Competitive Impacts of IT Innovation: An Empirical Analysis of Software Patents in the IT Industry

Completed Research Paper

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Abstract

While prior research has examined the role of Information Technology (IT) investments in the process and performance of innovation, there is relatively little research on the business value of IT innovation itself. In particular, the impact of a firm's IT innovation on the performance of the firm's rivals remains unexplored. In order to advance our understanding of the competitive impact of IT innovation, we investigate the impact of a firm's software patents on rivals' market value using data from the US IT industries. Theoretically, there are two countervailing forces influencing the competitive impact of software patents: market-stealing and spillover. Therefore, the net impact of a firm's software patents on rivals depends on the relative magnitude of these two forces, and is essentially an empirical question. We find that a focal firm's software patent stock is negatively associated with its rivals' market value. In addition, we find interesting moderating effects of two factors: hardware patent stock and competitive intensity. Our results indicate that the focal firm's hardware patent stock amplifies the negative impact of its software patent stock on rivals' market value. Furthermore, we find that the competitive intensity of the industry mitigates the competitive impact of software patent stock. We discuss the implications for research and practice.

Keywords: IT innovation, software patent, rivals, market competition, firm value, market stealing, spillover

Introduction

Innovation is an essential strategic endeavor that plays a critical role in both the survival and prosperity of firms in every industry (Utterback 1994). A firm's innovations are often manifested in new ways of doing things or new products and processes that contribute to the competitiveness and performance of the firm. In today's digital age, firms rely heavily on investments in information technology (IT) to innovate and manage the process of innovation (Kleis et al. 2012). Consequently, researchers have examined the role of IT investments and capabilities in generating patented innovation (Joshi et al. 2010; Kleis et al. 2012) as well as the impact of complementarities between IT investment and innovation processes on firm's financial performance (Bardhan et al. 2013).

However, there has been relatively little research on the business value of IT innovation itself (e.g., Brynjolfsson and Saunders 2009). Further, the limited extant research investigating the impact of IT innovation has focused primarily on the value of IT innovations to the focal firm that innovates, and found that IT innovations increase the financial market value of the innovating firm (Chung et al. 2013; Hall and MacGarvie 2010). Although the results demonstrate the value of IT innovations, it is not clear whether this value is created at the expense of the competitors of the focal firm or such IT innovations are beneficial to the whole industry in which the focal firm operates (i.e., the focal firm's innovation benefit not only itself but also its competitors in that industry). Therefore, in this study we examine the impact of IT innovations by a focal firm on the firm's competitors.

In order to protect their IT innovations and prevent other firms from using them, firms frequently rely on patents, which are one of the strongest forms of firms' intellectual property (Teece 1998). Patents grant legal authority to the inventor to prohibit others from making or selling the patented invention for a fixed period of time. Although IT innovations can result in hardware as well as software patents, our study focuses on software patents. Unlike hardware patent focusing on hardware technologies, software patents involve a logic or algorithm for processing data and have been defined as patents on any performance of a computer realized by means of a computer program (FFII 2007; Hall 2003). Software patents have highly abstract property due to its complexity (Bessen and Hunt 2007).

In the past, only hardware innovations were patentable while software innovations were not, because of their abstract nature and also because the lengthy process of patenting made the software patents, which have a short commercial life, irrelevant (Bender and Barkume 1992). However, since the landmark court decision in 1998 that made software patentable, the number of software patents has been increasing.[1] At the same time, patent infringement lawsuits involving software have increased considerably. According to a report by US Government Accountability Office (GAO), from 2007 to 2011, the number of overall defendants in patent infringement lawsuits increased by about 129 percent, and lawsuits involving software-related patents accounted for about 89 percent of the increase in defendants (GAO 2013).

Further, although prior research has examined the value of patents mostly at the economy level (i.e., across various heterogeneous industries), prior research suggests that industries differ in terms of the average number of patents generated by each dollar of R&D investment (Scherer 1983), their ability to appropriate returns from their R&D investments, and the value of the patents themselves (Hall et al. 2005; Levin et al. 1987). Therefore, there has been a call for patent research within specific industries (Cockburn and MacGarvie 2011; Mykytyn et al. 2002). Given that software innovation is the core product innovation in the IT industry - an industry that is characterized by fierce competition and fast technological changes, we focus on examining the value impacts of software patents in the IT industry. The aforementioned increase in software-related lawsuits including the highly publicized lawsuits between Samsung and Apple attest to the strategic importance of software patents in the IT industry.

Despite the growing importance of software patents and the call for research on their impacts on firm value and competitive advantage (Kazuyuki 2009; Mykytyn et al. 2002), there has been relatively little empirical research on the business value and competitive effect of software patents. While a few studies

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[1] The number of software-related patents grew steadily from the mid-1990s to 2005, at an average rate of 4.7 percent a year from 2000. In 2005, more than 50,500 international patent applications were filed under the PCT (Patent Co-operation Treaty) to protect inventions in IT. In fact, the number of software-related patents increased more rapidly than the total number of PCT applications. In 2005, more than 15,000 software patents were granted and its proportion exceeded 12%.

have examined the impact of software patents on firm performance (Hall et al. 2005; Hall and MacGarvie 2010), there is a paucity of research on the competitive impact of software patents. As a result, our understanding of whether and how software patents impact competition is still limited. In this study, we attempt to fill this research gap by empirically investigating the relationship between the software patents of a firm on its competitors' financial market value.

Empirically examining the relationship between a firm's software patents and its competitors' market value is important especially because the impact of a focal firm's patented software innovations on its competitors is theoretically ambiguous (Fosfuri and Giarratana 2009; McGahan and Silverman 2006; Teece 1986). On one hand, a focal firm's software patents can have *market-stealing* effects: software patenting by a firm may generate property rights that give the firm a competitively advantageous position, thereby adversely affecting the competitor firms' market value. On the other hand, a focal firm's software patents can also have *spillover* effects on the rival firm: a software innovation patented by a firm may trigger greater technological opportunity for the rival firms, or the disclosure of software patents by a firm may provide crucial information on which rival firms can build their own products/services, thereby enhancing the rival firms' market value. Therefore, the net impact of a focal firm's software patents on a rival firms' market value depends on the relative magnitude of these two countervailing forces, and hence is an empirical question.

To address this empirical question, we employ a large panel dataset covering 420 firms (including their rivals) in US IT industries over the 1998-2006 period and investigate whether a focal firm's software patents have a positive or negative impact on rival firms' market value. We also examine whether the focal firm's hardware patents moderate the impact of its software patents on the rival firms' market value. Furthermore, we examine the moderating role of competitive intensity, one of the key environmental variables used by prior studies.

The paper makes several contributions to both theory and practice. First, we contribute to the literature on the value of patents in general (e.g., Ernst 2001; Hall et al. 2005; Hall and MacGarvie 2010), and the nascent literature on the value of IT patents in particular (e.g., Chung et al. 2013) by separating the two types of IT patents—software and hardware patents—and theorizing and empirically assessing the competitive impact of software patents. Our finding that a firm's software patents have a negative impact on its rivals' market value, while the impact of the firm's hardware patents is insignificant, highlights that different types of patents have distinct characteristics and need to be examined separately to gain a richer understanding of their impacts.

