DOUBLE-EDGED SWORD OF SOFTWARE PATENTING: BALANCING BENEFITS WITH KNOWLEDGE DISCLOSURE

by

KAMESH MALLAMPALLI

(Under the direction of Terence Saldanha and Elena Karahanna)

ABSTRACT

Patents on software innovations have seen rapid growth in the last twenty years. Recent scholarship has clarified the value of software patent stocks to firms owning them, and the effect of firms' innovation orientation, market environment and use of software patent stocks for strategic purposes. However, we know little about the role of knowledge disclosure about the patent innovation and of patent enforcement on patent value appropriation. These can be used as levers by a firm to enhance patent value appropriation. First, we investigate the influence of knowledge disclosure, as software patents have been criticized for not having an impact on a firm's profits because they have unclear boundaries. The boundaries of patent protection are set by the knowledge disclosed about the software innovation which defines the patent scope. This is an important aspect because the firm has discretion on how to disclose the knowledge of its software innovation in the patent. We assess the separate effects of two distinct dimensions of patent scope, the technological scope of the core software innovation and the diversity of the innovation's applications across other domains, on the value of software patents. We argue that a larger technological scope is necessary for realizing better value from the software patent stock. This is because precise and detailed documentation of the technological scope in terms of requirements and design specifications is important to define proper boundaries of protection for the disclosed software innovation. Diversity of applications, however, exposes the patent to more potential competition and criticisms of being too broad in scope and therefore increases the risk of invalidation. Second, we study the effect of patent enforcement on the value of software patents. Patents as exclusion rights, require enforcement action by the patent owner. Patent

enforcement through litigation, as a costly and visible signal of the firm’s intentions, creates a reputation for aggressive defense of intellectual property and we suggest that such a reputation is beneficial for the value of a firm's software patent stock.
INDEX WORDS**:** Software Patents, Patent Scope, Technological Scope, Application Diversity, Patent Enforcement, Reputation for IP toughness

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KAMESH MALLAMPALLI

BIS, University of Delhi, India, 2001

PGDM, Indian Institute of Management Kozhikode, India, 2006

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KAMESH MALLAMPALLI

Major Professor: Elena Karahanna
Major Professor: Terence Saldanha
Committee: Amrit Tiwana

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
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INTRODUCTION AND PROBLEM MOTIVATION

1.1. Patents and Appropriation of Innovation Value

Patents are an important appropriability mechanism used by organizations to realize returns from innovation. Specifically, there is an increasing trend for acquisition of software patents, i.e., patents over innovations implemented in computer software. There is an ongoing debate on the impact of software patents on firm performance and competitive advantage (Chung et al. 2019; Mykytyn et al. 2002). Patenting innovations introduces trade-offs between the benefit of obtaining legal protection and the cost of knowledge disclosure (Ahuja et al. 2008). The knowledge disclosure required for obtaining patent protection introduces both upside and downside possibilities. The primary appropriability benefit of patenting to a focal firm is an opportunity to appropriate the value of its innovation by exercising monopoly for a period. There is also a potential generative appropriability benefit i.e. having an advantage in generating follow-on innovations compared to rivals, due to codification of knowledge required for acquiring a patent (Encaoua et al. 2006).

However, the knowledge disclosure also has some downsides. The costs for acquiring a patent are enforcement costs and the possibility of imitation or spillover of knowledge to competitors. Understanding this tradeoff is important for organizations to assess patenting for capturing the value of their innovation. Extant appropriability literature defines appropriability regimes as an intersection of the level of intellectual property rights protection in a particular market and the nature of the patented technology (Teece 1986). These taken together indicate the ease of imitation by competitors. Appropriability regimes are suggested to influence the possible value capture by innovators. Higher ease of imitation will lead to rapid reduction of returns to innovation. Therefore, the disclosure of knowledge required for patenting innovation by enabling imitation, has consequences for firm's appropriability of the innovation and subsequently firm performance. Alternatively, patent disclosure leads to knowledge spillover from the focal firm into the wider market (Somaya 2012). If that spillover results into widening the market for products based on the knowledge spillover through the introduction of improvements by competitors, the focal firm could still reap benefits by addressing the expanded market by building on its own innovative idea. In such a case, the patent owner need not have to create a market for their innovation by having to undertake risky commercialization of the innovation, but can benefit from the market created for it by others, by virtue of holding codified and tacit knowledge of the innovation (Novelli 2015). On the other hand, it is also possible that competitors can internalize the disclosed knowledge and are able to build on it, thus reducing the potential of appropriability for the patent owner. Therefore, disclosure of knowledge in patents can imply differing consequences for innovating firm's appropriability and financial performance.

