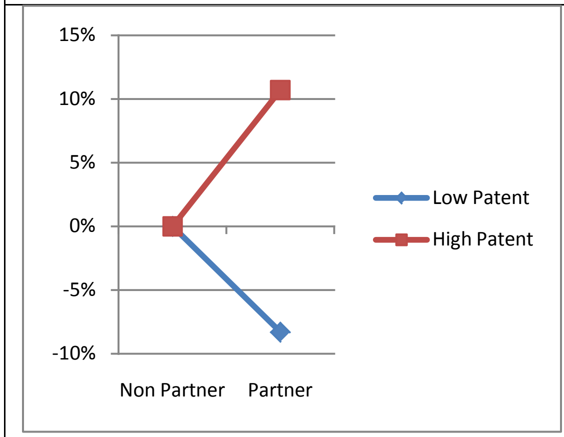

Figure 3.2d: Marginal Effect of Partnership on IPO Likelihood by Patent Stock

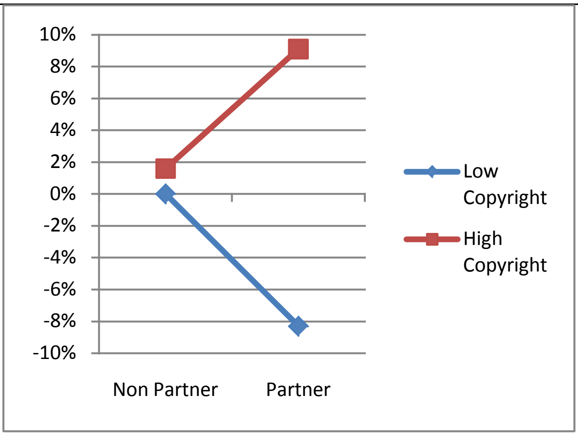

Figure 3.2e: Marginal Effect of Partnership on IPO Likelihood by Copyright Stock

Notes:

1. Marginal effects on sales are measured by percent increase
2. Marginal effects on IPO are measured by increase in percentage point

Figure 3.2 Moderating Effects of Patents, Copyrights and Trademarks

3.4.5. Moderating Effect of Appropriability Mechanisms for IPO

I find that the positive effect of joining a platform ecosystem on the ISVs' likelihood of issuing an IPO is also moderated by their appropriability mechanisms. Table 3.7 presents the results of this model. Confirming Hypothesis 4a (column 3 of Table 3.7), I find that the increase in the likelihood of obtaining an IPO will be 19.0 percentage points higher provided the ISV also has high patent stocks and 15.8 percentage points higher provided it also has high copyright stocks. These results are statistically significant at conventional levels. I do not find evidence that ISVs with high trademarks experience greater benefits from partnering. The moderating effects of IPR are illustrated in the lower panel of Figure 3.2. In addition, I find that if the innovations of an ISV are not protected by any appropriability mechanism, there is no evidence that partnering will increase the likelihood of obtaining an IPO. This can be seen from the insignificant (and negative) coefficient of the *partner* variable.

I believe that the lack of result for the interaction of *partner* and *highTrademark* may be due to a feature of my data: the number of IPOs decline dramatically throughout my sample because of the deterioration of financial market conditions in the wake of the dot-com bust. At the same time, the fraction of firms with *highTrademark* increases from 22.0% (in 1996) to 38.0% (in 2004). Thus, it is difficult for me to separate the effects of increasing trademarks from deteriorating financial market conditions on the likelihood of an IPO. In a separate set of regressions, I interacted my *partner* variable with a post-2001 dummy and found that the marginal effect of *partner* on IPO declines substantially post-2001 because of this change in external environment. Thus, I believe my coefficients for the *partner* × *highTrademark* variable are biased downward because of this change in economic and financial conditions. As a robustness check, I also used the alternative measure *anyService* (column 4 and column 5) but again found no evidence that this measure of downstream capabilities was complementary with partnership. [29]

While I do use firm fixed effects in all of my models in Tables 6 and 7, one potential concern is that there may exist time-varying omitted variables that may be correlated with *partner* and its interaction with *highPatent*, *highCopyright* and *highTrademark*. If that is the case, then my estimates of these parameters may be biased. However, use of instrumental variables for the complete set of endogenous variables is difficult in my setting: This would require a set of four separate instruments, which would compound the usual problems that fixed effects remove all of the useful cross-sectional variation in the data and in the presence of measurement error give rise to attenuation bias (Angrist and Pischke 2009; Greene 2002). To reduce the number of endogenous variables that I must instrument for, I create a new variable called *highIPR* which equals to one if either *highPatent* or *highCopyright* is one. Since patents and copyrights are used as substitute forms of IPR protection in the software industry (Lerner and Zhu 2007), this variable is a combined measure of IPR protection for the ISV.

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[29] Note that because I measure no significant moderating effects of trademarks on IPO likelihood, I do not include a graph of these results in Figure 3.2.

Table 3.7 Moderating Effect of IPR and Downstream Capabilities, IPO

Variables	(1) Baseline model	(2) With firm level controls	(3) With year dummies	(4) With service only	(5) With service and trademarks
Partner	-0.077	-0.081	-0.083	-0.068	-0.080
	(0.071)	(0.072)	(0.071)	(0.042)	(0.071)
HighPatent	0.002	0.002	-0.000	-0.001	-0.001
	(0.008)	(0.010)	(0.009)	(0.009)	(0.009)
HighCopyright	0.016*	0.016	0.016	0.015	0.015
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
HighTrademark	0.004	0.000	-0.000		-0.000
	(0.004)	(0.004)	(0.004)		(0.004)
AnyService				0.006	0.006*
				(0.004)	(0.004)
Partner × HighPatent	0.194**	0.189*	0.190*	0.180*	0.179*
	(0.098)	(0.102)	(0.101)	(0.103)	(0.100)
Partner × HighCopyright	0.162**	0.160**	0.158**	0.160**	0.163**
	(0.068)	(0.068)	(0.067)	(0.068)	(0.069)
Partner × HighTrademark	0.005	0.005	0.007		0.016
	(0.054)	(0.054)	(0.054)		(0.053)
Partner × AnyService				-0.041	-0.045
				(0.031)	(0.028)
Age		0.001	-0.001	-0.001	-0.001
		(0.000)	(0.001)	(0.001)	(0.001)
Age^2		-0.000	-0.000	-0.000*	-0.000*
		(0.000)	(0.000)	(0.000)	(0.000)
Publication		-0.004*	-0.004*	-0.005*	-0.005*
		(0.002)	(0.002)	(0.003)	(0.003)
Employee		0.004***	0.004**	0.004**	0.004**
		(0.002)	(0.002)	(0.002)	(0.002)
Cinvest		0.041	0.041	0.041	0.041
		(0.028)	(0.028)	(0.028)	(0.028)
Pinvest		0.004	0.004	0.004	0.004
		(0.005)	(0.005)	(0.005)	(0.005)
Vinvest		0.024	0.026	0.027	0.027
		(0.021)	(0.021)	(0.021)	(0.021)
IndustryGrowth		0.002	-0.001	-0.001	-0.001
		(0.002)	(0.002)	(0.002)	(0.002)
Year dummies	No	No	Yes	Yes	Yes
Constant	-0.001	-0.026***	0.003	-0.001	-0.000
	(0.003)	(0.009)	(0.021)	(0.020)	(0.020)
Observations	6266[1]	6266[1]	6266[1]	6266[1]	6266[1]
Number of firms	1175[1]	1175[1]	1175[1]	1175[1]	1175[1]
R-squared (within)	0.038	0.053	0.058	0.060	0.060
R-squared (with fixed effects)	0.660	0.669	0.671	0.672	0.672

Notes. Fixed effects panel data models with robust standard errors in parentheses.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

[1]: only private companies are included. Post IPO observations are dropped.

Thus, I have three endogenous variables: *partner, partner* × *highIPR,* and *partner* × *highTrademark.* Following prior literature on the use of instrumental variables in nonlinear (in variables) settings (Gallant 1987, p. 440), I instrument for these variables using the predicted values of partner using the method above, and the interaction of this variable with *highIPR, highTrademark,* and other exogenous variables such as age, age-squared, and sales growth. In total, I have eight instruments for three endogenous variables.

Instrumental variables estimates for my sales regressions are included in column 6 of Table 3.6. My results are qualitatively robust to the use of instrumental variables and fixed effects. The coefficient estimates show that partnership will only be associated with an increase in sales in the presence of *highIPR* and *highTrademark*. The coefficient for the interaction of *partner* with *highIPR* remains significant at the 10% level. The interaction of *partner* with *highTrademark*, while not significantly different than zero at conventional levels, remains statistically significant at the 12.5% level.