Second, more importantly, we contribute to the literature by examining the competitive effects of software patents. Most prior patent studies have focused on examining the impact of firms' patents on their own performance, and the impacts on rivals' performance remain relatively unexplored. Although prior studies suggest that a firm's innovation can benefit rival firms through knowledge spillover (McGahan and Silverman 2006), our results suggest that market-stealing effects dominate in the case of software patents in the IT industries. This is consistent with our conceptualization of software patents as a key resource in the IT industry that can offer competitive advantage, and extends the handful of studies that have examined the value of software patents (Bessen 2011; Graham and Vishnubhakat 2013; Hall and MacGarvie 2010).

Third, our analysis of the moderating role of hardware patent stock and competitive intensity provides new insights into the conditions under which the effects of software patents on rivals (i.e., either market-stealing or spillover) can be magnified or mitigated. Prior patent studies have mostly focused on the main effect of patents, and, for the most part, have not identified factors that can influence the extent to which patents create value (Bessen 2011; Hall and MacGarvie 2010; Liu and Wong 2011). Our finding that a firm's hardware patent stock strengthens the negative impact of the firm's software patent stock on rivals' market value provides empirical evidence on the importance of complementary assets (hardware patents in our case) in developing competitive advantage from innovations (Teece 1986). This also underscores the importance of having a systems approach to IT innovations—firms are more likely to gain competitive advantage from IT-based innovations including both hardware and software components, compared to those focusing solely on either software or hardware innovations.

Further, by examining the moderating effect of competitive intensity in the context of software patents, we extend the strategy literature that has examined the impact of external environments on the competitive dynamics (Keats and Hitt 1988; Megna and Klock 1993; Sirmon et al. 2007; Zahra and Bogner 2000). Our finding that the negative impact of a firm's software patent stock on rivals' market value is mitigated under a higher level of competitive intensity has an important policy implication.

Theoretical Background and Research Questions

Drawing on the resource-based view (RBV) (Barney 1991; Wernerfelt 1984), we conceptualize software patents as a key resource in firms in IT industries. RBV stresses the role of heterogeneous firm resources in gaining competitive advantage, and we argue that software patents are such a resource because they are valuable, rare, imperfectly imitable, and difficult to substitute for (Barney 1991).[2] While IS scholars have applied RBV to identify key IT resources that can lead to superior performance (see for a review, Wade and Hulland 2004), they have focused on IT human resources (especially managerial skills possessed by IT workers). In this study, we conceptualize software patents as another key resource in the IT industry for gaining competitive advantage, and examine their competitive effects.

Table 1. Two Competing Perspectives on the Impact of Software Patents on Rivals' Performance

	Market-Stealing	Spillover
Anticipated Impacts on Rivals	Negative	Positive
Underlying Arguments	A firm's software patents can enable the firm to improve its products and services, and increase efficiency, thereby helping solidify the firm's competitive position relative to its rivals (Teece 1986; Teece 1998). A firm's software patents can generate property rights that give the firm a competitively advantageous position and an ability to take legal actions against its rivals that attempt to copy its technologies without permission (Levin et al. 1985; McGahan and Silverman 2006).	A firm's software patents can trigger greater technological opportunities for rival firms (Jaffe et al. 2000). The disclosure of software patents by the firm provides crucial information about the innovation. Based on this information, the rivals can imitate a focal firm's innovation and develop similar or better products and services (McGahan and Silverman 2006).
Related Empirical Works	Patents have a market-stealing effect in the semiconductor industry (Megna and Klock 1993). Rival product announcements have a market-stealing effect in mature product market (i.e., carbonated soft drink industry) (Fosfuri and Giarratana 2009).	Patents have a spillover effect in the biotechnology industry (Austin 1993) and the pharmaceutic industry (Furman et al. 2005). Alliance announcements have a spillover effect on allying firms' rivals in the telecommunications and electronics industry (Oxley et al. 2009) and open innovation alliances (Han et al. 2012).

Prior studies on innovation have discussed two distinct effects of a firm's innovations on its rivals: *market-stealing* and *spillover* (Levin et al. 1985; McGahan and Silverman 2006; Teece 1986). The market-stealing effect occurs when a firm's innovations enable the firm to improve its products and services, increase efficiency, or gain stronger competitive advantage against its rivals. On the other hand, the spillover effect occurs when the knowledge generated by a firm's R&D becomes available to other firms, consequently benefiting its rivals as well as the focal firm. These two effects may co-exist in the case of software patents. Specifically, software patents help a firm legally protect its knowledge so that rivals cannot copy its improved products and services, thus generating a competitive advantage beyond that from its initial R&D. At the same time, however, the disclosure involved in the patenting process may diffuse knowledge about the patented innovation that may spill over to other firms, its rivals in particular, thereby benefitting the rivals. Table 1 summarizes the arguments for each of these two effects in the context of software patents and related empirical work. These two effects have countervailing influences on a firm's market value (McGahan and Silverman 2006; Teece 1986) and which effect will dominate is an

[2] In IT industry one finds companies providing three different types of products and services: hardware (e.g., computers, and telecommunications equipment), software and related services (e.g., systems integration, and tailored product development, etc.). Within the computer software segment, two major types of companies are to be found: computer hardware/software producers, such as IBM, Apple, Sun Microsystems and Compaq, and independent software producers such as Microsoft and Oracle.

empirical question. If the market-stealing effect is dominant, rivals' software patents will have an adverse effect on the focal firm's market value; if the spillover effect dominates, however, rivals' software patents will have a net positive impact on the focal firm. Summing both perspectives, we arrive a set of competing hypotheses:

H1a: *A firm's software patent stock is positively associated with its rivals' market value.*

H1b*: A firm's software patent stock is negatively associated with its rivals' market value.*

More importantly, under what conditions a firm's software patents influence rivals' performance more (or less) has not been studied. To address this gap in the literature, we examine the moderating role of two factors: a focal firm's hardware patents and industry competitive intensity. First, we examine the role of hardware patents developed by the focal firm that may enhance the value of the firm's software patents as complementary resources. To understand the interaction between hardware and software patents, we need to understand the concept of software stack. A software stack (Gao and Iyer 2006) divides the software activity into layers that are complementary to each other. At a highest level one can define a two-layer stack comprised of hardware and software. Integration between these layers has implications for competition in the industry—a firm that can integrate various layers of the stack can increase switching costs for users, which in turn enhances the market performance of the firm (Gao and Iyer 2006). While a firm only having superior software resources in the form of patents would have to rely on other firms in the industry that own hardware patents and coordinate with such firms to succeed, a firm with strong software as well as hardware patent stock is able to create complementarities between their superior hardware and software innovations. This, in turn, can strengthen the firm's competitive advantage (Gao and Iyer 2006; Teece 1986). Moreover, such a firm can consolidate its position in the industry as a technological leader, thereby extracting greater rents from its resources and outperforming its competitors (Gao and Iyer 2006; Piccoli and Ives 2005). Thus, greater hardware patent stock possessed by a firm will strengthen the market-stealing effect of its software patent portfolio.

