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Participation in a Platform Ecosystem: Appropriability, Competition, and Access to the Installed Base*

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Abstract

In this study we examine the antecedents of small independent software vendor (ISV) decisions to join a platform ecosystem. Using data on the history of partnering activities from 1201 ISVs from 1996 to 2004, we find 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, we show 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. The results highlight the role of innovation appropriation, downstream complementary capabilities, and collaborative competition in the formation of a platform ecosystem.

Key words: platform ecosystem; partnership; intellectual property rights; downstream capabilities

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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.[1] 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 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 owner due to risk the latter may eventually compete in the 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 Michael L. 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.

[1] In this paper we 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.

In this study we 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, we 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 we use as our dependent variable. SAP certification means that SAP engineers have tested and endorsed that the ISV's software integrates with SAP (SAP 2009). 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).

We 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 to 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, risk of entry, and threat of knowledge expropriation – are the main trade-offs to the partnering decision that we examine in this study.

We test our 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, we 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, we find that small ISVs utilize both intellectual property rights protection and downstream capabilities to prevent expropriation. In particular, we 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, we find that the incentive of ISVs to join an ecosystem is positively influenced by the penetration of complementary SAP products (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, we 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 article is organized as follows. In the next section we present an overview of related research and discuss our contributions to the literature. In section 3, we introduce the research setting and briefly describe SAP's partnership program with ISVs. Section 4 presents our hypotheses. Section 5 describes the data and empirical models. We present the results, as well as a set of robustness checks, in section 6. In section 7, we discuss the implications of our study and conclude.

2. Literature Review

Our paper contributes 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. We discuss each of these in turn.

2.1. Technology Platforms and Two-Sided Markets

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 our own work is research related to 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) 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 paper takes a first step towards filling this gap by examining how appropriability and competition influence the decision to partner.

2.2. Appropriating the Returns from Innovations

Profiting from innovative solutions 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 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 our 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. Our setting allows us 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, we show that appropriability strategies—including IP protection, ownership of downstream complementary capabilities and their interaction—are crucial drivers of the formation of such partnerships.

2.3. 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 to 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. Our 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.

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). We 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.

4. Theory and Hypotheses

In this section we detail our theory and hypotheses. A simple model, which builds on and extends prior work by Gans et al. (2002), appears in the Appendix. Our model 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 we describe a set of hypotheses that map to the comparative statics in the model.

4.1. 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, we 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. We 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.*

4.2. 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, Gans and Stern 2003, Rothaermel and Hill 2005). 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 1994) and may also act as a barrier to entry. Therefore, we propose

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

4.3. 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 we 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 our model in the Appendix, here we 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, we 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.*

4.4. 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, we 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.*

4.5. 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 paper, we 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, we 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.*

5. Methods and Measures

5.1. Sample

We test our theoretical predictions using a longitudinal data set of 1201 ISVs over the period of 1996-2004. Our sample begins in 1996 since we observe no such partnerships in our 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 we 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.

CorpTech includes a proprietary classification system that allows the researcher to identify software firms and the types of products they offer. Here we provide an overview of our sample construction, further details are provided in Data Appendix B. To construct a representative sample of ISVs that are likely to form partnerships with SAP, we match the existing SAP partners (retrieved from SAP's web portal) to their corresponding records in the CorpTech data set and examine their product portfolios. Based on this comparison, we find that manufacturing software and warehousing/distribution software are the most frequently produced by SAP's partners. We therefore select all U.S. firms that have a primary industry of computer software, and use those that produce "warehousing and distribution" or "manufacturing" software as our data sample. As we are primarily interested in the drivers of partnership formation for small, entrepreneurial software companies, to reduce unobserved heterogeneity across firms we further remove established incumbents from our sample. Following prior literature (Petersen and Rajan 1994, Puranam et al. 2006), we refine the ISVs to include those established after 1980, with sales less than $500 million and with fewer than 1000 employees throughout our sampling period. As an additional check, we visit the website of each firm (if the company no longer exists, we visit the archival web site www.archive.org instead) to confirm that the ISVs indeed produce enterprise software applications, and delete those that do not fit the profile. Our final sample consists of 1201 ISVs.