Instrumental variable results related to the IPO equation with interactions are not shown due to the poor fit of the model (negative R-squared) and the inability to identify the effects under study. I believe that this is due partly to the difficult data environment: In the IPO regressions my dependent variable is binary, a particularly challenging setting to estimate via nonlinear IV (instrumenting for partnership and its interactions) using only the *within* firm variation (because of my use of firm fixed effects). Further, as noted above, the effect of *highTrademark* is inherently more difficult to identify in this setting because of the aggregate time series trend in *highTrademark* and *partner*.

3.5. Conclusions

To summarize, I report participating in a platform ecosystem as a new and viable innovation commercialization strategy employed by small ISVs. My results demonstrate that, on average, ISVs can achieve significant benefits through participation in a platform ecosystem—benefits that can translate into significant increases in sales and an increased likelihood of eventually attaining an IPO, a widely recognized measure of success for start-up firms. However, there exists considerable heterogeneity in the extent to which ISVs can capture the value co-created by these partnerships. In particular, ISVs without downstream marketing or service capabilities or without IPR such as patents and copyrights will appropriate less of the co-created value generated from compatibility with the platform. These results are robust to a battery of robustness checks, including instrumental variables analysis and a falsification exercise.

Limitations. I believe that my study represents a careful analysis of the impact of platform participation on small firm performance. However, like any empirical study, it does have several limitations. One potential issue arises from sample definition, in particular how to determine the “at- risk” set of potential participants in the ecosystem. As noted above, in this study I identify the set of at-risk firms as those software firms producing manufacturing and warehousing/distribution software. I chose not to extend my sample to firms producing other product types for two reasons. First, many of the software firms in my sample produce other types of products beyond manufacturing and warehousing/distribution. Thus, my sample includes a much broader cross-section of software products than might appear at first glance. For example, among my sample of 1210 ISVs, 474 also produce accounting software, 323 provide utility systems software, and 256 also provide sales/marketing software. Second, selecting on other software product types would introduce significant unobserved heterogeneity into my sample by adding many firms whose products are unrelated to SAP's software and for whom the benefits of partnership are likely to be extremely low. For example, if I add producers of accounting software to my list (SOF-AC; the group with the next highest hazard rate of partnership), it would increase my sample size by over 2000 firms, but would add only 14 partners.

Implications for Other Industry Environments. My study follows prior work that has used case studies of individual industries to examine the implications of platforms for producer and user behavior (Adomavicius et al. 2008; Nair et al. 2004). I believe this approach is appropriate for the study of platform industries insofar as it reduces unobserved heterogeneity across observations and improves internal validity. However, my focus on platform ecosystems is valid across a wide variety of settings. Large ecosystems have been fundamental to the success (in terms of platform sales, and ultimate business survival) of IT platforms such as Ethernet (13 vendors supported Ethernet in 1982 compared to the three vendors supporting Token Ring; Von Burg 2001); Microsoft Windows (38,338 vendors, including 3,817 ISVs; Iansiti and Levien 2004); Palm Handhelds (who claimed over 140,000 developers for its standard in 2001; Nair et al. 2004); and iPhone (50,000 applications as of June 2009),[30] as well as Real estate platforms like Multiple Listing Service (12,322 listings in the Madison, WI area according to Hendel et al. 2009).

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[30] http://tech.fortune.cnn.com/2009/06/10/apple-fact-check-50000-iphone-apps/

Moreover, the key platform issues that I study—the benefits to joining a platform from signaling technological compatibility and the risks of entry from the platform owner—also have widespread validity. For example, complementors benefit from compatibility with platforms such as Microsoft Windows, the Cisco Internetwork Operating System (IOS), and Intel microprocessors, however the threat of incursion from the platform owner into the complementor's market has been a focus of theoretical work and case studies in all three industries (Eisenmann et al. 2007; Gawer and Cusumano 2002; Gawer and Henderson 2007).

While my setting shares many features with other IT platforms, one key difference is that complementors in my setting have the option to choose between joining a platform and selling platform-independent, stand-alone applications. In particular, in my setting, the platform plays the role of reducing compatibility costs among heterogeneous components, rather than providing an infrastructure that includes components required for complementary applications to run. In that way, my setting shares similarity with environments like Cisco's Internetwork Operating System (IOS) platform (which reduces the costs of communication among heterogeneous routers and switches) rather than the Microsoft Windows or Xbox platforms (which includes key infrastructure required for complementors' applications to run). More empirical research is needed in this latter, important area.

It is important to state how ecosystem partnerships are distinct from other forms of IT value co-creation (Kohli and Grover 2008). Like other settings of IT value co-creation, in my setting IT is "instrumental in creating a product to co-create business value" (Kohli and Grover 2008). However, in other settings IT is used to co-create value by facilitating standardization of business processes or improving information flows between heterogeneous systems of individual firms (Markus et al. 2006). In this way, IT facilitates value co-creation by reducing transaction costs through inter-organizational systems that, among other things, strengthen supply chain relationships (Bharadwaj et al. 2007; Clemons et al. 1993; Gerbauer and Buxmann 2000; Melville et al. 2004). In my setting, partnership aids in the standardization of interfaces between software products that are used to co-create business value. In so doing, I add to the evolving work in IS that seeks to understand how firms co-create value through IT platforms (Dhar and Sundararajan 2007).

Theoretical Implications. Platform-based innovation ecosystems present an interesting setting for studies on the dynamics of inter-organizational collaboration and competition. An increasing body of theoretical work has examined firm strategies in platform markets, including decisions on the extent to which a platform should be opened (Eisenmann et al. 2008; Parker and Van Alstyne 2008; West 2003) and vendor reactions to open and closed platforms (Lee and Mendelson 2008; Mantena et al. 2007). However, there has been little research that measures the value co-created through participation in such a platform. My study takes initial steps to investigate these issues from the perspective of small, complementary solution providers in the enterprise software industry.

Perhaps most significantly, I establish a set of boundary conditions on the extent to which this value is captured by small ISVs. These findings extend and complement Chapter 2, where I show that highly innovative ISVs are more likely to join a platform ecosystem. Interestingly, while this focus on establishing the conditions for appropriating value from IT investment has long been a focus on other ecosystems studied in the information systems literature such as supply chain relationships (Grover and Saeed 2007; Subramani 2004), it has drawn relatively little attention in empirical work on software platforms. I feel this is a fruitful area for future research.

Finally, my contributions to the markets for technology literature stems naturally from my focus on the enterprise software industry. In this setting technology commercialization by entrepreneurial companies may be facilitated by joining the platform ecosystem. Such partnerships represent a natural setting for the identification of the effect of IPR on technology commercialization and firm performance, a key objective of this study and the markets for technology literature (Arora and Ceccagnoli 2006; Arora et al. 2001; Cockburn and MacGarvie 2006; Cockburn and MacGarvie 2009; Gans et al. 2002). Indeed, unintended knowledge spillovers are particularly salient during SAP software certification, which requires partnering firms to closely integrate their product interface designs. This highlights a clear tradeoff for technology commercialization by ISVs. My results imply that strong IPR directly influence this tradeoff by affecting the likelihood of expropriation of IP rights and platform owner entry. Further, strong IPR will indirectly benefit the platform owner by nurturing the platform ecosystem with innovative software solutions. In other words, IPR appear to favor both value appropriation and value co-creation in the enterprise software industry.

Managerial Implications. My findings have important implications for both platform sponsors as well as those who participate in the platform ecosystem. First, my results suggest that under certain conditions ISVs who join a platform ecosystem will see gains in operational performance. However, ISVs whose innovations are not protected by IPR or downstream complementary capabilities should be cautious about initiating partnerships. To prevent the threat of invasion from the platform owner, they should actively seek IPR protection, or secure complementary downstream capabilities first. Finally, I believe that it is critical for the platform owners to understand the incentives of complementary product providers. In particular, the appropriate management of the expropriation concerns of its smaller yet most innovative entrepreneurial partners represents a potential strategy to sustain their innovation ecosystems.

More generally, my results suggest some conditions under which a “virtuous cycle” may be realized in a software platform ecosystem. As is well known, there is significant variation in the extent to which formal appropriability mechanisms like patents and copyrights are effective at protecting firms’ IP rights (Cohen et al. 2000). My results suggest that ISVs who participate in markets for which appropriability mechanisms like patents are strong will see greater returns from partnership. These greater returns will in turn encourage new partners to join the ecosystem, and will also draw in additional customers (and in turn, more partners). My results similarly suggest conditions under which this virtuous cycle is unlikely to occur, however. In environments where appropriability mechanisms are weak, my results suggest that the expected gains from partnership are relatively low, and under such conditions the platform ecosystems are most likely to be unsuccessful in attracting complementary innovation.