Once a patent has been granted to a firm it confers only a right to exclude others from using the invention delineated by the claims in the patent filing (Somaya 2012). The strategic actions of firms with respect to patents fall into three domains – Rights acquisition and maintenance, Licensing and Openness, and Enforcement and litigation (Somaya 2012). Rights acquisition and maintenance involves actions related to acquiring, renewing, reissue and maintenance of patents as well as acquiring patents in the secondary market. Licensing relates to the actions for sharing rights with other firms to use patented technology, to appropriate the value it generates outside the firm's boundaries. Enforcement refers to the detection of unauthorized use and the threat or use of litigation to ensure stopping or compensation for the loss of value due to the unauthorized use. Patent enforcement is an expensive and multi-stage process (Somaya 2012). Due to this, enforcement action taken by a firm sends important external signals that would potentially dissuade knowledge spillover and unauthorized use (Agarwal et al. 2009). Due to such deterrence the possibility that the value of the patented invention getting lost is reduced with consequent impact on firm financial performance. Therefore, accounting for the enforcement strategy of patent owning firms would be necessary to study the relationship between their patent stock and financial performance.

1.2. Patents and Appropriation of Software Innovation Value

For intellectual property protection of software-based innovations, copyright law and patent law were treated as competing approaches in the U.S. jurisdiction with copyrights being preferred during the early evolution of the I.T. industry in the 1960s and 1970s (Graham and Mowery 2003). During that era computer programs were delivered to the end customers as source or object code, initially by large vertically integrated systems manufacturers such as IBM. Additionally, customers would develop many more programs in-house for their specific use. By the 1980s, the rapid adoption of personal computers led to the market entry of large independent software vendors to address the needs of the individual users. The software introduced by these vendors continued to be protected under the copyright law as this industry was similar in characteristics to other intellectual property-based industries such as publishing of books or music, such as high initial development costs but lower reproduction cost and in the case of software approaching zero. Moreover, these industries also exhibited high returns for a successful product and very low returns for failed products, and in the case of software network externality benefits as well. The success of Internet and the start of the dotcom boom in the 1990s however, changed this situation, with the actual software code no longer delivered to the end users, who instead interacted with processes implemented in software over the Internet. The weakening of copyright protections in this era and the simultaneous easing of requirements for patenting software generated interest in patenting as an alternative intellectual property protection mechanism especially for innovations which are accessed remotely through the Internet. The extension of this approach of accessing innovations has happened beyond end-customer facing processes to all types of processes as indicated by the usage of web services and APIs.

The definition and clarification of intellectual property rights under the patenting framework for software-based innovations has happened through a series of court judgments in the 1990's (Graham and Mowery 2003), culminating with USPTO guidelines in 2000. Since that dimension of appropriability regime is given, the unique nature of software innovations needs to be considered to qualify the impact of software patents on firm performance. In case of software sold by independent software vendors, though only binary code may be released, there is still potential for reverse engineering. Accordingly, independent software vendors use appropriability mechanisms like copyrights, lead time etc. in preference to patents (Chung et al. 2019). However, process technology is more protectable irrespective of patent protection as there is higher likelihood of process innovation being accompanied by high levels of tacit knowledge which cannot be observed by competitors. The disclosure requirements for patents imply a requirement for codification of knowledge which will then be exposed as claims in patent information (Teece 1998).

In the patent application, the patent claims represent the codified knowledge of the information system which is the subject of the innovation. As per the statutory requirement for disclosure with patents, the information provided should enable a person skilled in the art to be able to replicate the patented innovation. For software patents this implies that the disclosure is like documenting complete details of the system design such that it could be implemented using a programming language. An example of the claims section from a software patent is depicted in appendix A, that shows the system design description for the innovation. Since this disclosure does not involve the actual source or object code of the information system but only the design specification, ease of imitation will not be facilitated through reverse engineering. However, disclosing the design specification implies that the knowledge about the software innovation needs to be codified and presented to the patent examiner.

While this codification of knowledge may allow better replication within the firm and hence generative appropriability (Ahuja et al. 2013), it increases the possibility of imitation by competitors when it is exposed through patents and hence affect firm performance negatively (Teece 1998). On the other hand, codification of knowledge in software patents may also allow the patent owners to enforce rights more effectively and consequently affect firm performance positively. Codification of the knowledge underlying their invention allows the patent owners to better document the full extent of the patent scope in terms of both variations of the innovative idea and positioning of those claims in technological domains. A properly specified patent scope could be a deterrent by increasing the probability that a new invention by a competitor building on that knowledge is more likely to infringe on the patent itself (Novelli 2015). Moreover, if an infringement dispute does occur, any adjudication of litigation on the patent happens only with reference to the patent scope (Merges and Nelson 1990). Since patent litigations are costly, the documentation of patent scope becomes an essential element for attempts at enforcement. An argument against software patents from venture capitalists and practice is that such innovations are ambiguous (Chung et al. 2019) and as a result difficult to enforce. But, if patent disclosure requirements for software patents do imply that the disclosed knowledge is highly codified, then enforcement should be easier as the innovator will be able to prove infringement due to better documentation of the features of the innovation in the patent disclosure. Easier enforcement would allow the innovator to deter infringement and therefore capture more value from the innovation and higher firm performance.