5.2. Variable Definition and Operationalization

5.2.1. Dependent Variable

The dependent variable is whether an ISV enters into partnership with SAP in a particular year. While one approach would be to identify partners listed directly on the SAP platform ecosystem web site, using this method we would be unable to identify the timing of partnership events. Instead, we identify partnership formation events through press releases by searching the Lexis/Nexis database. To test the viability of this approach, we compared the list of partners obtained through this method with a list obtained from the SAP web site and found that our method identifies 98% of partners mentioned by SAP.[2]

The unit of observation in our data is a firm-year, with the partnership variable equal to 1 if a first-time alliance is formed in that year, 0 otherwise. Post-alliance observations are deleted as the firms are no longer exposed to the hazard of forming a partnership with SAP. In total, our sample includes 6381 firm-year observations. The data is structured as an unbalanced panel since there are late entries and exits.

5.2.2. Independent Variables

Patents. We 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, we restrict our patent measure to software patents only (however our results are similar if we 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). We follow Hall and MacGarvie (2006) in using the intersection of these two methods to identify software patents.[3] As a robustness check, we also use the union of the software patent sets identified by the two methods and derive alternative measures; our empirical results are robust to the different measures of patents stock. To account for the heterogeneity in the impact and importance of innovation, we 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, we

[2] Further discussion of our method for identifying partnerships is provided in the Data Appendix.

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

construct the 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).[4] 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. We computed averages of the Likert responses at the 5-digit international patent class (IPC) level and linked to our data by the corresponding IPC class of the patents owned by ISVs in our 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. We 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 2005). According to the USPTO, a trademark represents "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 we 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 database. We use only software trademarks that are currently "live" as of the date of observation (further details on the construction of this variable are available in the Data Appendix).

Target industry penetration. In order to construct a valid measure of SAP's market penetration in the ISV's target industries, we 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 technology; our sample of data from the CI database includes all establishments with over

[4] 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).

100 employees.[5] We identify the set of firms that have adopted SAP in each year and weight these by the number of employees[6]. We use these data to compute the SAP penetration rate for the industries served by the ISVs (details are provided in the Data Appendix).

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). We 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, we also construct alternative measures of product overlap by dividing the number of common product lines by 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.

5.2.3. Control Variables

We 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, we add both linear and quadratic terms of age. We 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.

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[5] 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).

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

We 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. We 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, we 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, we also retrieve forward citation data for all the publications and construct citation weighted publications.

5.3. Model Specification

We 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*.

We 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 our specification, we have $h_i(t \mid \mathbf{x}_{i,t-1}) = h_0(t)\exp(\mathbf{x}_{i,t-1}\boldsymbol{\beta})$, and

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

Where $h_i(t \mid \mathbf{x}_{i,t-1})$ is the conditional instantaneous hazard rate for ISV *i* in year *t*, and $h_0(t)$ is the unspecified baseline hazard in year *t*. We 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, we use a (firm) fixed effects linear probability model to study the event history (Wooldridge 2001), allowing for firm-level unobserved heterogeneity. We 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.[7] 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 we 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.

6. Results

6.1. Findings

Table 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 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).

[Insert Table 1 about here]

Results from Cox proportional hazard survival models are presented in Table 2. In all regressions we 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

[7] 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 our setting, this would include any ISV that does not eventually become a partner.

protection, downstream capabilities and publications are included. In column 2 we 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. We add the full set of control variables in Column 4. Finally, in column 5 we add patent effectiveness to control for potential differences in patent propensities among firms.

[Insert Table 2 about here]

Examining the results of the final model, we 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, we do find evidence that the effectiveness of patent protection increases an ISVs' 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, our theory implies that firms with stronger patents are expected to enforce their patents with a greater probability of success. Consistent with expectations, we 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. We also find a strong positive effect of trademark stock on the partnership formation across specification and models, confirming hypothesis H2. Consistent with our expectation, we 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, we consider a log transformed variables x_i in the Cox proportional hazard model. Suppose we increase x_i by 100%, while holding other variables constant, the hazard ratio is