CHAPTER 4

CO-INNOVATION IN ENTERPRISE INFORMATION SYSTEMS AND IT PRODUCTIVITY: EVIDENCE FROM SAP ECOSYSTEM

4.1. Introduction

To the extent that pure technology advance alone is not sufficient to generate significant economic value, co-inventions around the base technology is often a determinant of its adoption and diffusion (Bresnahan and Greenstein 1996). For example, while digital TV broadcasting technology has been invented long ago, it wasn't widely adopted until complementary innovations in high definition TV sets, digital recording devices and rich content provision were made available. Complementary innovation is especially important to platform-based technologies such as personal computer (Bresnahan and Greenstein 1999), video game console (Zhu and Iansiti 2007) or PDA/ handheld computers (Boudreau 2008), as they are characterized by indirect network effects which arise when the benefit of using the underlying platform increases with the availability of complementary, platform-compatible applications or programs (Katz and Shapiro 1994; Nair et al. 2004). Prior research has documented that technology users are an important source of innovation (Von Hippel 1994a), for they are often the first to develop and use prototypes of enhanced features and add-on functions (Morrison et al. 2000). Innovation ecosystem strategy, in which owners of platform technologies actively seek complementary, third-party innovation from resources located outside the firm, is widely used to encourage user participation in co-innovation (Adner 2006). For example, owners of IT hardware and software platforms such as Apple, Microsoft, IBM, and SAP often sponsor web-based online communities of innovation, which may embrace a series of web 2.0 technologies such as forum, wiki, blogs and code sharing to promote learning, innovation, and knowledge exchange among platform users and developers of the complementary programs.

While there is anecdotal evidence that platform owner-sponsored online communities are often used for promoting innovation and peer-support among platform adopters, and they bear similarity to open source communities in many ways (Gorman and Fischer 2009; Von Hippel 1994a), there has been a lack of formal studies that examine the extent to which user firms of technology platform benefit from participation in those online communities. Given that platform sponsors have invested heavily in building such online innovation communities and they were embraced by millions of members in some cases, answer to this question is critical in the understanding of platform ecosystems. In addition, although recent studies on IT value have established a positive relationship between IT investment and firm performance (Aral et al. 2006; Brynjolfsson and Hitt 1996; Brynjolfsson and Hitt 2003; Dewan and Min 1997), there remains to be considerable variation in the distribution of IT productivity among individual firms (Brynjolfsson and Hitt 2000). Recent studies have attributed this variation to complementarities between IT investment and firm workforce practice (Bresnahan and Greenstein 1996), investment in human capital (Brynjolfsson and Hitt 2000), IT governance (Gu et al. 2008) or actual IT usage (Devaraj and Kohli 2003). However, this research has largely ignored the role of user co-innovation in information systems in explaining this variation. Indeed, “understanding co-invention is a key to understanding the economic payoff to invention in new information technologies today" (Bresnahan and Greenstein 1996).

In this research I try to bridge the gap in prior literature by linking IT productivity theory with research on platform innovation ecosystem. Built upon resource based view of firms and theory of dynamic capabilities, I argue firms' co-innovation in information systems complements their adoption of IT infrastructure and it helps to enhance firm's IT productivity. Following prior research (Bresnahan and Greenstein 1996), I define IT co-innovation as the collection of idiosyncratic adaptations that an IT using organization invents around its computing platform to create a useful mapping between IT and business operations, adaptations that may include configuration, customization and modification of vendor supplied technology, technical solutions and workarounds developed internally to meet idiosyncratic user needs and integrate various IT components, or changes in business processes that can better harness the power of underlying technology. Note my definition of IT co-innovation excludes technology invented by vendors and market supply of complementary applications, which, from the perspective of resource based view, cannot constitute a source of sustained competitive advantage due to its perfect mobility across firm boundaries (Mata et al. 1995). Enterprise software, being the backbone of enterprise information systems, presents an exemplary context where user firms engage in extensive co-innovation. Enterprise software products are highly business process-oriented and usually need to be tailored to fit business practices, where idiosyncratic local needs usually drive innovations in work practices (Hitt et al. 2002; Von Hippel 2005). Starting from a core enterprise software platform, customers simultaneously adapt the software and their business processes to create a socio-technical system that represents a useful mapping between the two. Over time, local innovations and workarounds make their way into the socio-technical system through adaptations to software and formal processes (Gorman and Fischer 2009). This way, firms' accumulation of complementary innovation constitutes an important source of intangible asset that complements firms' IT capital. To empirically test the complementarity between user co-innovation in corporate information systems and IT capital, I construct a sample from Fortune 1000 firms and collect data on their implementation of SAP enterprise software, their IT infrastructure, their stock of co-innovation in SAP's software platform, and their business performances. I adopt the production function framework (Brynjolfsson and Hitt 1996; Dewan and Min 1997; Mittal and Nault 2009) to identify the moderation effect of firms IT co-innovation on their IT productivity. The empirical evidences suggest that firms with mean level stock of IT co-innovation extract as much as 54.5% greater productivity from their IT investment than those without IT co-innovation, and the results are robust to a number of model specifications, alternative measurement of production output, and endogeneity issues.

This research contributes to the extant literature in several ways. First, my view of ecosystem from the perspective of platform adopter reveals key implications on the business value of platform innovation ecosystem. Combined with insights from prior literature that primarily focuses on strategies of the platform sponsor (Boudreau 2007; Eisenmann et al. 2007; Eisenmann et al. 2008), this study provides a holistic understanding of platform ecosystem formation and its value. Second, by investigating the complementarity between user IT co-innovation and IT investment, I add to the current literature on IT business value (Brynjolfsson and Hitt 1996; Dewan and Min

1997) and synergy between IT investment and organizational assets (Brynjolfsson and Hitt 2000; Gu et al. 2008), and identify user co-innovation as one of the important source that contribute the variation of IT productivity across firms.

The rest of the chapter is organized as follows: in section 4.2 I review the relevant literature in IT business value and IT co-innovation, and lay the theoretical foundation of complementarities between IT investment and IT co-innovation. In section 4.3 I propose an innovative way to measure co-innovation in enterprise information systems through an online community of innovation ecosystem. Section 4.4 describes the empirical models and the data set. I present the empirical evidences in section 4.5. Section 4.6 provides conclusions and implications.

4.2. IT Business Value and IT Co-innovation

4.2.1. IT Business Value and Theory of Complementarity

Since the early 1990s' a series of studies on IT business value has presented firm-level evidences that link investment in IT assets to various firm performance measures, such as productivity, financial market valuation, and operational level performance (Aral et al. 2006; Bresnahan et al. 2002; Brynjolfsson and Hitt 1995; Brynjolfsson and Hitt 1996; Brynjolfsson and Hitt 2003; Dewan and Min 1997; Hitt et al. 2002). While it is now generally accepted that investment in information technology is often associated with higher firm performance, studies also reveal that there exists considerable variation in the returns to such investments (Brynjolfsson and Hitt 1995; Brynjolfsson and Hitt 2000). To explain this observation, researchers have proposed that complementary organizational practices/assets are often required in order to extract productivity and other performance premiums from IT investment (Aral et al. 2009; Aral and Weill 2007; Bresnahan et al. 2002; Brynjolfsson et al. 2002). In other words, the value of IT investment is magnified when a firm also invests heavily in organizational practices and business process changes in a way that the strategic use of computing power can be harnessed to achieve business objectives. For example, from the theoretical perspective of resource based view of IT, Melville et al. (2004) argue that successful application of IT is often accompanied by significant organizational changes, such as polices and rules, organizational structure, workplace practices and organizational culture. However, caution must be exercised when management tries to introduce an extensive set of organizational changes that are intended to complement new information systems investments, for the co-introduction of IT and complementary organizational practices may not result in immediate success due to adjustment costs, learning and other factors (Brynjolfsson et al. 1997; Melville et al. 2004).

A number of empirical studies have investigated the complementarity between IT investment and other organizational practices/assets. For example, in the retail industry, it has been shown that IT alone does not create sustainable performance advantages, but firms that use IT to leverage intangible human resources and business resources achieve superior performances (Powell and Dent-Micallef 1997). Brynjolfsson et al. (2002) find that one dollar of IT investment is associated with ten dollars of financial market value, and nine dollars out of these can be attributed to investments in complementary organizational assets. Aral and Weill (2007) demonstrate that different strategic purposes of IT assets are associated with higher firm performance along different dimensions, and variations in the impact of IT assets on firm performance is partially driven by organizational IT capability, which may encompass IT skills of employees, management commitment to IT initiatives, and a series of organizational practices, etc. Similarly, Gu et al. (2008) argue that IT governance mode is part of the complementary organizational capitals, and show that firms with low IT governance misalignment obtain two to three times the value from IT investment compared to firms with average IT governance misalignment. In addition, Devaraj and Kohli (2000) report, by examining longitudinal data collected from 8 hospitals, that IT investment contributes to higher revenue, but the effect is more pronounced for organizations that also implement corporate initiatives such as business process reengineering (BPR). A recent study by Aral et al. (2009) also reveals that there are three-way complementarities among IT adoption, performance pay and monitoring practices.