On the other hand, greater hardware patent stock owned by a firm can weaken the spill-over effects of the firm's software patent portfolio. The spillover effect requires rival firms to be able to learn and build upon the knowledge disclosed by the focal firm's software patents. However, the hardware and software patents in the focal firm's portfolio may create complex knowledge interdependencies which make it difficult for its rivals to leverage the knowledge embedded in software patents (Jain and Jain 2011). Thus, the extent of knowledge spillover from a focal firm's software patents and its impact on rivals would be smaller in the presence of high stocks of hardware patent owned by the focal firm.

To summarize, in the presence of greater hardware patent stock owned by a focal firm, the market-stealing effect of its software patents will be stronger and the spillover effect of its software patents will be weaker. Taken together, this implies that the focal firm's hardware patents will negatively moderate the relationship between the firm's software patents and the market value of its rivals. In other words, when the spillover (market-stealing) effect of the firm's software patents dominates, the firm's hardware patent stock will weaken (strengthen) the positive (negative) impact of its software patents on rivals' market value. In order to empirically verify this conjecture, we examine the competing set of hypotheses:

H2a: *The more a firm's hardware patents, the stronger the association between the firm's software patents and its rivals' market value.*

H2b: *The more a firm's hardware patents, the weaker the association between the firm's software patents and its rivals' market value.*

Next, building on prior research suggesting that the outcomes of market-stealing and spillover may vary depending on industry characteristics (Austin 1993; Megna and Klock 1993), we argue that competitive intensity can have a significant influence on the effects of rivals' software patents. Competitive intensity refers to the extent to which a firm's external environment is characterized by intense competition (Matusik and Hill 1998). In a more competitive environment, there are more competitors, and it is difficult for a firm to predict its competitors' actions. In such environment, firms need to be very agile in responding to competitors' moves to stay ahead of the competition.

A large body of research highlights that a firm's own patents offer a more significant boost to its market value in industries that are characterized by strong protection of intellectual property rights (Cockburn and Griliches 1988; McGahan and Silverman 2006; Teece 1986). However, in a highly competitive industry where many firms try to differentiate themselves from and stay ahead of their competition, the market-stealing effect of rivals' software patenting may be severely dampened.

On the other hand, a high level of competitive intensity leads to the erosion of software patent protection because it allows rival firms to exploit the knowledge embedded in the innovations more easily. In other words, under highly competitive environments, outcomes of patented innovations tend to become rapidly diffused over the population of competitors without consent of the patent owner (Jansen et al. 2006; Levinthal and March 1993). Thus, in a more competitive environment, we expect the spillover effect of a firm's software patents on rivals' performance to be stronger. Taken together, this implies that competitive intensity will positively moderate the relationship between a firm's software patents and the market value of its rivals. In other words, when the spillover (market-stealing) effect of a focal firm's software patents dominates, competitive intensity will strengthen (weaken) the positive (negative) impact of the firm's software patents on rival firms' market value. Thus, these two camps of arguments give rise to our competing set of hypotheses:

H3a: *The more competitive intensity of market environment, the stronger the association is between a firm's software patents and its rivals' market value.*

H3b: *The more competitive intensity of market environment, the weaker the association is between a firm's software patents and its rivals' market value*

Research Data

IT industries provide an ideal setting for our study because profitability in IT industries depends critically on firms' abilities to create and commercialize new technologies and defend rivals' infringement of intellectual property (Hall and MacGarvie 2010). Our empirical analysis employs data on software patents in the IT industries (twenty two four-digit industries[3] within SICs 357, 366, 367, 381, 382, 384, and 737) during the 1998-2006 period. We obtained the patent data from the National Bureau of Economic Research (NBER) constructed by Hall et al. (2001).[4] This dataset covers detailed information on all patents granted by the US Patent and Trademark Office (USPTO) between 1976 and 2006. It includes, among other items, annual information on patent assignee names (mainly, the firm), the number of patents, the number of citations received by each patent, the technological class of the patent, and the year that the patent application was filed and granted. We recorded patents by their filing year, rather than their granted year, as there may be arbitrarily long lags between application year and granted year (see Benner and Tushman 2002).

Because the USPTO published new guidelines for software patentability on March 29, 1996 and our analysis requires patent citation information, we choose our sample period to be 1998-2006. Furthermore, we obtained firm-level measures from the Compustat database, which provides data of all public firms in the US. Following the method suggested in Hall et al. (2001), we matched the NBER data with the financial data from *Compustat* (see also Hall et al. 2005; Hall and MacGarvie 2010; Liu and Wong 2011).

We used patent technology classes to categorize software and hardware patents. Specifically, we identified those technology classes related to software and/or hardware patents and categorized all of the patents within these technology classes as either software or hardware patents. First, regarding software patents, we identified all of the US patent classes in which top 20 software firms[5] patented, and categorized patents falling within these classes as software patents, following Hall and MacGarvie (2010). We ruled out those patent classes for which the share of the top 20 software firms was under 20%. Further, we also included any additional technology classes that had been classified as software patents in prior research (Bessen 2011; Graham and Mowery 2003; Hall 2003). Next, we identified hardware patents by adopting

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[3] We focus on the IT industry that consists of 22 sub-industries, based on SICs from the US Bureau of Economic Analysis' (BEA) guidelines.

[4] The NBER data have been updated through 2006 and are available online:
https://sites.google.com/site/patentdataproject/Home.

[5] The top 20 firms were selected by the sales of their calendar 2006 revenues from the NAICS 511210 group (i.e., software publishers). These firms are *Microsoft, Oracle, SAP, SunGard Data Systems, Symantec, CA, Electronic Arts, Adobe, Amdocs, Intuit, Konami, Dassault Systems, Autodesk, BMC Software, Cadence Design Systems, Activision, Business Objects, Compuware, BEA Systems, and Comverse Tech.*

the classification method employed in prior studies (Choi et al. 2007; Schaaper 2003). Finally, we re-examined patent classes for which the consistency among patent classes suggested from prior studies, as well as our own classification, is low. Three coders, who are experts in information technology, validated and re-classified these patent classes after independently reading the definitions of these classes in detail. The inter-rater reliability for the coding of software and hardware patent was 0.94, suggesting a high level of agreement. The resulting categorization of software patents consists of 22 technology classes and that of hardware patents contains 25 technology classes.