Given that software patents represent one of the multiple appropriability mechanisms available for value capture of software innovations, choosing patents involves negotiating the tradeoff between the benefits of patent protection and the costs of knowledge disclosure and enforcement (Anton and Yao 2004) unlike mechanisms such as copyrights (Graham and Mowery 2003). Extant literature on the value of software patents clarifies that software patent stocks have value for the firms owning them (Hall and MacGarvie 2010), that the value is contingent on the innovation orientation of the firm and the market environment in which it operates (Chung et al. 2019) and their use for strategic purposes (Noel and Schankerman 2013). However, there is no guidance on how the nature of knowledge disclosure required for patents influences the value of the software patent stock held by the firm. That the knowledge disclosure might be important is indicated by the popular perception of software patents as being ambiguous and difficult to enforce (Chung et al. 2019). The knowledge disclosed in patents by outlining the patent scope defines the boundary of protection provided by the patent and enables the innovating firm to prevent rivals from making use of the knowledge (Novelli 2015). Patent scope varies across two distinct dimensions. The first dimension is the technological scope of its invention which pertains to the core inventive idea and its variations as claimed by the innovator and represents the size of the inventive space. The second dimension is the positioning of the claims over technological domains representing the location of inventive space occupied by the innovation (Novelli 2015). These two dimensions together define the full scope of the knowledge disclosure of the innovator, and enforcement of patent rights mainly happens with reference to these dimensions.

For software patents, the first dimension relating to the size of the inventive space is delineated by fully describing both the technological problem being addressed by the innovator and the software-based solution that uniquely solves the problem. The second dimension pertains to the identification of other contexts, industries, or technological domains where the software-based solution created by the innovator is applicable. Therefore, the second dimension places the patent rights claimed by the innovator, beyond the specific context in which it was developed and applied, therefore increasing the coverage of the patent rights. By studying both these dimensions (encapsulating the complete scope of patent rights in terms of the information systems design that is an innovative solution to a technological problem and application of the solution in different contexts), we aim to clarify the contingent effect of software patents on firm performance depending on the knowledge disclosure by the innovating firm.

Additionally, as patents are only rights to exclude others from using the knowledge disclosed in the patent application (Somaya 2012), it is the responsibility of the owner of software patents to enforce the rights granted by patent ownership. While patent enforcement more frequently happens informally and only 1-2% patents are litigated (Weatherall and Webster 2014) due to the expense and time involved in litigation, they still represent an important option for software patent owners. Since, knowledge disclosure of the software innovation is required for a patent, the possibility of competitors appropriating value of the innovation arises, due to the knowledge spillover. To mitigate this possibility, firms could use litigation to defend higher value patents or patents at the base of a technology chain and reduce spillover of benefits captured by rivals (Lanjouw and Schankerman 1999). Litigation may also be used itself, as a value appropriation strategy as the patent owner can derive direct and exclusive benefits of a successful infringement challenge (Lanjouw and Schankerman 2001). Also, patent litigation as a costly and highly visible strategic action, may be used to build a reputation for aggressive defense of patent rights infringement Such a reputation helps value appropriation by reducing spillover of knowledge through employee movements (Agarwal et al. 2009). Extant literature on software patents does not consider the role of patent enforcement for its potential influence on the value of a firm's software patent stock. Therefore, given the important potential role of knowledge disclosure as outlining the patent scope and patent enforcement through litigation on the value of a firm's software patent stock, we propose the following research question:

How does the level of knowledge disclosure and enforcement activity influence the effect of software patents on firm value?

The dissertation proceeds as follows in the subsequent chapters. In chapter 2, first we review the general patents literature on the impact of patents on firm value. We also review patent scope and patent enforcement and look at their consequences on the value of patents. Then we review the literature on software patents and the various results pertaining to the relationship between software patent stock and firm value. In chapter 3, we build the theoretical foundations for the influence of patent scope and enforcement on the value of software patents and introduce the research model. Chapter 4 provides the details of the research design and the methodology we will adopt for empirically testing the research model. In Chapter 5, we present the results of the empirical investigation of the research model and discuss the findings. Finally, in chapter 6 we discuss the expected theoretical and practical contributions for this dissertation and conclude with a note on the limitations and future possibilities.

CHAPTER 2

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1. Theoretical Background

In this section, we review the extant literature relevant to this study, drawing upon investigation into patents in general as well as software patents specifically. First, we look at the relationship between patents and firm value. This literature draws upon the resource-based view of the firm, the real options framework, and the knowledge-based view of the firm. The resource-based view and the real options theory frameworks (James et al. 2013; Somaya 2012) primarily approach patents as strategic tools for gaining competitive advantage and realize superior firm performance. The knowledge-based view approach looks at patents as knowledge assets (Hall et al. 2005) and therefore a mechanism to appropriate the value of innovations generated by the firm (Ahuja et al. 2008; Teece 1998). This is the perspective that we adopt in this dissertation. The usage of patents as an appropriation mechanism for innovations, requires attention from the firm towards two important characteristics of patents as knowledge assets.