Although prior studies have examined a broad range of organizational assets/practices that may complement a firm's investment in IT capital, the role of co-innovation in enterprise information systems has been largely ignored. In the following I extend the theory of IT and complementarities to the construct of IT co-innovation.

4.2.2. Enterprise Information Systems and Co-innovation

Pure technical progress alone is rarely sufficient to bring about significant economic returns. Among other factors, technology users' co-innovation, through their experimentation and discovery, often make the technology more valuable. For example, Bresnahan and Greenstein (1996) show that new technology platform, such as client/server, requires significant customization within each idiosyncratic organization, and the costs of co-invention are important to understand the transition from mainframe computing to client/server computing architecture. Similarly, Von Hippel (1994a) find that user were the developers of over 70% innovations in the field of scientific instruments and semiconductors/printed circuit boards manufacturing. Augier and Teece (2006) argue, according to the theory of dynamic capabilities, that accumulation of complementary innovation is especially valuable to users in enterprise software industry. These types of complementary innovation are a source of co-specialized asset to a firm's investment in computers and software than can be coordinated to build a (dynamic) capability to seize new opportunities and manage threats. The co-specialized innovations are hard to contract from markets and are often path-dependent, therefore the accumulation of them can lead to a firm's competitive advantage. From a resource based view of IT, once the IT co-innovations are in place, the unique combination of them with IT investments can be economically valuable, scarce, and difficult to imitate due to path dependencies, embeddedness, causal ambiguity about the source of competitive advantage, and time diseconomies of imitation (Barney 1991). In addition, because of the differences in firms' strategic priorities, the deployment of the IT resources and IT co-innovation are heterogeneously distributed and unlikely to be perfectly mobile across firm boundaries. This suggests that co-innovation in enterprise information systems may in part explain the differences in the return of firms' IT investments.

I argue that a firm's accumulation of co-innovation around its information technology infrastructure constitutes a source of intangible organizational asset that may enhance its IT productivity. First, the adoption and exploitation of information systems often require invention of idiosyncratic, complementary technical solutions (co-innovation) on the part of the IS users. For example, implementing of the off-the-shelf enterprise software modules usually requires users to customize the configuration of a series of system parameters, choosing specific add-on functions and features, and sometimes even devising specific tools to meet heterogeneous user needs. In addition, to facilitate the interoperability of the enterprise system with legacy IT infrastructure, or the seamless integration with the information systems of its partners, suppliers and customers, the end users often have to create workarounds and solutions to interface various IS components. According to a study conducted by Panorama Consulting Group (Kimberling 2009), only 23% of organizations implement vanilla, off-the-shelf ERP software with little to no customization. The remainder of organizations in the study customized their software, with 34% indicating that they heavily customized their software. When a firm takes tremendous effort to create co-innovation that better integrate computers into existing business systems, it is more likely to achieve efficient use of information technology and unlock its productivity.

Second, implementation of enterprise systems is likely to bring about change in the way of conducting business, which requires co-innovation in business process and workplace practices (Melville et al. 2004). These co-innovation activities may involve changing jobs, hierarchies, and other organizational structures by changing the information that flows through them (Bresnahan and Greenstein 1996). As Davenport (1993) points out, IT is often viewed as an enabler of process innovation which makes new process design possible. When new IT functionality is implemented, it has the potential to alter the basic principles and assumptions that the set of current business processes subscribe to, such as centralization versus decentralization, coordination and control mechanisms, new metrics for performance monitoring, time to market of new product design, and the degree to which the supply chain is integrated with partners (Venkatraman 1994). Changes in these first principles, coupled with innovative way of process redesign, can lead to significant improve in firm productivity. For example, when new EPR system is introduced at IBM PC division, IBM reengineered its business processes to respond to Dell's build-to-order business model by eliminating non-value-adding activities. Among other changes, the fulfillment process, in which the distributors often had to disassemble PCs they received and modify them to meet customer needs, were changed such that IBM delivered components instead of assembled PCs to its distributors. As a result, IBM and its distributors were able to cut the inventory lead time from 12 weeks to just 2 weeks (Chen 2001). Indeed, co-innovation in business processes, just as technical co-innovation around computing platform, is instrumental in unleashing the computing power to drive productivity gains (Brynjolfsson et al. 2008).

In addition, IT resource needs to be coupled with human expertise to create economic value for a firm (Melville et al. 2004). Based on Barney's (1991) classification of firm resources, Bharadwaj (2000) propose that human IT resource is an important dimension of firm's overall IT resources, along with IT infrastructure and IT enabled intangibles. Human IT resources include both technical IT skills, such as system analysis and design, application programming, knowledge in emerging technology, etc.; and managerial IT skills, such as effective management of various IS functions, ability to lead and motivate development teams to complete IT projects according to specification and within time and budget constraints, and effective communication and interaction with end users. These human IT resources usually are tacit, take long periods of time to evolve, and tend to be highly local or organization specific (Sambamurthy and Zmud 1994). For example, building a large scale software application requires locating and assembling specialized domain expertise, building effective coordination mechanisms among team members, securing management commitment, and strong leadership to allocate resources and set priorities, which can only be cultivated and perfected over time through a series of learning-by-doing practices. Participation in the co-innovation activities in enterprise information systems helps internal IT professionals to learn and reinforce their domain knowledge about a firm's information systems, build up mechanisms and routines that allow effective communication and coordination, strengthen their ability to continuous innovate and improve IS practices to meet end user requirements, and develop management skills to lead IS projects and motivate IS staff.

The proposition that IT co-innovation is an integral component of intangible IT assets is also consistent with Aral and Weill (2007) who argue that IT resource is a combination of mutually reinforcing IT capital and IT capabilities. The two main conceptual building blocks of IT capabilities, competencies and practices (Nelson and Winter 1982), are both related to co-innovation activities. In summary, I propose that accumulation of IT co-innovation around a firm's enterprise information systems is likely to complement its IT investment to boost productivity.

4.3. Measuring Co-innovation: SAP Community Network (SCN)

One of the practical challenges of this study is the accurate measure of firms' co-innovation in their underlying computing platform. I resolve this challenge by focusing on the backbone of enterprise information systems: adoption of enterprise software (SAP particularly), and collect data on SAP user firms' participation and contribution to SAP-sponsored online community network.

As part of its platform strategy, SAP established its online community of innovation since 2003, with SAP developer network (SDN) and business process expert (BPX) as its two major modules. It serves as a resource reservoir and collaboration channel for SAP users, developers, architects, consultants and integrators to create and exchange knowledge about adopting and implementing SAP solutions. SAP community network hosts forums, expert blogs, a technical library, article downloads, a code sharing gallery, e-learning catalogs, Wikis and other facilities through which its members contribute their knowledge. All these web 2.0 technologies support open communication between active members of the community, which amount to more than 1,820,000 as of 2010. This online community enables interesting co-innovation patterns among its members. For example, in 2006 two developers from Colgate-Palmolive invented SAPlink, a tool that provides the ability to easily distribute and package custom objects on SAP's NetWeaver platform, and made it available freely to other SDN members (Iansiti and Lakhani 2009). Soon after its release it attracted other developers to contribute, and 19 additional plug-ins are added to handle other object types.

A unique feature of SAP community network is that its members' contribution to the community can be quantified. To reward active members, SAP has developed the Contributor Recognition Program (CRP), which awards points to community members for each technical article, code sample, video, wiki contribution, forum post, and weblog authored. For example, in the case of forum discussion participation, 2, 6, or 10 points may be awarded for forum posts replying to existing threads marked as questions depending on the helpfulness of the answer. Points are awarded at the discretion of the poster of the original thread. Similarly, awards with varying points go for contributing other resources such as code samples, wikis, videos, podcasts or e-learning materials.

SAP publicly recognizes its most active members. For example, on the “Top Contributors” page, the top 50 contributors are listed in recognition of their contribution. On each forum page, the top three contributors to that forum are listed, with their total reward points displayed. In addition, SAP identifies and provides special status to exceptional and high-value members of SAP Developer Network and Business Process Expert communities by granting them the title of “SAP Mentor”. SAP Mentors are role models who differentiate themselves through the high quality and frequency of their community contributions, their perspectives, attitudes, and interaction styles. They are subject-matter experts who are passionate about SAP and share their opinions and insights with the community. SAP Mentors are offered unique opportunities for access to SAP senior management, early access to information on products and programs and greater visibility in the online communities as well as at SAP events such as SAP Tech Ed.