In line with prior research (Hall et al. 2005; Hall and MacGarvie 2010; Liu and Wong 2011), we computed the patent stock measure in year t for firm i using a single depreciation rate (ρ) for the patent value, which is assumed to be 20%, consistent with prior research. We also calculated the R&D stock in year t for firm i using the same depreciation rate.[6] To control for the size of R&D investments, we scaled the patent stock by the R&D stock following prior studies (Griliches 1981; Hall et al. 2005; Hall and MacGarvie 2010; Liu and Wong 2011). Another reason we use the ratio of patent stock to R&D stock is that once R&D is observed, the market presumably knows how to price the expected value of the innovative stream that will result from it, including the expected number of patents that will come further down the line (Griliches 1981). Thus, the additional informational value of patents once R&D has already been factored in must be captured by the number of patents per dollar of R&D. In sum, the ratio of software patent stock to R&D stock indicates the software patent yield of R&D. If the yield of R&D in terms of software patents is higher than average, it may indicate that the R&D project succeeded beyond expectations, conversely so if the patent yield is low.[7]

Prior studies on identification of rivals (e.g., Eckbo 1983; Oxley et al. 2009) suggested both incumbent rivals that were recognized as leaders in the corresponding industry in year t and peer rivals comprised firms whose total asset size was close to that of a focal firm. In this study, we used peer rivals to capture direct, short-term competition in a certain year. We identified peer rivals of an IT firm using procedures similar to those used by Han et al. (2012). To minimize possible noise in the data for the identification of the peer rivals, the sample data was refined in several ways. First, we identified a group of peer rival firms sharing the same primary four-digit SIC with the focal firm, constrained within +/- 20 percent of total asset compared with that of focal firm on the basis of the year of patent applications. Second, firms whose rivals could not be identified accurately through the use of multiple sources such as Hoover's company profiles were removed from the sample. This resulted in 567 rivals during nine years.[8]

To capture market competition, we employ two measures of industry concentration: the four-firm concentration ratio (CR4) which is measured as the ratio of the total sales of the top four firms in an industry to the total industry sales, and the Herfindahl-Hirschman Index (HHI). We calculated CR4 and HHI for each four-digit SIC industry and each year to measure the market concentration. Higher values indicate lower market competition (Han and Mithas 2013; Mithas et al. 2013). To avoid confusion in interpreting the coefficient, we use the log of the reciprocal of the HHI in the estimations so that the higher the value of this index, the higher the degree of market competition.[9]

As our main dependent variable, we use rivals' Tobin's q that captures the financial market performance of rivals. Given that it offers the advantage of capturing both short-term performance and long-term prospects based on the market value, it has been widely used in prior IS literature (Bardhan et al. 2013; Bharadwaj et al. 1999; Kohli et al. 2012; Xue et al. 2012) and prior research examining the impact of rival's activities on a focal firm's market value (Fosfuri and Giarratana 2009). Moreover, Tobin's q covers the market-based measure of a firm's tangible and intangible value because it is forward-looking, risk-adjusted, and less volatile to changes in accounting practices. In order to effectively capture the competitive impact of software patents, which may have long-term consequences not recorded in rivals' financial statements, we use rivals' Tobin's q to measure the market performance.[10]

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[6] Our empirical results are not sensitive to the chosen value of the depreciation rate (e.g., 0.2, 0.15, etc.).
[7] Using raw software patent stock (without scaling by R&D stock) yielded similar results.
[8] For a robustness check, we also applied 10% and 30% as the criteria for selecting peer rivals, and obtained similar results.
[9] With CR4, we obtained similar results.
[10] We use the average value of rivals' Tobin's q. Using an aggregated value yielded similar results.

We included a number of control variables that can affect rivals' Tobin's *q*.[11] To control for the growth opportunities available to rivals, we included rivals' R&D intensity, which was computed as the total amount of R&D expenditures in a given year, divided by total sales for each firm, and the industry Tobin's *q* (Bardhan et al. 2013; Bharadwaj et al. 1999; Xue et al. 2012). We also included the total number of employees as a control for firm size, and included advertising intensity and net income (Hitt and Brynjolfsson 1996; Xue et al. 2012). Finally, a set of industry dummies at the four-digit SIC level were included to control for time-invariant industry-specific effects. Year dummies for the sample years from 1998 to 2006 were included to control for year-specific effects. Table 2 summarizes the definitions of variables, and Table 3 provides correlations among the variables.

Table 2. Definitions and Descriptive Statistics of Key Variables

Variable	Definition/Operationalization	Mean	Std.	Q1	Median	Q3
Rivals' Tobin's *q*	Average of each rival's Tobin's *q* measure as in Bharadwaj et al. (1999) in year *t*	3.374	5.807	1.052	2.106	5.639
Firm's S/W patent stock	Firm's cumulative software patent counts, scaled by R&D stock in year *t*	0.162	0.544	0.051	0.131	0.309
Firm's H/W patent stock	Firm's cumulative hardware patent counts, scaled by R&D stock in year *t*	0.191	0.712	0.039	0.136	0.358
Firm's S/W patent citation stock	Firm's cumulative citation-weighted software patent counts, scaled by R&D stock in year *t*	4.528	18.908	0.713	2.604	7.604
Firm's H/W patent citation stock	Firm's cumulative citation-weighted hardware patent counts, scaled by R&D stock in year *t*	5.249	26.631	0.141	2.274	8.310
Rivals' S/W patent stock	Average of each rival's cumulative software patent counts, scaled by R&D stock in year *t*	0.145	0.921	0.036	0.102	0.254
Rivals' H/W patent stock	Average of each rival's cumulative hardware patent counts, scaled by R&D stock in year *t*	0.151	0.478	0.028	0.112	0.305
Rivals' firm size	Average of each rival's total employees	4.947	15.688	0.851	3.477	10.044
Rivals' R&D intensity	Average of the ratio of each rival's R&D expenses to its sales in year *t*	0.296	2.265	0.163	0.238	0.422
Rivals' advertising intensity	Average of the ratio of each rival's advertising expenses to its sales in year *t*	0.029	0.074	0.012	0.026	0.061
Rivals' net income	Average of each rival's net income in year *t*	2.073	2.443	1.071	3.852	5.698
Industry Tobin's *q*	The median Tobin's q for the firm's industry measured at the fiscal year end of year *t*, based on the firm's SIC4	2.255	1.113	1.269	2.015	3.244
Market competition	The log value of the reciprocal of the HHI	1.995	0.629	1.517	1.919	2.507

Table 3: Correlation Coefficient among Key Variables

	1	2	3	4	5	6	7	8	9	10
1. Rivals' Tobin's *q*	1.00									
2. Firm's software patent	-0.53	1.00								
3. Firm's hardware patent	-0.04	0.19	1.00							
4. Rivals' software patent	0.08	0.03	0.01	1.00						
5. Rivals' hardware patent	0.05	-0.04	0.13	0.36	1.00					
6. Rivals' firm size	-0.04	0.01	-0.01	-0.03	0.03	1.00				
7. Rivals' R&D intensity	0.08	0.04	0.09	-0.03	-0.18	-0.30	1.00			
8. Rivals' advertising intensity	0.12	-0.06	0.04	-0.10	0.02	-0.01	0.13	1.00		
9. Rivals' net income	0.14	-0.05	-0.05	-0.03	-0.05	0.64	-0.24	0.27	1.00	
10. Industry Tobin's *q*	0.02	-0.05	-0.04	-0.01	-0.13	-0.03	0.03	0.13	-0.01	1.00
11. Market competition	0.03	-0.04	-0.04	0.05	-0.01	0.04	0.28	-0.04	0.05	0.17

Our initial matched panel dataset contains 7,538 firm-year observations covering 1,133 unique IT firms from 1998 to 2006. We removed 1,528 observations for which we could not identify rivals, and additional

[11] We also use the average value for the control variables in the model.