The first characteristic is patent scope which delineates the boundary of protection offered by the patent. We review the literature on patent scope and its relationship to firm value. To specify patent scope, a firm must be able to codify some of the knowledge of its innovation to be disclosed in exchange for the patent protection (Novelli 2015). While such codification may enable a firm to replicate the knowledge internally in a cost-effective manner, the disclosure of that knowledge in patents could reduce its replication cost for competitors (Teece 1998). To tackle such a scenario, the second characteristic of patents, as property rights requiring enforcement becomes important. Therefore, we next, review the literature on patent enforcement and its impact on firm performance (Lanjouw and Schankerman 2001; Weatherall and Webster 2014). Specifically, we look at patent litigation as it is an important and observable method of patent enforcement and its implications for appropriation of innovation value using patents.

Next, we review the literature specific to software patents. We first look at the various ways in which patents are classified as software patents, as the extant classification systems used by patent offices did not specifically differentiate software patents from other patents (Graham and Mowery 2006). We then discuss the two distinct perspectives taken in prior research to evaluate software patents. The first one is the regulator perspective where the value to society of allowing software patents is investigated. This research was in response to the easing of regulations for patenting software-based innovations in the 1990s. The second perspective is of the firm, and here primarily the value of software patents to the patent owning firms is addressed. As this study's research questions at the firm level, we discuss this literature in more detail. In line with general patents literature, the software patents literature at the firm level also utilizes the resource-based view of the firm (Hall and MacGarvie 2010), the real options framework and the knowledge-based view of the firm (Chung et al. 2019; Noel and Schankerman 2013).

2.2. Patents and Firm Value

Patents are one of the four primary mechanisms available to firms that enable them to capture value generated by their innovations (James et al. 2013). The other mechanisms available are secrecy, lead time and complementary assets. Patents provide a time-limited right to exclude competitors from using an invention which is defined in the claims documented in the patent (Somaya 2012). For utilizing patents as an appropriability mechanism, firms engage in strategic actions to obtain, utilize (develop and market the technology or share through licensing) and enforce the rights. These strategies eventually affect firm value through the appropriability outcomes generated by them (Somaya 2012).

A resource based view framework explanation connects the strategic use of patents to competitive advantage by describing patents as representing surrogates of resources (Somaya 2012). One strategic use of patents is to raise barriers to imitation for the firm's intellectual property. The basic rationale and structure of patent protection is built around limiting the imitation from the firm's competitors for the time the patent is in force in exchange for providing public information about the intellectual property. Therefore, barrier to imitation is one of the intermediary mechanisms apart from innovation output, knowledge exposure, incentives to innovate etc. which subsequently lead to performance consequences measured by competitive advantage, profits, and economic performance (James et al. 2013).

Another theoretical explanation for the value of patents is based on the real options theory. Since patents are rights to exclude others from using the technology described in the patent filing, owning patents enables the firm to choose how to utilize it anytime during its validity (Chung et al. 2019). Patents therefore enable strategy options for the firm, such as, a proprietary, defensive or leveraging strategy as appropriate to address its market and environment conditions (Somaya 2012). Being able to use an appropriate strategy, such as a proprietary strategy involving pre-emptive patenting is associated with superior firm performance when innovation is largely incremental (Ceccagnoli 2009). Similarly, being able to pursue a defensive strategy to neutralize competitive disadvantage from the patent portfolios of rival firms increases the freedom to operate for the focal firm (Somaya 2012). Finally, a leveraging strategy enables the firm to generate revenue opportunities such as licensing, thus not being required to develop and market products based on the patent technology on its own. It could also enable the firm to participate in standard setting in its favor, by owning and providing enabling patents for the standard. Therefore, the options created for a patent owner creates the flexibility to choose actions that minimize the uncertainty of appropriation of innovation returns and creates opportunity for better firm performance.

Another approach to studying the linkage between patents and firm performance comes from the knowledge based view of the firm (Teece 1998). Knowledge assets of a firm becomes a differentiator and hence a source for competitive advantage by being difficult to replicate and if deployed effectively. Patents as a mechanism for protecting knowledge assets, provide both a legal barrier to imitation as well as well as confer property rights that could potentially be monetized through licensing. An important characteristic of patent as a knowledge asset is the breadth of protection sought through a patent filing, also known as patent scope. Patent scope has been suggested to have an effect on firm value (Lerner 1994). Further, patent scope is a reflection of the knowledge and capabilities possessed by the firm to generate innovation and codify knowledge about the innovation in the form of a patent (Novelli 2015; Teece 1998). Therefore, patents serve as a mechanism to utilize knowledge and related capabilities of the firm to create competitive advantage and sustain performance. We next discuss the literature related to patent scope in more detail.