The participation in the community network is completely voluntarily and anyone can register as a member by providing basic personal information. One piece of such profile information is the company affiliation of the member and his/her relationship to SAP, which he/she may choose whether to disclose or not. Other identifying information includes email address, phone number, expertise, and LinkedIn profile page, etc. By aggregating contribution (award points) from individual level to firm level, I can derive any SAP-adopting firm’s contribution to the community network. I use this variable as a proximate for the level of co-innovation of the SAP user firm.

4.4. Methodology

4.4.1. Production Function Framework

A typical production function relates firm output to factors of input of production. For example, a simple form of three-factor Cobb-Douglas production function has been widely used in prior studies on IT productivity (Brynjolfsson and Hitt 1996; Dewan and Min 1997; Mittal and Nault 2009):

$$Y = AK^{\alpha}L^{\beta}Z^{\gamma} \tag{4.1}$$

Where Y is the quantity of production output, K is the stock of non-IT capital, L is the stock of labor, Z is the stock of IT-capital, and A denotes the total factor productivity (TFP). TFP is defined as the output contribution that is not explained by the factor inputs and often interpreted as technological progress (Mittal and Nault 2009). In this case, the output elasticity of IT-capital, $\gamma = \partial lnY/\partial lnZ$, represents the percentage increase in output due to a one percent increase in IT capital. The marginal product of IT capital, which is measured as the increase of output due to an additional dollar investment in IT capital, can be calculated as $f_c = \gamma \cdot (\frac{Y}{Z})$. The output elasticity and marginal product of other factors can be similarly derived.

The Cobb-Douglas production function can be employed to estimate the factor productivities by implementing the following model:

$$lnY = a + \alpha lnK + \beta lnL + \gamma lnZ + \epsilon \tag{4.2}$$

In order to test my theory of complementarities and detect if firms' co-innovation activities in enterprise information system enhance their IT productivity, I interact co-innovation with IT-capital and estimate the following model

$$lnY = a + \alpha lnK + \beta lnL + \gamma lnZ + \delta C \cdot lnZ + \epsilon \qquad (4.3)$$

where C denotes the firms' co-innovation. In the empirical investigation, I use both discrete measure of C (high co-innovation vs. low co-innovation) and continuous measure of C (log form of co-innovation, due to over-dispersion of this variable) to test the model. Since co-innovation is not a direct production input but a source of firm heterogeneity, I cannot introduce it into the regression as a separate explanatory variable. The treatment of co-innovation in production function is similar to the role of IT risk in Dewan et al. (2007). The functional specifications are also similar to that of Mefford (1986), which tests a production function with the assumption that technology level of the plant enhance the stock of capital and skill level of workforce enhance the stock of labor. Therefore, a positive, significant coefficient δ would demonstrate the complementarity between co-innovation and IT capital, and the total output elasticity of IT capital, taking into account the interaction between co-innovation and IT capital, is $\gamma + \delta C$.

An alternative way to measure the value of co-innovation to firms' IT investment is to estimate its contribution to increasing effective IT stock, using similar framework developed by Mittal and Nault (2009). Specifically, assuming that co-innovation multiplicatively augment firms' IT-capital, I define the augmented, co-innovation adjusted effective quantity of IT-capital as

$$\tilde{Z} = Zf(C)$$

With the augmentation increasing in co-innovation, $f'(C) > 0$, and there is no augmentation if there is no co-innovation, $f(0) = 1$. The augmented Cobb-Douglas function becomes

$$Y = AK^{\bar{\alpha}}L^{\bar{\beta}}\tilde{Z}^{\bar{\gamma}}$$

Consistent with Mittal and Nault (2009), I further specify the form of the augmentation of IT-capital as

$$\tilde{Z} = Ze^{\eta C}$$

The exponential form of augmentation is chosen as the original Cobb-Douglas production function is nested in the augmented form in that if η=0, the latter is reduced to the former. This allows me to directly test if the augmentation effect is present, by empirically testing if η=0. Taking nature log on both sides, the estimation equation becomes

$$lnY = a + \bar{\alpha}lnK + \bar{\beta}lnL + \bar{\gamma}lnZ + \kappa C + \epsilon \tag{4.4}$$

where $\kappa = \bar{\gamma}\eta$. The augmentation factor, η, is captured by $\kappa/\bar{\gamma}$. The estimated augmentation factor for a firm with co-innovation level of C is identified as $e^{(\kappa/\bar{\gamma})C}$.

4.4.2. Data and Variables

I test the relationship between co-innovation in enterprise systems, IT capital, other production factors and production output by constructing a dataset of firms that are SAP enterprise software users and are publicly traded. I use the Computer Intelligence (CI) database to determine the status of SAP adoption, as well as to obtain IT investment data. The CI database records detailed information about IT infrastructure for most Fortune

1000 firms, which include data of the quantity of mainframes, peripheral, minicomputers, servers and PC systems, as well as other IT hardware stocks. Recent CI data also includes information on firms' adoption of enterprise software such as accounting, supply chain, CRM or human resource modules, etc. The data were collected via a variety of methods including surveys, physical audits, site visits and telephone interviews. CI database has been widely used by prior studies to investigate issues related to IT productivity (e.g., Chwelos et al. forthcoming). The CI data were then matched with Standard and Poor's Compustat database to obtain financial information of the publicly traded companies. Using similar method of prior research (Brynjolfsson and Hitt 1996; Brynjolfsson and Hitt 2003; Chwelos et al. forthcoming; Dewan and Min 1997), I use the financial data to construct measures of production output, non-IT capital stock and labor expenses. As the Contributor Recognition Program on SAP community network starts from year 2004, I choose the sample as cross section data of firms in 2006, which allows 3 years for the sample firms to accumulate co-innovation in their enterprise systems.

Sample. As my measure of co-innovation activities in enterprise systems is limited to SAP enterprise software platform, I am interested in sample firms that are SAP adaptors. 2006 CI database provides detailed, establishment level information on the enterprise software that is adopted by each firm. By examining the data of enterprise software adoption I retrieve a list of firms that are based in the United States, and have adopted at least one enterprise software module that is produced by SAP as of 2006. I further remove consulting firms that are major SAP implementation partners, as their co-innovation activities in SAP systems are usually driven by customer demand instead of their own use of enterprise systems, therefore are unlikely to affect their IT productivity.

The set of firms is then matched with Compustat, which result in a total of 295 publicly traded, SAP adopting companies.

IT Capital. The measure of IT capital is derived from Computer Intelligence (CI) Technology database, maintained by Harte Hanks. The information in the database covers major IT areas, such as personal computing, systems and servers, networking, software, storage and managed services (Gu et al. 2008). However, one issue of the database is that it no longer includes direct measures of IT capital stock after year 1998 (Tambe and Hitt 2008). To construct the IT capital variable, I adopt the method used by Chwelos et al. (forthcoming) who use hedonic regression to impute the value of equipments using historical data (1987-1994) and estimate the value of IT stock in later years using implicit prices. According to Chwelos et al. (forthcoming), the estimated IT stock is highly correlated with the original CI IT capital measure (Pearson correlation coefficient > .92). Specifically, I obtained the implicit prices for eight major IT components[31] that are estimated by Chwelos et al., and retrieve the quantities of sample firms' IT stock in these 8 categories from the CI database.[32] The IT capital is calculated as the predicted total value using the implicit prices and IT equipment stocks.

Co-innovation in Enterprise Software. The extent of firms' co-innovation in their enterprise information systems is measured by their employees' contribution to the SAP community network, that is, the sum of reward points earned by their employees. First, I retrieve a complete list of contributors at SAP community network in year 2004, 2005

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[31] The eight categories are: IBM mainframes, non-IBM mainframes, mini-computers, PCs, local-area networks, mainframe tape drives, mainframe disk drives, and dumb terminals.

[32] Statistics on dumb terminals are no longer provided by CI database for recent years, due to the shift of computing paradigm from mainframe to client/server architecture. As a result, dumb terminals are not incorporated in my calculation of IT capital.

and 2006 together with the number of reward points each member has earned during this period.[33] The period starts from 2004 as it is the first year that the SAP Contributor Recognition Program is implemented and reward points are available. I then use a crawler program to acquire the information on the user profiles for all the registered users of SAP Community Network, such as their name, address, company, profession, email address, country, personal website, LinkedIn profile, etc. Next, I select all the members reside in the United States, and match them with companies in my sample by examining their company affiliations and the domain of their email addresses. I then aggregate the individual level award points to firm level according to the members' affiliation information, and use the firm level reward points as a measure of the stock of co-innovation in enterprise information systems of the firms.