2,542 observations with missing or zero values in software or hardware patents stock. Next, we removed 2,162 observations with missing or zero values for advertising expenses or R&D spending, and 55 observations with missing market values used in computing Tobin's *q*. The final sample consists of 1,251 observations from 420 firms spanning nine years. Table 4 provides our sample distribution by sub-IT industry at the four-digit SIC level. Our sample consists of hardware manufacturing industries that correspond to the SIC codes 35, 36, and 38, and software industries corresponding to the SIC code 73. We compare the amount of software and hardware patent stock across industries. The overall ratio of software patent stock to IT patent stock is 53.4% and it is not significantly different across sub-IT industries.

Table 4. Sample Distribution by Sector

SIC4	Sector	# of firms	# of obs.	Total patent[a]	S/W patent[a]	H/W patent[a]	R&D Expense[b]
3571	Electronic Computers	6	23	968.32	550.73	285.25	830.55
3572	Computer Storage Devices	18	76	135.48	34.65	15.16	154.05
3576	Computer Communications Equipment	9	12	10.11	5.15	3.83	34.42
3577	Computer Peripheral Equipment, NEC	9	21	104.96	8.73	87.37	30.43
3651	Household Audio and Video Equipment	5	26	23.56	7.07	10.03	6.59
3661	Telephone and Telegraph Apparatus	30	86	28.44	6.04	9.19	33.97
3663	Radio and Television Broadcasting and Communications Equipment	28	65	152.59	31.60	66.31	221.14
3669	Communications Equipment, NEC	7	14	13.33	1.36	9.49	15.58
3674	Semiconductors and Related Devices	84	183	656.42	150.68	264.94	375.05
3679	Electronic Components, NEC	10	27	274.60	4.55	20.66	170.02
3812	Search, Detection, Navigation, Guidance, Aeronautical, and Nautical Systems	2	6	6.42	1.19	5.02	4.68
3823	Industrial Instruments for Measurement, Display, and Control of Process Variables; and Related Products	4	10	39.62	22.93	2.28	26.97
3825	Instruments for Measuring and Testing of Electricity and Electrical Signals	19	62	150.62	34.62	20.32	152.43
3826	Laboratory Analytical Instruments	6	11	38.92	1.64	0.64	52.51
3829	Measuring and Controlling Devices, NEC	7	23	30.27	5.69	8.00	11.26
3844	X-Ray Apparatus and Tubes and Related Irradiation Apparatus	1	6	13.76	2.62	2.42	6.59
3845	Electromedical and Electrotherapeutic Apparatus	10	25	28.83	4.13	4.18	11.70
7370	Computer Programming, Data Processing, Etc.	19	92	1289.86	583.03	327.98	591.55
7371	Computer Programming Services	2	5	1.84	1.55	0.27	3.50
7372	Prepackaged Software	111	388	51.01	36.69	12.16	184.25
7373	Computer Integrated Systems Design	31	87	514.61	156.45	149.17	309.48
7374	Computer Processing and Data Preparation and Processing Services	2	3	3.90	3.09	0.80	37.31
Total		420	1,251	296.20	104.04	90.82	229.14

Note: [a] The mean of stock of patent. [b] Unit: million $

Models and Results

We now describe our econometric models followed by a discussion of the results along with several robustness checks.

Econometric Estimation

Our empirical specification is similar to what has been used in prior studies (Griliches 1981; Hall et al. 2005; Liu and Wong 2011). In particular, as noted above, following prior studies, we use software (and hardware) patent stock scaled by R&D stock in order to control for the size of R&D investments and to capture the additional informational value of patents beyond what is already captured by R&D investments.[12] To examine our three research questions, we use the following empirical specification:[13]

$$\begin{aligned} \textit{Rivals' Tobin's } q_{j,t} = {} & \beta_0 + \beta_1 \textit{ Firm's SW Patent}_{i,t} + \beta_2 \textit{ Firm's HW Patent}_{i,t} + \beta_3 \textit{ Market Competition}_{k,t} \\ & + \beta_4 (\textit{Firm's SW Patent}_{i,t} \times \textit{Firm's HW Patent}_{i,t}) \\ & + \beta_5 (\textit{Firm's SW Patent}_{i,t} \times \textit{Market Competition}_{k,t}) \\ & + \beta_6 (\textit{Firm's HW Patent}_{i,t} \times \textit{Market Competition}_{k,t}) \\ & + \beta_7 \textit{ Rivals' SW Patent}_{j,t} + \beta_7 \textit{ Rivals' HW Patent}_{j,t} \\ & + \Sigma\beta_m \textit{ Rivals' Controls}_{j,t} + \Sigma\beta_s \textit{ Year Dummies}_s + \Sigma\beta_k \textit{ Industry Dummies}_k + \varepsilon_{i,t} \qquad (1) \end{aligned}$$

Equation (1) assesses the relationship between a firm's patents (software and hardware) and rivals' market value (H1). It also includes the interaction term between a firm's software patents and hardware patents to examine the possible complementarities between them (H2). Further, the equation includes the interaction term between a firm's software patents and market competition to examine the moderating effect of competitive intensity (H3). We first estimate the model without the interaction terms to examine the unconditional effects of a firm's software patent stock on rivals' market value. Then, we re-estimate the model with the interaction terms to examine the moderating effects of a firm's hardware patents and market competition, respectively. In addition to a firm's own patents, we include rivals' software and hardware patents as they have been shown to impact its firm value (Chung et al. 2013). In addition, we include a comprehensive set of rival-specific exogenous variables, as noted earlier.

We center the variables comprising the interaction terms by calculating the deviations from their respective mean values to reduce the multicollinearity between the main and interaction terms (Pinsonneault and Kraemer 1997; Smith and Sasaki 1979). We then perform several diagnostic checks to ensure the stability of our estimation results and do not detect any significant problems. The variance inflation factors (VIFs) of all independent variables did not exceed 10, a commonly used cut-off value.

In order to account for unobserved heterogeneity across industries in our data, we first considered fixed-effects and random-effects models. To choose between fixed- and random-effects models, we conducted a Hausman test and could not reject the null hypothesis that the errors are not correlated with the explanatory variables ($Prob > chi^2 = 0.142$). Then, we ran the Breusch-Pagan Lagrange multiplier (LM) test and could reject the null hypothesis that there is no significant unobserved heterogeneity across firms ($Prob > chi^2 = 0.000$). These test results suggest that our use of a random-effects model is warranted.[14] Because the Wooldridge test for autocorrelation indicates the presence of first-order autocorrelation (AR1) in our panel dataset ($F = 65.42$, $p < 0.01$), we employ a random-effects model with a correction for AR(1) errors, using the *xtregar* procedure in the STATA software.