2.3. Patent Scope

An important way through which the knowledge assets of a firm reflect in a patent owned by them is indicated by the breadth or scope of the patent. Patent scope specifies the inventive space occupied by the patent within a technological domain and therefore delineates the novel aspects of the innovation protected by the patent (Novelli 2015). Patent scope describes the inventive space occupied by the patent across two dimensions. The first is the number of variations of the core idea which identifies the extent of application of the inventive idea. Patents of a larger scope in this dimension represent broader or more general ideas and those of smaller scope are more focused. The second dimension is the number of technological domains represented by the assigned patent classes, over which the variations of the idea span. This dimension represents the positioning over technological domains of the variations of the patent. Therefore, the first dimension of patent scope defines the boundaries of the core idea that is claimed by the innovator as a novel and non-obvious contribution over prior art and the second dimension denotes the diversity of contexts identified by the innovator, where the core idea can be applied.

Patent scope of a patent is determined by the extent of exclusion rights allowed by patent examiners out of the total set of exclusion rights claimed as a novel advance by the patentee. This conceptualization presumes that given a certain attitude of leniency by the patent examiner, the patentee is able to extend the claim to a full set of exclusion rights possible for their innovation (Novelli 2015). However, recent research relaxes the assumption that patentees are able to take full advantage of leniency of a patent regime and instead suggests that patent scope is a function of the capability of a firm to properly identify the scope of protection its innovative idea requires (Novelli 2015). Such capability is built upon the scientific knowledge possessed by the firm and its inventive experience accumulated by the firm. Therefore, the knowledge possessed by the firm and its capability to convert it into innovation reflects in the scope that the firm can identify in its patent applications.

Along with patent scope, patent length or duration of patent protection is the other important characteristic of patents (Lerner 1994). While patent scope defines the boundaries of what is covered and what is not covered by the protection provided to the patent, patent length denotes the statutory duration of protection provided in a particular jurisdiction. Patent length is generally uniform for all patents awarded in the jurisdiction. The combination of patent scope and length determine the total effective protection that a patent owner gets from their patent and therefore the possibility for appropriation of innovation returns (Encaoua et al. 2006). The patent scope determines the possible quantum of revenue flow from the patent ownership and the length determines how long this revenue flow could last before the patented knowledge can be utilized by other entities without compensation to the patent owner. Though extant literature in economics investigates the theoretical tradeoff between patent scope and length on social welfare outcomes such as innovation diffusion (Lerner 1994), in practice, patent length in a particular jurisdiction is uniformly fixed across all types of industries (Encaoua et al. 2006).[1] Patent scope on the other hand is determined by both statutory actions such as the judicial decisions affecting the grant and enforceability of software patents as well as the actions of regulators and innovators in defining the scope of protection specified and allowed in each patent application. Therefore, patent scope becomes an important lever for the regulator and the innovator, whose respective goals are to maximize social welfare or firm value. The variation in patent scope is associated with firm value (Lerner 1994) as the opportunity to appropriate the value of the innovation depends on the level of protection gained from patent scope. However, while the effect of the two dimensions of patent scope has been investigated on follow-on innovation by the patent owning firm (Novelli 2015), their distinct effects on the firm's market value have not been explored. As the patent scope varies across its two dimensions, the protection offered by a

[1] There are rare instances of changes to patent length, with the most recent being a change in U.S. patent awards from seventeen years from award date to twenty years from filing date. This change was brought in to align with the Uruguay round of Agreement on TRIPS (Trade-Related Aspects of Intellectual Property Rights) in 1995. This policy change had potentially valuable implications and might have led to a broader range of inventors filing applications (Webb et al. 2018). However, such statutory changes in patent length are few and far between and uniformly applicable to all patents issued by a jurisdiction.

patent also varies across them. As a result, the potential value appropriation that the patent owning firm can do, could also vary, with implications for the firm value. In the next section, we review the literature on patent enforcement, as enforcement action by patent owners to protect the property rights granted by a patent is an important consideration for realizing value from a patent.

2.4. Patent Enforcement

Patent enforcement can be an important influence on the relationship between patents and firm value as it is related to the key purpose of the acquisition of patent rights. While patents provide a legal right to the holder to exclude others from utilizing the invention described in the patent, the exercise of the right in terms of deterrence of unlawful use, detection, and legal action if unlawful use is found, rests on the patent owner. Therefore, quick and efficient enforcement of patent rights are important for the intended benefits of the patent appropriability regime (Weatherall and Webster 2014). A successful patent infringement suit's benefit is directly and exclusively captured by the patent owner (Lanjouw and Schankerman 2001). However, each patent held by a firm may not be equally likely to be enforced through litigation as litigation is a costly and time-consuming exercise. Therefore, patent owner might choose specific and more consequential patents to be enforced through litigation (Lanjouw and Schankerman 1999).

Despite the low percentage of patents actually litigated by patent owners due to the expense of infringement detection and pursuit of legal actions, such actions when initiated do have positive effect in terms of building a reputation for toughness (Agarwal et al. 2009). Such a reputation is shown to reduce spillover of technological knowledge from employees exiting the firm. The costliness of such action implies that patent enforcement is a useful signal to the rivals about the expected action from the focal firm in case of an unauthorized use of their patented technology. Therefore, patent enforcement has important implications for the value appropriation for a firm's patent portfolio (Lanjouw and Schankerman 2001).