Production Output and Other Production Factor. Following prior literature (Brynjolfsson and Hitt 1996; Dewan and Min 1997), I use financial data from Standard and Poor's Compustata database to construct variable of production output (Y), non-IT capital stock (K) and labor expense (L). Two most commonly used output measures for each firm in year 2006 are obtained: (1) annual sales and (2) added value, which is defined as sales minus materials. Sales are chosen as the production output in the baseline models. Added value is chosen as it is said to be less noisy and more comparable across industries (Dewan and Min 1997). Annual sales of a firm are obtained directly from Compustat. Material is calculated by subtracting labor and related expenses (Compustat data item XLR) from total operating expenses (Compustat data item XOPR).

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[33] The information is obtained from: http://www.sdn.sap.com/irj/sdn/topcontributors.

Non-IT capital stock is calculated by subtracting IT capital stock (explained above) from a firm's total capital stock. Consistent with prior studies (Dewan and Min 1997; Hall 1990), I define the total capital stock as the sum of: net value of property, plant and equipment (Compustat data item PPENT), value of the firm's inventories (Compustat data item INVT), value of investments in unconsolidated subsidiaries (Compustat data item IVAEQ and IVAO), and intangibles (Compustat data item INTAN).

For a subset of firms, Compustat provides data on Labor and Related Expenses (data item XLR). For these firms, labor expenses are directly obtained from Compustat. For firms with missing values for XLR, it is conventional to use one of the two ways that are adopted by prior literature to impute this variable. First, following Wilson (2009), I calculate the labor expenses by multiplying the firm's reported number of employees (Compustat data item EMP) by the 3-digit industry (SIC) mean of per-employee labor expenses, which is computed over firms in the Compustat universe with non-missing values for XLR. If 3-digit industry average cannot be obtained, I use the 2-digit industry mean instead. Second, consistent with prior studies (Bloom and Van Reenen 2007; Bresnahan et al. 2002; Brynjolfsson and Hitt 2003), for firms that do not report labor expenses expenditures, I obtain average weekly wages and benefits at the four-digit industry (NACIS) level from Bureau of Labor Statistics (BLS), and derive industry level annual per-employee compensation (assuming a 52-week year) and multiply this number by the firm's reported employment level. When 4-digit NACIS average cannot be obtained, I use 3-digit industry average instead. The two measures of labor expenses are highly correlated (ρ=0.81) and all the results are robust to the use of either measure. For brevity, the results reported below use the first measure.

Table 4.1 presents the summary statistics of the variables. The average firm in the sample has sales of $13.58 billion, with 33,690 employees, indicating the sample contains relatively large companies. This is consistent with my sample being publicly traded, Fortune 1,000 SAP adopters. In addition, the firms invest heavily in IT capital, which has a mean level of $9.68 million and maximum of $345.23 million. Table 4.2 provides the correlation matrix among the key variables.

Table 4.3 presents a breakdown of the sample firms by vertical industries, which is based on 2-digit NACIS code. It is notable that firms in manufacturing industry account for the majority of the sample, which amount to over 70% of the total. This indicates that enterprise resource planning software is heavily used among manufacturing companies.

Table 4.1 Descriptive Statistics

Variable	Description	Obs	Mean	Std. dev	Minimum	Maximum
S	Annual sales (million $)	295	13582.57	25716.08	48.405	204892
VA	Added value (million $)	295	5051.506	8719.877	16.1359	71835.91
K	Non-IT capital (million $)	295	13254.07	45427.28	11.74955	661702.9
L	Labor expense (million $)	295	2538.453	4457.188	9.271005	38906.54
Z	IT capital (million $)	295	9.680195	24.0529	0	345.228
C	Co-innovation (reward points)	295	64.88814	336.0369	0	4234
Emp	Number of employees (thousands)	293	33.69048	51.3339	0.07	355.766

Table 4.2 Pearson Correlation Matrix of Selected Variables

Variable	Description	S	VA	K	L	Z	C	Emp
S	Annual sales (million $)	1.0000						
		(-)						
VA	Added value (million $)	0.8111	1.0000					
		(0.0000)	(-)					
K	Non-IT capital (million $)	0.5892	0.7156	1.0000				
		(0.0000)	(0.0000)	(-)				
L	Labor expense (million $)	0.5396	0.8423	0.4631	1.0000			
		(0.0000)	(0.0000)	(0.0000)	(-)			
Z	IT capital (million $)	0.4343	0.4218	0.2193	0.4287	1.0000		
		(0.0000)	(0.0000)	(0.0001)	(0.0000)	(-)		
C	Co-innovation (reward points)	0.3017	0.1644	0.0423	0.1325	0.4003	1.0000	
		(0.0000)	(0.0046)	(0.4692)	(0.0228)	(0.0000)	(-)	
Emp	Number of employees (thousands)	0.6688	0.8126	0.4738	0.8184	0.4968	0.1431	1.0000
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0143)	(-)

Table 4.3 Industry Segments of the Sample

2-digit NACIS	Description	Freq.	Percent
11	Agriculture, Forestry, Fishing and Hunting	1	0.34
21	Mining	10	3.39
22	Utilities	13	4.41
23	Construction	2	0.68
31-33	Manufacturing	213	72.2
42	Wholesale Trade	7	2.37
44-45	Retail Trade	3	1.02
48-49	Transportation and Warehousing	6	2.03
51	Information	12	4.07
52	Finance and Insurance	4	1.36
53	Real Estate and Rental and Leasing	2	0.68
54	Professional, Scientific, and Technical Services	10	3.39
56	Administrative and Support and Waste Management and Remediation Services	2	0.68
62	Health Care and Social Assistance	2	0.68
72	Accommodation and Food Services	5	1.69
99	Unclassified	3	1.02
Total		295	100

4.5. Results

To examine the effect of co-innovation on a firm's IT productivity, I estimate equations 3 and 4 which correspond to the complimentarity and augmentation arguments, respectively. In the baseline models annual sales are used as production output, and the results are reported in Table 4.4. First, in column 1 I present the results from a 3-factor Cobb-Douglas production function using non-IT capital (K), IT-capital (Z) and labor (L) as production inputs, without considering firms' co-innovation in their enterprise systems. Consistent with prior studies (Brynjolfsson and Hitt 1996; Dewan and Min 1997), I find that IT-capital is significantly correlated with production output. The estimated elasticity of output for IT-capital is 0.162 ($p<0.01$), indicating one percent increase in IT-capital is associated with 0.16 percent increase in the production output. To control for heterogeneity in IT productivity across different industries, I create 16 industry dummies according to the two-digit NACIS codes, and run a test with these industry segments as controls. The results are presented in Column 2 of Table 4.4. It is noticed that after removing industry differences, the estimated elasticity of output with regard to IT capital is reduced to 0.128 ($p<0.001$). The estimated output elasticity of IT capital is quantitatively similar to that of prior research, such as 0.12 in Dewan and Min (1997), 0.109 in Brynjolfsson and Hitt (1995), or 0.11 in Lichtenberg (1995).

Next I turn to the effect of IT co-innovation, the main variable of interest, on production output. In order to test if there is systematic differences in IT productivity between low co-innovation and high co-innovation firms, I create a dummy variable, *highInno*, which is set to one if a firm's co-innovation, or sum of the reward points from SAP community network, is greater than 80 (the 90th percentile of the population of the sample), and zero otherwise. I then generate the interaction of this dummy variable with IT capital and test a model with this interaction added to other production factors. The results are presented in column 3 of Table 4.4. By examining the coefficient of this interaction term, I find that IT productivity is significantly higher for firms that accumulate large stock of co-innovation in their enterprise systems. The results indicate that the average elasticity of output with regard to IT capital is 0.110 ($p<0.05$) for a low co-innovation firm, but for a firm with high co-innovation, the elasticity is increased by 0.118 ($p<0.01$) to 0.228. As a robustness check, I create an alternative measure of high co-innovation dummy, *highInno2*, which is based on the 50th percentile of the total reward points in the sample. The results, presented in column 4 of Table 4.4, consistently show that a significant difference in IT productivity exists between high co-innovation and low co-innovation firms. Next, I introduce an interaction between IT capital and a continuous measure of IT co-innovation, log (C), and test the model of equation 3. The results in column 5 suggest that, while output elasticity of a firm without co-innovation is about 0.11, for a firm with mean level of IT co-innovation (64.89 reward points), one percent increase in IT-capital lead to 0.17 percent ($=0.105+0.0155\times\ln(64.89)$) increase in output, due to the complementary effect of co-innovation to IT investment. Comparing the two, IT productivity is 54.5% higher for a firm with mean level co-innovation than that with no co-innovation.