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

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

$$\frac{h(t \mid 2x_1, 2x_2, \mathbf{x}_{-1,2})}{h(t \mid x_1, x_2, \mathbf{x}_{-1,2})} = \frac{\exp[\beta_1 \ln(2x_1) + \beta_2 \ln(2x_2) + \beta_3 \ln(2x_1) \times \ln(2x_2)]}{\exp(\beta_1 \ln x_1 + \beta_2 \ln x_2 + \beta_3 \ln x_1 \times \ln x_2)}$$
$$= \exp[\beta_1 \ln 2 + \beta_2 \ln 2 + \beta_3((\ln 2)^2 + \ln 2 \times \ln x_1 + \ln 2 \times \ln x_2)]$$
$$= 2^{.663} \times 2^{.929} \times \exp[(-.571) \times ((.693)^2 + .693 \times .378 + .693 \times .333)] = 1.730$$

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 our 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. We 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 up 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.

6.2. Tests for Robustness

Although survival analysis is suitable for modeling event history and our specification of Cox proportional hazard model does not impose restrictions on the baseline hazard function, there are two possible concerns associated with our 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, our 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 3 presents the results of estimating a standard fixed effects ('within firm') model. Comparing the results with those of Table 2, we 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. We 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 our variables measuring IP appropriation are robust to the use of fixed effects, estimates for the effects of penetration and product overlap are weaker. We 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 our conjecture and demonstrates a much stronger and significant effect of penetration and product overlap (between estimation results are available upon request).

[Insert Table 3 about here]

We further explore the robustness of our findings through several alternative models and measurements of the independent variables. In column 1 of Table 4 we present results of our 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 and 3, the variable may not capture the extent to which SAP perceives the ISV as a competitor. We replace the variable by normalizing it using SAP's product portfolio and present the results in Column 2 of Table 4. In both cases we find the set of results is similar to those in Table 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 4 we 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. We 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. We present the results of an exponential hazard model with inverse-Gaussian *frailty* in column 4 of Table 4. The likelihood ratio test for heterogeneity does not reject the null of no heterogeneity (p=.304), indicating that our set of explanatory variables is sufficiently inclusive. The different models listed in Table 4 provide further evidence of the robustness of our results.

[Insert Table 4 about here]

7. Discussion and Conclusion

7.1. 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 and antecedents of the formation of such ecosystems from the perspective of its participants. Our 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. We 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 entry discourages such partnership.

We envision several broad implications of our 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, our 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.

Our 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 our research is set in the enterprise software industry, we 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 player, iPod.

7.2. Limitations and Future Research

Although patents and copyrights appear as effective measures of IP protection, we acknowledge our 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; Cohen et al. 2000). 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. 2008, Mann and Sager 2007), or characteristics of the technology (Hall and Ziedonis 2001). We 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 we 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 Martin 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 Martin 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.

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

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

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

Appendix A. Partnering to Achieve Platform Compatibility: A Simple Model

We present a simple multi-stage game to formalize the payoff structure related to an ISV's decision to join a platform ecosystem and to motivate our 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 A1 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