Since patents represent rights to exclude others from using the technology claimed in the patent, its main purpose is to provide a legal impediment from the patent disclosure being misused by entities other than the patent owner. However, the onus of exercising the right by utilizing proprietary, defensive, or leveraging strategy lies with the patent owner (Somaya 2012). Therefore, unless there is confidence that the rights can be enforced efficiently, the utility of the patent system would not be high for innovators wanting to appropriate value from their innovations (Weatherall and Webster 2014). A significant level of enforcement action occurs informally such as notifications to competitors or resolution in alternative mechanisms. On average only 1-2% of patents are observed as having litigation action. However, the efficacy of the litigation is suggested to have an effect on the informal enforcement mechanism as well as patent right may not be seen as providing an effective deterrent (Weatherall and Webster 2014). Therefore, litigation actions provide an important observable indication of patent enforcement in action.

Patent based litigations could either be enforcement actions initiated by the patent owner and are called infringement suits. Patents could also be challenged for their validity and if successful, has a positive externality by opening the technological space occupied by the invalidated patent. However, patent infringement suits denoting enforcement activity by the patent owner form up to 84% of litigation cases and are therefore more common (Lanjouw and Schankerman 2001). As litigation is a costly and time-consuming patent enforcement method, their utilization is an indicator of the innovation value appropriation strategy of the patent owners (Lanjouw and Schankerman 2001). It is suggested that more valuable patents such as the base patents in a technological chain would be more subject to litigation action. Also, litigation could be used as a signal to build reputation as being tough on intellectual property infringement. This is especially true for patents in narrow technological fields. Such reputation building is also useful in reducing knowledge spillover due to employee movements to other organizations (Agarwal et al. 2009). Therefore, litigation is an important patent enforcement mechanism for appropriating value from patented innovations.

Table 1 summarizes the key studies from general patents literature, which we will draw upon for theoretical development in the next chapter. We present the key findings of the studies, the dependent and independent variables and the level of analysis employed. In the next section, the literature specific to software patents is discussed in detail.

Table 1: Key studies from general patents literature and findings

Citation	**Key Findings**	**DV**	**IVs**
Patent Scope			
(Novelli 2015)	Two distinct dimensions of patent scope (1) the number of variations to the core inventive idea reflected in the number of its claims and (2) the positioning of such variations in the inventive space, reflected in the number of technological classes When the scope of a patents spans across a higher number of technological classes, follow-on innovation by the inventing firm with the knowledge underlying its own patent is lower	Forward self-citations (Patent Level)	Number of claims, Number of classes
(Lerner 1994)	Broader patent scope is associated with higher forward citations, probability of litigation and market value for start-up firms	Forward citations, Probability of litigation, Firm value	Number of classes

(Lanjouw and Schankerman 2001)	Probability of patent litigation rises with the increase in value of the patent right and any indirect benefits to the litigation (such as to strengthen reputation and bargaining power)	Probability of litigation (Patent Level)	Patent citations, Number of claims, Number of classes,
Patent Enforcement			
(Agarwal et al. 2009)	Corporate reputation for toughness in patent enforcement significantly reduces spillovers otherwise anticipated from departures of employee inventors	Total citations to firm's patents (Firm Level)	Litigiousness, Employee Mobility

2.5. Software patents and Firm Value

The first step to study software patents specifically, requires defining what are software patents and how they are identified empirically in patent data. The basic definition of software patents, based on legal adjudication of patentable subject matter, indicates that software patents are essentially process patents. Also, they are defined as "business method" patents which describe the implementation of a business method using computer software (Hall and MacGarvie 2010). However, locating such patents empirically within the patent data set have utilized various approaches with varying sets of patents classified as software patents.

The approaches for technological classification of patents in the general patents literature use either the patent classification system of the patent office or required manual reading and classification of individual patents to assign them to a particular technology field (Bessen and Hunt 2004). Drawing from these approaches, studies on software patents using patent classification systems (Chung et al. 2019; Hall and MacGarvie 2010; Noel and Schankerman 2013) have been more widely used due to ease of classification compared to the second approach. There is one instance of the second approach used, though through automated text analysis, supported by a manual classification of a training set (Bessen and Hunt 2004), but the accuracy this approach has been questioned (Graham & Mowery 2006). The patent classification system also has two possibilities, first using USPTO 3-digit class/subclass classification and the other using international IPC class/subclass classification. For studies focused on U.S. appropriability regimes, USPTO classification is more commonly used for classifying software patents.