Results

Table 5 reports the results of estimating a random-effects model. We only include the control variables in Model 1 and add our focal variables in a hierarchical manner. In all Models, rivals' own software and hardware patents are positively associated with its firm value, confirming the previous finding that a firm's IT patent stock significantly contributes to firm value (Chung et al. 2013). We include a firm's software and hardware patents in Models 2 through 4. In Model 5, we include the interaction term

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[12] Prior studies have used R&D stock (input) as a determinant of patents (output). In order to account for the endogeneity of software (hardware) patents, we also estimated a system of equations using a 3SLS technique: in the first equation, software (hardware) were regressed on R&D stock and a set of control variables; and in the second equation, Tobin's q was regressed on software (hardware) patent stock (not scaled by R&D stock) and R&D stock as well as other control variables. The 3SLS results were similar to our main results and are available upon request. We also used software (hardware) patent divided by firm assets (Hall et al. 2005, Xue et al. 2012), and obtained similar results.

[13] We take the natural logarithm of *Rivals' Tobin's q*, *Rivals' and firm's Software (Hardware) Patent Stock*, and *Rivals Controls* to control their skewedness and the different absolute magnitude.

[14] Random effects estimation models have also been used by Kleis et al. (2011) and Bardhan et al. (2013) to estimate the impact of R&D and IT on firm value (or firm productivity).

between a firm's software patents and hardware patents to examine the complementarity between the two types of patents. In Model 6, we include the interaction between a firm's software patents and market competition. In Model 7, we include all the terms specified in Equation (1).

We observe that rivals' software patents are negatively associated with firm value (see Models 2 – 7). This result indicates that a firm's software patent stock significantly diminishes its rivals' market value, supporting H1b (rejecting H1a). Specifically, based on Model 1, a 1% increase in a focal firm's software patent stock is associated with approximately a 0.03% decrease in the rivals' market value. This suggests that the market-stealing effect is more dominant compared to spillover effect in the case of software patents. Although not our focus, it is worth noting that the impact of a firm's hardware patents on rivals' value is not significant. Next we find that the interaction between a focal firm's software and hardware patents is negative (in Model 5, β = -0.025, p < .05; in Model 7, β = -0.021, p < 0.05); this suggests that a firm's hardware patents play a role of a complementary asset to their software patents, thereby strengthening the market-stealing effects of software patents while weakening the spillover effects, consistent with H2a.

Table 5. Estimation Results of Random-Effects Model with AR1 Adjustment

	Model 1 (*z*-stat.)	Model 2 (*z*-stat.)	Model 3 (*z*-stat.)	Model 4 (*z*-stat.)	Model 5 (*z*-stat.)	Model 6 (*z*-stat.)	Model 7 (*z*-stat.)
DV: Rivals' Tobin's q	*ln*(Y)	*ln*(Y)	*ln*(Y)	*ln*(Y)	*ln*(Y)	*ln*(Y)	*ln*(Y)
Firm's S/W patent		-0.029** (0.015)		-0.032** (0.015)	-0.034** (0.015)	-0.038** (0.018)	-0.040** (0.020)
Firm's H/W patent			0.011 (0.014)	0.017 (0.015)	0.013 (0.016)	0.019 (0.020)	0.017 (0.018)
Firm's S/W patent × H/W patent					-0.025** (0.010)		-0.021** (0.011)
Firm's S/W patent × Market competition						0.040** (0.024)	0.041** (0.021)
Firm's H/W patent × Market competition						-0.011 (0.027)	-0.013 (0.028)
Rivals' S/W patent	0.058** (0.018)	0.058** (0.018)	0.058** (0.017)	0.055** (0.017)	0.054** (0.017)	0.059** (0.018)	0.060** (0.017)
Rivals' H/W patent	0.021* (0.019)	0.023* (0.019)	0.021* (0.019)	0.022* (0.018)	0.023* (0.018)	0.022* (0.019)	0.023* (0.019)
Rivals' firm size	-0.102*** (0.014)	-0.102*** (0.014)	-0.104*** (0.014)	-0.104*** (0.014)	-0.103*** (0.014)	-0.103*** (0.014)	-0.102*** (0.014)
Rivals' R&D intensity	0.079*** (0.020)	0.079*** (0.020)	0.079*** (0.020)	0.079*** (0.020)	0.080*** (0.019)	0.080*** (0.020)	0.080*** (0.019)
Rivals' advertising intensity	-0.008 (0.012)	-0.007 (0.013)	-0.008 (0.013)	-0.007 (0.012)	-0.007 (0.012)	-0.008 (0.013)	-0.008 (0.013)
Rivals' net income	0.135*** (0.009)	0.135*** (0.010)	0.134*** (0.009)	0.135*** (0.009)	0.136*** (0.009)	0.134*** (0.009)	0.135*** (0.009)
Industry Tobin's q	-0.019 (0.022)	-0.020 (0.023)	-0.019 (0.023)	-0.020 (0.023)	-0.021 (0.023)	-0.016 (0.022)	-0.017 (0.023)
Market competition	0.104 (0.095)	0.106 (0.095)	0.105 (0.095)	0.107 (0.095)	0.096 (0.095)	0.090 (0.095)	0.081 (0.096)
Intercept	0.894*** (0.417)	0.835** (0.418)	0.896** (0.420)	0.871** (0.419)	0.915** (0.419)	0.897*** (0.419)	0.936** (0.419)
Wald χ^2 (df)	518.20*** (37)	520.49*** (38)	518.84*** (38)	529.34*** (39)	535.72*** (40)	533.33*** (41)	550.47*** (42)
R^2 (%)	27.86	30.07	28.05	32.33	34.64	34.61	39.86
N	1,251	1,251	1,251	1,251	1,251	1,251	1,251

Note: Log scale. Significance: ***p < 0.01; **p < 0.05; *p < 0.10. Huber-White robust standard errors are shown in parentheses. Models include year or sector (SIC 4-digit) dummies but the coefficients are not reported for the brevity. All of the variable in the interaction terms have been centered. We use the log value of the reciprocal of the HHI as the market competition (i.e., large value of this measure means more competitive industries).

Next, we report the estimation results for Model 6 and 7 where we consider the interaction between a focal firm's software patents and market competition. We find that the interaction between a firm's software patents and market competition is positively significant (in Model 6, β = 0.040, p < .05; in Model 7, β = 0.041, p < .05). This finding suggests that the impact of a firm's software patents on rival's value is stronger in a less competitive market environment, thereby supporting H3b. In other words, an increase in the market competition mitigates the adverse impact of a firm's software patents on rivals' market value. The coefficients in Model 6 indicate that when market competition increases from 0 to 1, the impact of the focal firm's software patents on rivals' market value changes from -0.038 to 0.002. This suggests that as competitive intensity increases the spillover effect becomes stronger relative to the market-stealing effect, and under an extremely high level of competitiveness, the spillover effect dominates.