Column 6 of Table 4.4 presents the estimate of the model of equation 4, where the IT asset is assumed to be augmented by IT co-innovation. Examining the coefficient of κ, I find the empirical evidences also support the augmentation argument. The augmentation factor, η, which is defined as $\kappa/\bar{\gamma}$, is estimated to be 0.0026. As an illustration of the augmentation effect, consider a comparison between a firm with zero IT co-innovation and another with mean level co-innovation. While a firm with zero IT co-innovation experience no augmentation of its IT asset, for a firm with mean level IT co-innovation (64.89 reward points), its IT asset is augmented by $e^{(\kappa/\bar{\gamma})C}$ =1.18. To put this augmentation effect into perspective, consider an average firm with \$9.68 million IT investment: the augmentation effect translates to an additional \$1.78 million investment in IT capital for this firm. Comparing the results from column 2 and column 6, it is interesting to note that when the augmentation factor is added, the estimate of the coefficient of non-IT capital (0.637, $p<0.01$ vs. 0.632, $p<0.01$) and labor (0.222, $p<0.01$ vs. 0.222, $p<0.01$) is almost unchanged, indicating that only IT capital experiences the augmentation by IT co-innovation.

Table 4.4 Sales as Production Output

Variables	(1) Baseline	(2) Industry dummies	(3) High Co-innovation	(4) Alternative HighInno	(5) Continuous Co-innovation	(6) Augmented IT-capital model
Log(K)	0.569***	0.637***	0.636***	0.633***	0.634***	0.632***
	(0.0291)	(0.0350)	(0.0332)	(0.0341)	(0.0331)	(0.0325)
Log(Z)	0.162***	0.128***	0.110**	0.115**	0.105**	0.110**
	(0.0473)	(0.0459)	(0.0462)	(0.0463)	(0.0472)	(0.0466)
Log(L)	0.254***	0.222***	0.212***	0.216***	0.213***	0.222***
	(0.0403)	(0.0424)	(0.0414)	(0.0419)	(0.0413)	(0.0406)
highInno×log(Z)			0.118***			
			(0.0388)			
highInno2×log(Z)				0.0583**		
				(0.0282)		
Log(C) ×log(Z)					0.0155***	
					(0.00571)	
C						0.000286***
						(5.70e-05)
Constant	1.881***	1.881***	1.969***	1.879***	1.916***	1.944***
	(0.177)	(0.182)	(0.177)	(0.179)	(0.176)	(0.174)
Industry Dummies	No	Yes	Yes	Yes	Yes	Yes
Observations	295	295	295	295	295	295
R-squared	0.888	0.915	0.918	0.916	0.917	0.919

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

From a theoretical stand point, IT co-innovation does not enter into the production function as a separate production input as it is related to production output in an indirect manner through its complementarity with IT investment. As a result, co-innovation does not enter into regression model 3 as a separate term but only appears as an interaction with IT capital stock. Though theoretically correct, this may raise the concern that the detected effect of the interaction is just picking up the differences in productivity differences between high co-innovation and low co-innovation firms, which may not necessarily be related to IT investment. To address this econometric concern, I run split sample tests in which I divide the sample firms into high and low co-innovation groups based on the cumulative reward points they have earned. Consistent with the definition of high co-innovation in Table 4.4, variable *highInno* is defined based on 90th percentile of reward points and *highInno2* is based on 50th percentile. The results of the split sample tests are presented in column 1-4 of Table 4.5. By comparison it is clear that IT productivity is higher when a firm belongs to the high co-innovation group. For example, using the 90th percentile definition, firms in low IT co-innovation group on average have IT output elasticity of 0.143 ($p<0.01$), but the output elasticity is as high as 0.257 ($p<0.05$) for firms in the high IT co-innovation group. A Chow test confirms that the coefficient estimates are different across the two subsamples ($F(4,287)=4.5999$, $p<0.001$).

Table 4.5 Split Sample Tests

Variables	(1) highInno=0	(2) highInno=1	(3) highInno2=0	(4) highInno2=1	(5) non-manu	(6) manu	(7) non-manu	(8) manu	(9) non-manu	(10) manu
Log(K)	0.560***	0.776***	0.546***	0.608***	0.488***	0.695***	0.472***	0.695***	0.414***	0.439***
	(0.0283)	(0.124)	(0.0321)	(0.0586)	(0.0396)	(0.0371)	(0.0376)	(0.0372)	(0.0273)	(0.0335)
Log(Z)	0.143***	0.257**	0.156**	0.200***	0.128	0.117**	0.0922	0.117**	0.00893	-0.0240
	(0.0531)	(0.0988)	(0.0604)	(0.0662)	(0.0938)	(0.0521)	(0.0864)	(0.0534)	(0.0429)	(0.0310)
Log(L)	0.250***	0.0809	0.258***	0.202***	0.291***	0.147***	0.301***	0.146***	0.518***	0.575***
	(0.0425)	(0.102)	(0.0490)	(0.0634)	(0.0758)	(0.0437)	(0.0712)	(0.0437)	(0.0349)	(0.0366)
highInno×log(Z)					0.244***	0.0967**				
					(0.0796)	(0.0408)				
Log(C) ×log(Z)							0.0493***	0.0112*		
							(0.0131)	(0.00591)		
C									0.000476***	0.000109***
									(0.000132)	(3.82e-05)
Constant	1.976***	1.470*	1.987***	2.020***	2.226***	1.700***	2.307***	1.703***	0.654***	0.0744
	(0.183)	(0.747)	(0.208)	(0.331)	(0.403)	(0.177)	(0.394)	(0.179)	(0.220)	(0.133)
Observations	267	28	216	79	82	213	82	213	82	213
R-squared	0.886	0.871	0.885	0.882	0.840	0.921	0.850	0.921	0.951	0.964

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

Given that the sample of this study is dominated by firms within the manufacturing industry, a particular concern is whether the result of a significant complementarity between IT capital and co-innovation holds for industries other than manufacturing. To access the validity of my hypothesis across industries, I run a series of split sample tests by comparing firms in the manufacturing industry and firms in other industries. The results of the split sample tests are reported in column 5-10 of Table 4.5. Among them, column 5-6 compares the two groups using a discrete measure of co-innovation, and column 7-8 use the continuous measure of co-innovation. Column 9-10 test the augmentation models of equation 4. Examining the results I find that the effect of complementarity exists not only for manufacturing firms, but also for companies in other industries as well. In fact, the estimated effect of complementarity is even higher for non-manufacturing industries, a finding consistent with Dewan and Ren (2009).

Although sales are commonly used as a measure of production output in a series of IT business value studies (Aral et al. 2009; Brynjolfsson and Hitt 1996), some argue that added value as a production output is more comparable across industries (Dewan and Min 1997; Dewan et al. 2007). In Table 4.6 I report the results from similar analyses using firm annual added value as dependent variable in production functions. Similarly, I report results of the baseline, 3-factor production functions, with and without industry dummies, in column 1 and 2 respectively. Results from models of equation 3, using both discrete measures (90th percentile and 50th percentile) and continuous measures of IT co-innovation, are reported in column 3-5. Finally, the augmented IT capital model, corresponding to equation 4, is tested with the results presented in column 6. Interestingly, contrary to Dewan and Min (1997), a significant association between IT capital and firm added value is not detected, probably due to the cross-sectional nature of the data used in this study and the different sample period from that of Dewan and Min. However, consistent with the findings in the sales models, a significant complementarity between IT co-innovation and IT capital is discovered. For example, results from column 4 suggest that, while IT capital is statistically insignificant as a factor of input for low IT co-innovation firms, it has a positive contribution to production output for high IT co-innovation firms, and its output elasticity is 0.014. In other words, one percent increase in IT capital is associated with 0.014 percent increase in annual added value for firms with high IT co-innovation, which translates to a marginal product of $7.2, with average added value being $5.05 billion and average IT capital being $9.68 million. Or, by the results from column 5, while the output elasticity of IT capital is statistically indistinguishable from zero for a firm without IT co-innovation, it is increased to 0.010 for a firm with average level of IT co-innovation (64.89 reward points). The significant augmentation of IT capital by IT co-innovation is also confirmed by column 6 of Table 4.6, consistent with the sales model. It is notable that the estimated effect of complementarity is much stronger in the sales models than the added value models.