In line with the literature on patents in general, software patents also have two broad areas of investigation. The first approach looks at the consequences of software patent appropriability regime on innovation outcomes with a view to inform policy makers for adjusting the regime to promote better innovation outcomes (Bessen and Hunt 2004) (Graham & Mowery 2006). The second approach looks at software patents from a strategy perspective at the firm level and investigates the consequences of software patent strategic action on firm performance outcomes (Chung et al. 2019; Hall and MacGarvie 2010; Noel and Schankerman 2013). The basic argument for allowing software patents is similar to allowing patent for other classes of knowledge assets, that is, enablement of innovation diffusion through the creation of a market for knowledge assets (Teece 1998). Therefore, the two major areas of extant scholarship on software patents try to address whether and how the market for software-based knowledge assets functions from the perspective of social welfare and the perspective of the innovator making use of them as a value appropriation mechanism. The first area addresses knowledge diffusion, spillover and innovation enablement outcomes which are beneficial from overall economy perspective. The second area looks at the increased value that innovators can achieve in terms of firm performance by participating in the market for knowledge assets through obtaining software patents. In this area, extant literature looks at the influence of software patent stock on firm value

(Hall and MacGarvie 2010) and the contingent effects of innovation orientation, market environment (Chung et al. 2019) and knowledge spillovers (Noel and Schankerman 2013).

In the U.S. context software patent appropriability regime underwent a significant change in the 1990s with judicial decisions reducing uncertainty regarding software patent grants and enforceability (Chung et al. 2019). Prior to that software patents, i.e. patents on logic or algorithms for data processing were considered unpatentable subject matter (Bessen and Hunt 2004). Systems incorporating software could only be patented along with novel inventions pertaining to system hardware. The copyright law amended by U.S. Congress in 1976 and 1980 to explicitly include protections for computer programs was the main appropriability mechanism available for protecting software innovations. After the judicial and administrative decisions in the 1990s relaxing the restriction on patenting software innovations, a rapid increase in grant of software patents has been observed (Bessen and Hunt 2004; Hall and MacGarvie 2010).

This increase has however been observed as due to patenting activity by large manufacturing firms in industries with a history of strategic patenting. Only about 5 percent of the patents are assigned to software publishers based on a broad definition of software patents (Bessen and Hunt 2004). Hence there appears to be a continued preference of using other appropriability regimes possibly copyright laws in the software publishing industry in spite of the expectation that since their innovations would be purely based on software, there would be interest in obtaining software patents from that industry once it became easier to obtain them (Chung et al. 2019). For the firms that increased their software patenting, the traditional understanding of patent incentives, that more cost-effective patents increase profitability and induce an increase of R&D spending, does not seem to hold true. Software patents have been suggested to function as a substitute rather than complement for R&D spending by firms that increased their software patents relative to other patents (Bessen and Hunt 2004). The consequences of increased software patenting on market entry of firms are mixed. Software patents are shown to have both entry promotion and deterrence effect (Cockburn and MacGarvie 2011). Though the increase in relevant patents is associated with a reduction in rate of entry, potential entrants with relevant patent applications are more likely to enter, as patents take the role of complementary assets in the market entry process. Therefore, from the policymakers' perspective, the effect of increased software patenting on social outcomes such as innovation investment and competition is mixed. Firms have engaged in a race to acquire patents, but with minimal positive impact on software innovation (Hall and Harhoff 2012) and a mixed impact on market entry (Cockburn and MacGarvie 2011).

From the perspective of the firm, software patents have been demonstrated to influence firm value (Chung et al. 2019; Hall and MacGarvie 2010; Noel and Schankerman 2013). There is, however, firm level heterogeneity depending on innovation orientation (exploration or exploitation), environmental uncertainty in the industry, the firm operates in, and the size of patent portfolios held and knowledge spillover to rival firms. Additionally, the quality of patented innovation or its technological importance matters for market value, though each marginal patent right's effect is less clear (Hall and MacGarvie 2010). Overall, while the extant literature looks at innovation strategy of the firm and the external conditions, two important dimensions that distinguish patents from other appropriation mechanisms are unaddressed. These dimensions arise from the fact that patents are time limited rights to exclude others from using an invention whose knowledge must be disclosed (Somaya 2012).

Innovators intending to use software patents need to consider that obtaining patents will require disclosure of their invention in a way that enables them to utilize value appropriation opportunities properly. They also need to keep in mind that in case of unauthorized use of the disclosed knowledge, they need to enforce their rights to prevent misappropriation. Recent research indicates that there is firm level heterogeneity in the level of knowledge and capabilities to identify and define a proper scope of protection in patent filings (Novelli 2015). Depending on these factors, firms may or may not be able to properly appropriate value for the knowledge they disclose in their patent. If the knowledge disclosure is important in appropriating value from software patents, firms will need to consider if they have the capabilities required to ensure that knowledge disclosure in their software patent would enable them to properly appropriate the value of their software innovation.

Similarly, patent enforcement capabilities differ across organizations (Agarwal et al. 2009). If patent enforcement is important to ensure value appropriation of software patents, then firms would again need to consider the capabilities and strategy in this area. As software patents are one of the several appropriation mechanisms available to firms for their software innovations, the relevance of these factors would be important both for the kind of patent strategy they need to adopt (Somaya 2012) as well as to consider if other appropriation strategies would be more useful for protecting such innovations (James et al. 2013).

Table 2 presents the key studies and their findings from software patents literature, that will be utilized for our theoretical development. A summary of other important studies, that have been referred in the literature review in this chapter, is presented at the end of the document in the appendix B. In the next section, we develop the research model and the theoretical framework for the hypotheses around the effect of knowledge disclosure reflected in patent scope and firm patent enforcement strategy on the value of software patent stock.