Robustness Checks

Table 6. Estimation Results based on Citation-weighted Patent Stock

	Model 1 (*z*-stat.)	Model 2 (*z*-stat.)	Model 3 (*z*-stat.)	Model 4 (*z*-stat.)	Model 5 (*z*-stat.)	Model 6 (*z*-stat.)	Model 7 (*z*-stat.)
DV: Rivals' Tobin's q	*ln*(Y)	*ln*(Y)	*ln*(Y)	*ln*(Y)	*ln*(Y)	*ln*(Y)	*ln*(Y)
Firm's S/W citation-weighted patent		-0.053*** (0.011)		-0.052*** (0.012)	-0.054*** (0.012)	-0.052*** (0.013)	-0.057*** (0.013)
Firm's H/W citation-weighted patent			0.042 (0.012)	0.039 (0.013)	0.038 (0.013)	0.036 (0.012)	0.037 (0.012)
Firm's S/W × H/W (citation-weighted) patent					-0.046** (0.009)		-0.045** (0.008)
Firm's S/W citation-weighted patent × Market competition						0.042** (0.018)	0.041** (0.019)
Firm's H/W citation-weighted × Market competition						-0.020 (0.013)	-0.021 (0.012)
Rivals' S/W citation-weighted patent	0.068*** (0.018)	0.068*** (0.018)	0.068*** (0.017)	0.064*** (0.017)	0.063*** (0.017)	0.070*** (0.018)	0.071*** (0.017)
Rivals' H/W citation-weighted patent	0.051** (0.019)	0.053** (0.019)	0.051** (0.019)	0.052** (0.018)	0.053** (0.018)	0.052** (0.019)	0.053** (0.019)
Rivals' firm size	-0.098** (0.034)	-0.099** (0.035)	-0.098** (0.034)	-0.099** (0.034)	-0.098** (0.035)	-0.098** (0.034)	-0.099** (0.034)
Rivals' R&D intensity	0.071*** (0.020)	0.071*** (0.020)	0.071*** (0.020)	0.071*** (0.020)	0.079*** (0.019)	0.081*** (0.020)	0.079*** (0.019)
Rivals' advertising intensity	-0.008 (0.012)	-0.007 (0.013)	-0.008 (0.013)	-0.007 (0.012)	-0.007 (0.012)	-0.008 (0.013)	-0.008 (0.013)
Rivals' net income	0.112*** (0.009)	0.113*** (0.010)	0.113*** (0.009)	0.113*** (0.009)	0.112*** (0.009)	0.114*** (0.009)	0.115*** (0.009)
Industry Tobin's q	-0.019 (0.022)	-0.020 (0.023)	-0.019 (0.023)	-0.020 (0.023)	-0.021 (0.023)	-0.016 (0.022)	-0.017 (0.023)
Market competition	0.106 (0.095)	0.111 (0.095)	0.109 (0.095)	0.109 (0.095)	0.101 (0.095)	0.099 (0.095)	0.091 (0.096)
Intercept	1.040*** (0.570)	1.032** (0.514)	1.015** (0.528)	1.011** (0.520)	1.015** (0.512)	1.020*** (0.519)	1.011** (0.521)
Wald χ^2 (df)	812.34*** (37)	816.22*** (38)	811.29*** (38)	823.41*** (39)	826.09*** (40)	825.21*** (41)	842.89*** (42)
R^2 (%)	28.12	31.19	31.06	35.87	35.62	35.66	39.28
N	1,251	1,251	1,251	1,251	1,251	1,251	1,251

Note: Log scale. Significance: ***p < 0.01; **p < 0.05; *p < 0.10. Models are reported using random-effects with AR1 adjustments. Huber-White robust standard errors are shown in parentheses. Models include year or sector (SIC 4-digit) dummies but the coefficients are not reported for the brevity. All of the variable in the interaction terms have been centered. We use the log value of the reciprocal of the HHI as the market competition (i.e., large value of this measure means more competitive industries).

We have conducted several robustness checks. First, in order to check whether the quality of patents affect our results, we used an alternative measure of patent stock that can account for patent quality. Because patent quality is commonly measured by the number of citations a patent receives (Hall et al. 2005; Hall and MacGarvie 2010), we used *citation-weighted software (hardware) patent stock* as an alternative measure for software (and hardware) patent stock. We retrieved the number of subsequent citations (i.e., forward citations) a patent receives from the NBER patent database. Then, we computed the citation-weighted software and hardware patent stock, scaled by the R&D stock (Liu and Wong 2011). Using this alternative measure yielded similar results (see Table 6).[15]

Table 7. System GMM Estimation Results

	Model 1 (*t*-stat.)	Model 2 (*t*-stat.)	Model 3 (*t*-stat.)	Model 4 (*t*-stat.)
DV: Rivals' Tobin's q	ln(Y)	ln(Y)	ln(Y)	ln(Y)
Firm's S/W patent		-0.132** (0.054)	-0.080* (0.051)	-0.084** (0.049)
Firm's H/W patent		0.031 (0.049)	0.029 (0.050)	0.015 (0.051)
Firm's S/W patent × H/W patent			-0.030** (0.029)	-0.029** (0.031)
Firm's S/W patent × Market competition				0.079** (0.121)
Firm's H/W patent ×Market competition				0.050 (0.102)
Rivals' S/W patent	0.087** (0.048)	0.082** (0.049)	0.083** (0.049)	0.081** (0.048)
Rivals' H/W patent	0.064* (0.041)	0.065* (0.041)	0.062* (0.041)	0.063* (0.042)
Rivals' firm size	-0.128*** (0.075)	-0.115** (0.072)	-0.113*** (0.073)	-0.114*** (0.074)
Rivals' R&D intensity	0.160* (0.081)	0.076 (0.082)	0.051 (0.080)	0.048 (0.083)
Rivals' advertising intensity	-0.056 (0.002)	0.017 (0.003)	0.030 (0.003)	0.035* (0.003)
Rivals' net income	0.123*** (0.010)	0.124*** (0.011)	0.124*** (0.011)	0.127*** (0.012)
Industry Tobin's *q*	0.076 (0.082)	0.074 (0.083)	0.076 (0.083)	0.084* (0.084)
Market competition	0.061 (0.806)	0.054 (0.807)	0.057 (0.812)	0.054 (0.811)
Intercept	0.684*** (0.912)	0.634*** (0.913)	0.509*** (0.914)	0.685*** (0.915)
F-value (df)	15.70 (14, 419) ($p < 0.01$)	18.34 (16, 419) ($p < 0.01$)	21.56 (17, 419) ($p < 0.01$)	24.12 (19, 419) ($p < 0.01$)
N	1,251	1,251	1,251	1,251
Diagnostic tests				
Arellano-Bond test for AR(2) in first differences (*z*-stat.)	-0.97 ($p = 0.331$)	-1.22 ($p = 0.223$)	-1.34 ($p = 0.180$)	-1.54 ($p = 0.124$)
Hansen test of over identifying restrictions chi² (df)	63.69 (68) ($p = 0.626$)	122.10(108) ($p = 0.798$)	136.29(170) ($p = 0.973$)	152.05(238) ($p = 1.000$)
Difference-in-Hansen test of exogeneity of instrument subsets				
GMM instruments				
Hansen test excluding group χ^2 (df)	50.66 (54) ($p = 0.604$)	104.99(108) ($p = 0.564$)	117.89(135) ($p = 0.853$)	127.56(189) ($p = 1.000$)
Difference (null H = exogenous) χ^2 (df)	13.03 (14) ($p = 0.524$)	17.11 (28) ($p = 0.946$)	18.40 (35) ($p = 0.991$)	24.49 (49) ($p = 0.999$)
Exogenous variables				
Hansen test excluding group χ^2 (df)	47.56 (56) ($p = 0.782$)	108.25(124) ($p = 0.842$)	118.81(158) ($p = 0.991$)	143.35(226) ($p = 1.000$)
Difference (null H = exogenous) χ^2 (df)	16.13 (12) ($p = 0.185$)	13.85 (12) ($p = 0.310$)	17.47 (12) ($p = 0.133$)	8.70 (12) ($p = 0.728$)

Note: Significance: $^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.10$. Huber-White robust standard errors are shown in parentheses. We report two-step estimators, which are asymptotically efficient and robust to any panel-specific autocorrelation and heteroscedasticity.