Table 4.6 Added Value as Production Output

Variables	(1) Baseline	(2) Industry dummies	(3) High Co-innovation	(4) Alternative HighInno	(5) Continuous Co-innovation	(6) Augmented IT-capital model
Log(K)	0.435***	0.426***	0.425***	0.424***	0.424***	0.424***
	(0.0212)	(0.0268)	(0.0268)	(0.0266)	(0.0266)	(0.0267)
Log(Z)	-0.000723	-0.00752	-0.0157	-0.0139	-0.0175	-0.0147
	(0.0252)	(0.0250)	(0.0259)	(0.0260)	(0.0265)	(0.0262)
Log(L)	0.558***	0.578***	0.574***	0.575***	0.575***	0.578***
	(0.0256)	(0.0301)	(0.0303)	(0.0304)	(0.0303)	(0.0300)
highInno×log(Z)			0.0532**			
			(0.0263)			
highInno2×log(Z)				0.0277†		
				(0.0189)		
Log(C) ×log(Z)					0.00666*	
					(0.00382)	
C						0.000114***
						(3.87e-05)
Constant	0.205*	0.701***	0.741***	0.700***	0.716***	0.727***
	(0.118)	(0.131)	(0.131)	(0.129)	(0.129)	(0.130)
Industry Dummies	No	Yes	Yes	Yes	Yes	Yes
Observations	295	295	295	295	295	295
R-squared	0.960	0.966	0.967	0.966	0.967	0.967

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.
†: significant at 0.15 level.

Prior study by Anderson et al. (2003) has demonstrated that production inputs often have significant lagged effect, with IT capital spending affects returns several years into the future. In addition, Dewan et al. (2007) expressed similar concerns that in production function using annual output as dependent, the IT capital stock variable is likely to be endogenous because of the lagged effects. Although the IT capital stock used in this study already partially captures the lagged effects of IT investment, to allay these concerns, I conduct two sets of robustness tests. First, I replace the IT capital stock variable in year 2006 with two-year lagged value of IT capital stock, keeping other variables unchanged, and rerun the tests. Second, I conduct two-stage-least-square regressions in which I instrument the IT capital stock and its interaction with co-innovation by lagged value of IT capital, the interaction of lagged IT capital and co-innovation, and the contemporaneous values of all other variables. The results of the lagged IT capital variable tests are presented in column 1-4 in Table 4.7, and the results of the 2SLS tests are presented in column 5-8 in Table 4.7. In these two sets of tests, I run a baseline 3-factor production function model (column 1 and 5), a complementarity test of equation 3 with discrete measure of high co-innovation (column 2 and 6), a complementarity test of equation 3 with continuous measure of co-innovation (column 3 and 7), and an augmentation model of equation 4 (column 4 and 8). The estimated results are qualitatively similar to those presented in Table 4.4, indicating that all the major conclusions still hold even in the presence of lagged effects and endogenous IT stocks.

Table 4.7 Lagged Value of IT-Capital and IV Tests

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Lagged IT-capital				Instrumented IT-capital			
Variables	Baseline	High Co-innovation	Continuous Co-innovation	Augmented IT-capital model	Baseline	High Co-innovation	Continuous Co-innovation	Augmented IT-capital model
Log(K)	0.646***	0.643***	0.641***	0.638***	0.639***	0.638***	0.635***	0.633***
	(0.0356)	(0.0340)	(0.0337)	(0.0328)	(0.0353)	(0.0335)	(0.0334)	(0.0326)
Log(Z)	0.101**	0.0870*	0.0822*	0.0907**	0.118**	0.100*	0.0959*	0.107**
	(0.0448)	(0.0444)	(0.0449)	(0.0442)	(0.0527)	(0.0523)	(0.0530)	(0.0526)
Log(L)	0.223***	0.213***	0.214***	0.221***	0.224***	0.214***	0.215***	0.223***
	(0.0431)	(0.0424)	(0.0423)	(0.0414)	(0.0432)	(0.0423)	(0.0422)	(0.0415)
highInno×log(Z)		0.110***				0.120***		
		(0.0364)				(0.0388)		
Log(C) ×log(Z)			0.0157***				0.0163***	
			(0.00558)				(0.00580)	
C				0.000307***				0.000287***
				(4.88e-05)				(5.64e-05)
Constant	1.795***	1.895***	1.827***	1.882***	1.865***	1.956***	1.905***	1.940***
	(0.178)	(0.175)	(0.172)	(0.170)	(0.187)	(0.184)	(0.182)	(0.178)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	295	295	295	295	295	295	295	295
R-squared	0.913	0.916	0.916	0.917	0.915	0.918	0.917	0.919

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

4.6. Concluding Remarks

Prior research on IT business value has found complementarities between IT investment and a variety of organizational assets/practices, such as governance structures, human IT resources, business process reengineering, and IT management skills. In this study I advance this stream of research to examine the role of co-innovation in enterprise information systems on IT productivity. By measuring firms' participation and co-innovation activities in enterprise software user community, and incorporating IT co-innovation into models of production functions, I discover that firms with high levels of accumulated co-innovation in their adopted enterprise software have greater IT productivity than those with little IT co-innovation. The results hold for both manufacturing industry and other industries including mining, utilities and services, and are robust to a number of model specifications, different production output measures, and lagged effects and endogeneity issues of IT investment. The empirical findings are consistent with theoretical predictions that IT co-innovations, such as technical inventions and creative ways of conducting business processes, are an important component of a firm's intangible asset that complements IT investments. From a resource based view, only resources that are heterogeneously distributed and immobile can create sustained competitive advantages (Barney 1991; Barney 1986). For example, Mata et al. (1995) examine several potential sources of IT-based competitive advantages, and conclude that only managerial IT skills can be a source of sustained competitive advantage. Co-innovation is likely to satisfy these two basic assumptions. First, due to firms' different strategic pursuits, deployment of IT resource and co-innovation may center on different dimensions of value disciplines such as product leadership, operational excellence, or customer intimacy (Treacy and Wiersema 1993). Second, the accumulation of co-innovation is often hard to contract from markets or to be transferred across firm boundaries, and firms without these kinds of co-innovation find it costly to acquire and develop such intangible assets, due to history, causal ambiguity or social complexities (Mata et al. 1995).

This study has several major implications in the understanding of IT business value, platform-based technology, and co-innovation ecosystems. First, the study identifies IT co-innovation as a source of firm intangible assets that help to explain the large variations in IT productivity among different organizations (Brynjolfsson and Hitt 2000). For firms that adopt platform information technologies, it implies that they need to combine IT capital investment with creative co-innovations to maximize the return of their investment. Second, my results suggest that the strategy of innovation ecosystem by technology vendors may work to the benefits of technology adopters as well as technology owners. For platform technology owners, fostering a co-innovation ecosystem can facilitate knowledge exchange, reduce the cost of co-innovation, and encourage innovation activities which will enhance the value of the platform for its users. The availability of a large reservoir of co-innovation will further help the diffusion of the technology due to indirect network effects, therefore creating a virtuous cycle (Aral et al. 2006). Combined with prior research (e.g.,Ceccagnoli et al. 2009), this study sheds light on the economic value of platform ecosystems.

This study is not without limitations. First, due to data availability, the empirical exercises are conducted based on a cross section of firms in 2006. Although I control for industry segments of the sample firms, unobserved heterogeneities among firms may still exist in corporate structures, technical skills in human IT resources, and other intangible firm assets, which may lead to alternative explanations of the differences in IT productivity. With a longitudinal dataset, fixed effects models can be exploited to partially alleviate these issues. Second, while I use hedonic method to impute IT stock by implicit prices obtained from historical data (Chwelos et al. forthcoming), the contour of hedonic surface may have changed over time due to technology progresses or shift in computing paradigms (Triplett 1989). This may lead to biased but conservative estimates of the IT stock variable. Further, my measure of co-innovation only captures the part in enterprise information systems, therefore is unlikely to be a comprehensive measure that covers the whole spectrum of a firm’s IT infrastructure, such as those in personal productivity software. However, it should be noted that enterprise software is the backbone of a firm’s IT infrastructure, and accounts for a large proportion of IT investment of any firm, therefore the co-innovation activities in it would be highly correlated with other types of IT co-innovation.

In terms of future research, the current study can be extended in several ways to explore interesting research questions. First, it has been documented that switching costs are created when technology users make investments that are specific to a particular IT platform (Bakos and Treacy 1986), which suggests that IT users face higher switching costs when the stock of IT co-innovation is greater (Mata et al. 1995). Particularly, since IT co-innovations are specialized intangible asset that have little value when the underlying computing platform is changed, it is interesting to investigate the extent to which IT co-innovation creates vendor lock-in issues and prevents switching behaviors. Further, Aral and Weill (2007) show that different asset types in IT investments are associated with different firm performance dimensions. In addition, the business value of IT and co-innovation may be present at both the firm level and the intermediate process level (e.g., cost reduction, inventory turnover; see (Hitt et al. 2002)). While the focus of this study is on establishing a link between aggregate measure of co-innovation and production output, a closer look at how different types of co-innovation are associated with different dimensions of performance improvement may reveal more nuanced insights. Finally, to the extent that a firm's IT co-innovation may encompass both its creative adaptation of information technology to its business operations and its IT capabilities, and my measure of co-innovation from ecosystem contribution cannot separate the effects of the two, future research are called for to examine their disentangled effects.

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