$$\pi^n = \pi_e - \Delta_e p^n (1-\theta). \quad (1)$$

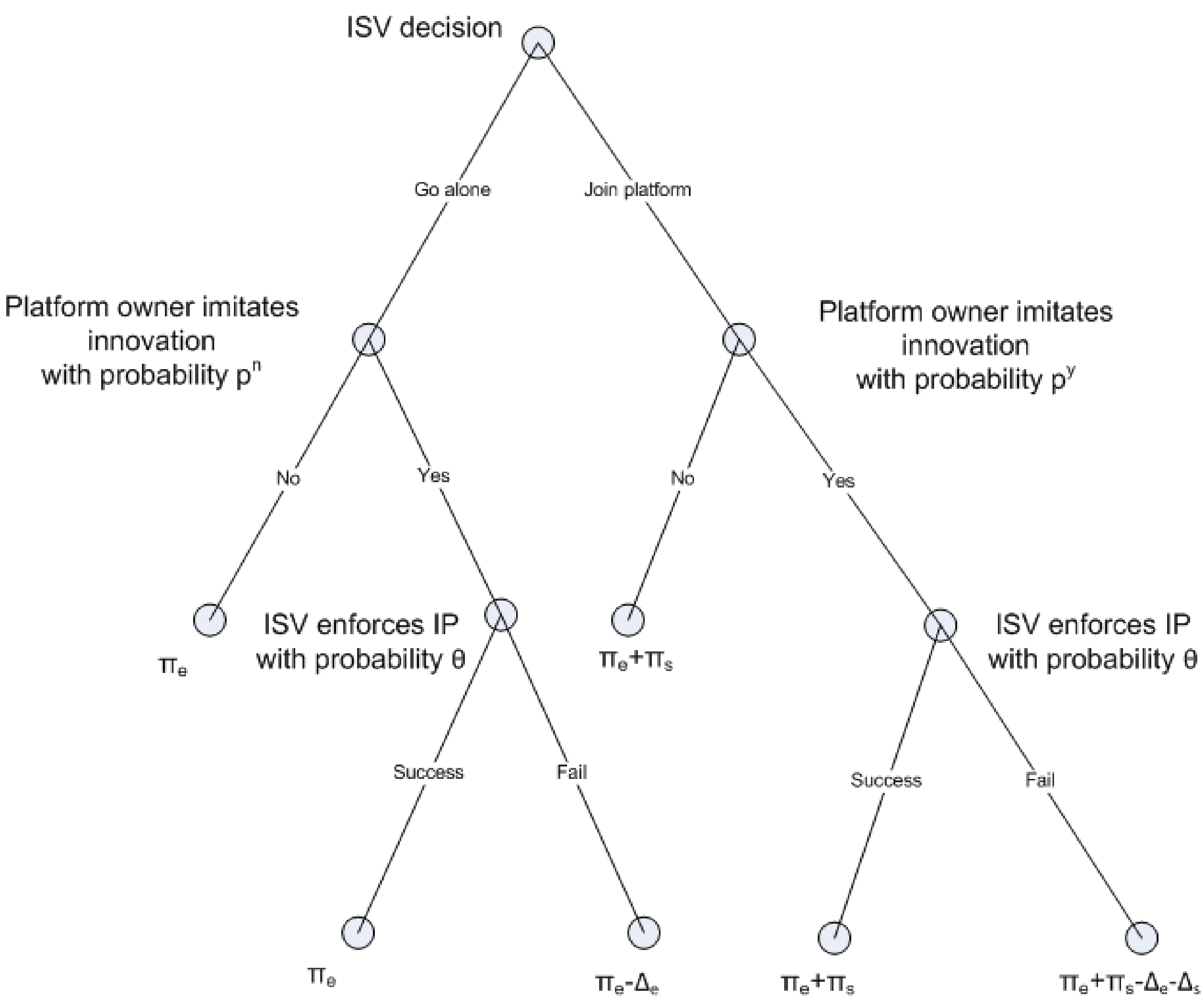
The ISV can also partner with the platform owner to tap into the customer base of the latter. Denote the additional profit the ISV enjoys from accessing the platform owner's installed base by $\pi_s(C,P,T)$. We assume π_s is decreasing in the intensity of product market competition between the platform 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 $\Delta_e(C,T)$. We 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

$$\pi^y = \pi_e + \pi_s - (\Delta_e + \Delta_s)p^y(1 - \theta). \quad (2)$$

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

$$S = \pi^y - \pi^n = \pi_s - \Delta_e(p^y - p^n)(1 - \theta) - \Delta_s p^y(1 - \theta). \quad (3)$$

Figure A1: The ISV's Payoffs



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

$$\frac{\partial S}{\partial \theta} = \Delta_e(p^y - p^n) + \Delta_s p^y > 0 \tag{4}$$

$$\frac{\partial S}{\partial T} = \frac{\partial \pi_s}{\partial T} - \frac{\partial \Delta_e}{\partial T}(p^y - p^n)(1-\theta) - \frac{\partial \Delta_s}{\partial T} p^y (1-\theta) > 0 \tag{5}$$

$$\frac{\partial^2 S}{\partial \theta \partial T} = \frac{\partial \Delta_e}{\partial T}(p^y - p^n) + \frac{\partial \Delta_s}{\partial T} p^y < 0 \tag{6}$$

$$\frac{\partial S}{\partial P} = \frac{\partial \pi_s}{\partial P} > 0 \tag{7}$$

$$\frac{\partial S}{\partial C} = \frac{\partial \pi_s}{\partial C} - \frac{\partial \Delta_e}{\partial C}(p^y - p^n)(1-\theta) - \frac{\partial \Delta_s}{\partial C} p^y (1-\theta) < 0 \tag{8}$$

(4) – (8) correspond to the five hypotheses H1 – H5, respectively, that we proposed in the main text.