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15 We also used citation-weighted software and hardware patent stock excluding self-citation and obtained similar results. Details are available upon request.

Second, there is a potential concern for the endogeneity of our patent stock variables. For example, a firm's decision to patent its innovations may be influence by its rivals' current and future performance (expectations) that is reflected in the rivals' market value. In this case, the firm's patent stock would be endogenous and our estimates would be biased. To address this potential endogeneity, we employ the Arellano-Bover/Blundell-Bond system GMM estimator (Arellano and Bover 1995; Blundell and Bond 1998). Our independent variables, except for the industry Tobin's q and year-sector dummies, are assumed to be endogenous and are instrumented with lagged values of the variables, in both levels and in their first differences. We estimate the two-step system GMM estimator, which is asymptotically efficient and robust to any panel-specific autocorrelation and heteroskedasticity. Furthermore, we correct for the downward bias in standard errors using the Windmeijer correlation (Windmeijer 2005).

Table 7 presents the system GMM estimation results which are qualitatively similar to our main results in Table 5. The results of the AR(2) test of the null hypothesis indicate that there is no serial correlation in the second differences of the residuals (p = -0.97, -1.22, -1.34 and -1.54, respectively). The Hansen test yields a J-statistic with a χ^2 distribution under the null hypothesis, indicating that the instruments are orthogonal to the error term. The results show that we cannot reject the null hypothesis that the instruments are valid (p = 0.626, 0.798, 0.973 and 1.000, respectively). Further, we report the results of a test of exogeneity of a subset of our instruments. Using a difference-in-Hansen test of exogeneity under the null hypothesis, indicating that the subset of instruments that we use in the levels equations are exogenous, we find that the p-value associated with the Hansen test imply that additional instruments in the system GMM estimation are exogenous as well. Overall, these results indicate that endogeneity is not a serious concern in our estimations.

Further, we used an alternative measure of market competition (i.e., CR4 instead of HHI). The overall estimation results based on CR4 are qualitatively similar to our main results. Finally, to further address cross-industry heterogeneity, quantile regression (Koenker and Hallock 2001) was employed with three quantiles (.25, .50, and .75). We found that the coefficient estimates on rivals' software patents are similar across quantiles (for the 25th percentile, β = -0.021, p < .05; for 50th percentile, β = -0.023, p < .05; and for 75th percentile, β = -0.024, p < .01). This suggests that there is no significant difference in the impact of a firm's software patents on rivals' value across different sectors in the IT industry.

Discussion and Conclusions

While prior research on IT and innovation has primarily examined the impact of IT investments on the innovation performance (Bardhan et al. 2013; Kleis et al. 2012; Xue et al. 2012), our study focuses on investigating the value impacts of IT innovation itself. Specifically, we examined the impact of a firm's software patents on the financial market value of its competitors in the IT industry and the moderating role of hardware patents and competitive intensity. Based on a sample of 420 firms in the US IT industry, we find that a focal firm's software patents are significantly associated with a decrease in the competitors' market value, captured by Tobin's q. On average, we find that a 1% increase in a firm's software patent stock is associated with a 0.03% decrease in rivals' financial market value.

More importantly, we have identified two factors that moderate the impact of a focal firm's software patents on its rivals' market value. Although a firm's hardware patents do not have a direct impact on rivals' market value, our results suggest that a firm's hardware patents amplify the competitive (negative) impact of its software patents. In addition, we find that market competition significantly influences the extent to which the stock of a firm's software patents affects rivals' market value. Specifically, an increase in the market competition mitigates the negative impact of focal firm's software patents on rival firms' performance. These findings provide unique and important implications for theory and practice, regarding the business value and impacts of software patents.

Theoretically, our study offers evidence of the important role played by software patents in the competitive dynamics in IT industry. Although considerable research has been conducted on the market performance of software patents (Chung et al. 2013; Fosfuri et al. 2008; Hall and MacGarvie 2010), prior studies have focused on the impact of software patents on the patent-owners' performance and there has been a paucity of research on the impact of software patents on rival firms' performance. By conceptualizing software patents as a key resource in the IT industry and adopting the perspectives of *market-stealing* versus *spillover*, this study addresses which effect (market-stealing or spillover) would dominate in software patents. By showing the significant competitive effects of software patents, our study provides a rationale for firms to invest heavily in software patents within the IT industry, thereby extending the prior studies that question the value of software patents (Bessen and Hunt 2007; Hall and MacGarvie 2010).

In addition, our analysis of the moderating role of hardware patent stock provides a richer understanding of the conditions under which the competitive effects of software patents can be magnified or mitigated. Our finding that a firm's hardware patent stock strengthens the competitive impact of its software patent stock underscores the importance of complementary assets (hardware patents in our case) in developing competitive advantage from innovations (Teece 1986). Furthermore, our study provides new insights into the relationship between a firm's software patents and the market competition. Extending prior research suggesting that the outcomes of market-stealing and spillover vary depending on industry characteristics (Austin 1993; McGahan and Silverman 2006; Megna and Klock 1993), our study finds that the adverse impact of a firm's software patents on rivals' performance is more salient in a less competitive environment. Our results suggest that when firms build capabilities through software patents, a focal firm's software patents may be more detrimental to rivals' performance in the presence of fewer rivals. In this respect, our study makes a meaningful contribution to the literature on the consequences of rivals' actions (Fosfuri and Giarratana 2009; McGahan and Silverman 2006; Oxley et al. 2009).

For managers, one of the most interesting results is the negative market-stealing effect of a firm's software patents on rival firms' financial market value in the IT industry. Our results provide an explanation as to why many firms adopted a system for tracking its rivals' patents portfolio, filing lawsuits against patent infringers to protect their intangible assets and to compensate for their loss (e.g., Nielsen 2013). Our results also imply that IT firms should carefully adjust their patenting strategies depending on the level of market competition in order to increase the financial returns to software patents. In particular, our findings underscore the importance of having a systems approach to IT innovations—firms are more likely to gain competitive advantage from IT-based innovations including both hardware and software components, compared to those solely focusing on either software or hardware innovations.

Furthermore, our study can inform policymakers about the importance of competitive intensity in IT industries in mitigating the adverse impact of software patents on rivals. Our result suggests that in a more concentrated (less competitive) industry, software patents have a greater competitive effect on rivals, which will further solidify the competitive position of the "strong" firms owning important software patents. Given the potential negative social impact of patents on innovation (Gans et al. 2008; Savich 2007), our result suggest that policy makers should take measures that can increase the competitive intensity in IT industries, thereby mitigating the competitive effects of software patents.

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