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: the additional risk of imitation $(p^y - p^n)$ due to partnering is (1) non-increasing in T, and (2) non-decreasing in C. Specifically, we have

$$\begin{aligned} \frac{\partial S}{\partial T} = {} & \frac{\partial \pi_s}{\partial T} - \frac{\partial \Delta_e}{\partial T}(p^y - p^n)(1-\theta) - \frac{\partial \Delta_s}{\partial T} p^y (1-\theta) \\ & - \Delta_e\left(\frac{\partial p^y}{\partial T} - \frac{\partial p^n}{\partial T}\right)(1-\theta) - \Delta_s \frac{\partial p^y}{\partial T}(1-\theta) > 0 \end{aligned} \tag{5'}$$

$$\frac{\partial^2 S}{\partial \theta \partial T} = \frac{\partial \Delta_e}{\partial T}(p^y - p^n) + \frac{\partial \Delta_s}{\partial T} p^y + \Delta_e\left(\frac{\partial p^y}{\partial T} - \frac{\partial p^n}{\partial T}\right) + \Delta_s \frac{\partial p^y}{\partial T} < 0 \tag{6'}$$

$$\begin{aligned} \frac{\partial S}{\partial C} = {} & \frac{\partial \pi_s}{\partial C} - \frac{\partial \Delta_e}{\partial C}(p^y - p^n)(1-\theta) - \frac{\partial \Delta_s}{\partial C} p^y (1-\theta) \\ & - \Delta_e\left(\frac{\partial p^y}{\partial C} - \frac{\partial p^n}{\partial C}\right)(1-\theta) - \Delta_s \frac{\partial p^y}{\partial C}(1-\theta). \end{aligned} \tag{8'}$$

Appendix B. Data Appendix

B.1. Identifying the Sample

To construct a representative sample of ISVs that are likely to form partnerships with SAP, we 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,[8] and a search 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 classifies the products using a product classification system.[9] We retrieve the distinct 2-digit level product classification codes of the 206 existing SAP software partners, and identify 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. We subsequently define our sample as firms that operate in the United States, with primary industry of computer software (identified by CorpTech's 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.

B.2. Identifying Partnerships

We 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 to identify partnerships, where "*XYZ*" is replaced by the ISV's name. For a random sample (60 firms) of the 411 existing SAP partners, we are 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. We subsequently apply the same algorithm to our 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. We 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), we use the first such event as the time the ISV joins SAP's platform ecosystem.

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

[9] 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".

B.3. Identifying Trademarks

For each trademark listed on the USPTO database, a Live/Dead indicator is assigned, which could be Registered, Pending or Dead. Dead marks may have been abandoned, cancelled, or may have 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, we 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 the software trademarks.[10] Afterwards, we 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, we calculate the expiration date as 10 years after the registration date, or 10 years after the latest renewal date if there has been any renewal record for the trademark.

B.4. Measuring the Penetration Rate for Industries Served by the ISV

We compute the penetration rates for industries in the SAP "master code" industry classification system, which is composed of indicators for 33 vertical industries (e.g., aerospace & defense, banking, and chemical, to name a few). We match the SAP master codes with the Standard Industrial Classification (SIC) codes provided for each firm in the CI database (the match table is available from the authors upon request). We calculate the 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. Next, we read the target industries description of our ISVs and create master code dummies for each of them (CorpTech 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 ISVs, 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, we use the average SAP penetration rate across all 33 industries to compute the penetration variable. We also create an indicator variable *multiple industry* to control for potential bias introduced by this coding. The variable is set to 1 if a firm's precise target industry is not given in CorpTech.

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[10] After thorough content analysis of 100 software trademarks, we 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".

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