Table 2: Key studies from software patents literature and findings

Citation	**Key Findings**	**DV**	**IVs**
(Chung et al. 2019)	Software patent stock with higher levels of explorative orientation associated with a higher firm value in environments with low dynamism and high competitiveness. Software patent stock with higher levels of exploitative orientation associated with a higher firm value in environments with high dynamism and low competitiveness	Firm Value	Software Patent Stock, Innovation Orientation, Environmental Uncertainty
(Noel and Schankerman 2013)	Strategic patenting and spillovers affect market value of software firms	Firm Value	Patent Portfolio Size, Patent Rights Fragmentation, Knowledge Spillovers
(Hall and MacGarvie 2010)	Stock market evaluated software patents as a negative development prior to easing patentability of software. Subsequently, firms with software patent stocks had higher market values than those without	Firm Value	Software Patent Stock, Industry

CHAPTER 3

THEORY AND HYPOTHESES DEVELOPMENT

3.1. Theoretical constructs and research model

The basic idea of patent protection derives from the resource based view that patents enable firms to protect their key competitive advantages from imitation by rival firms (Somaya 2012). This helps them to achieve better financial performance by appropriating the value of the innovations generated by the firm. Since, generating financial returns from innovation is a long process with technological, commercial and legal uncertainties, patents help in this process by generating real options that can be exercised by the firm depending on their conditions especially the right to enforce the patent through litigation (Somaya 2012). Patents also allow signaling and information disclosure actions that can influence rival firms. Therefore, patent rights, licensing and enforcement actions by firms enable firms to appropriate value from their innovation. Software innovations denote process innovation implemented in computer software and can be patented like other process patents also known as method patents in USPTO documentation.

By patenting software innovations, firms generate an option to appropriate the value of the innovation by controlling the market for that innovation for a period. They could exclude competitors from delivering products or services dependent on the innovation and therefore exercise a monopoly, or they could license the innovation for generating revenue. To the extent that there is a possibility for the firm to generate financial returns by patenting software innovation, a larger portfolio of patents would provide a larger opportunity for generating returns and therefore be associated with higher value (Chung et al. 2019). Therefore, based on prior literature, we expect that a firm's software patent stock is positively associated with firm value, and we do not pose a formal hypothesis for this. In the next section, we develop the definitions of the constructs and the hypotheses for our research model. Figure 1 provides a pictorial depiction of the model, and the construct definitions are summarized in table 3.

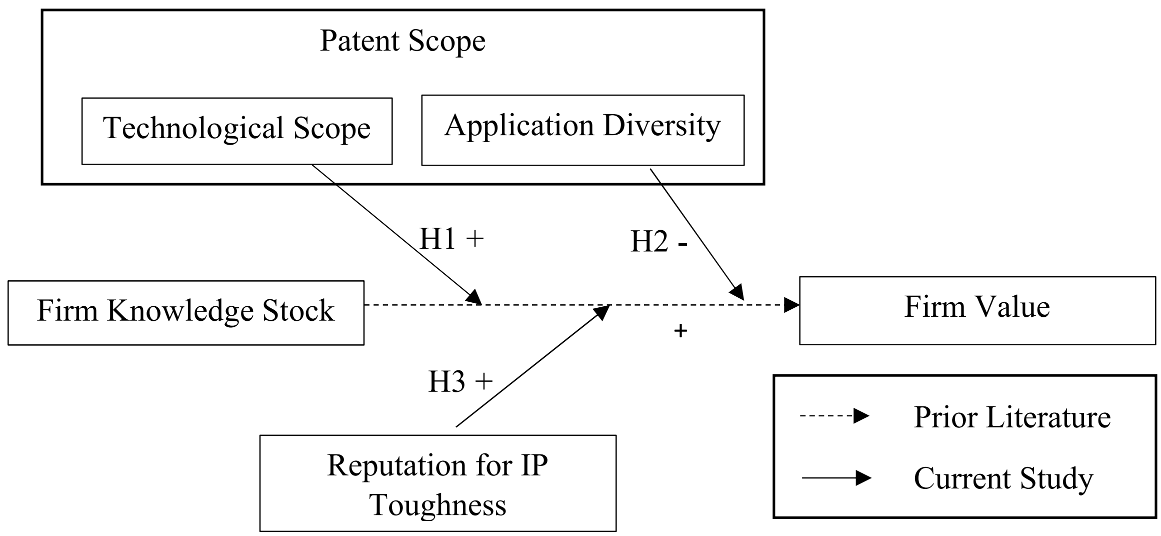

Figure 1: Research Model

Table 3: Definitions of constructs in the research model

Constructs and Definitions		
Concept	**Definition**	**Citations**
Firm Value	Present economic value of a firm in financial markets	(Bharadwaj et al. 1999; Hall et al. 2005)
Firm Knowledge Stock	Intangible assets created as the output of investment in R&D activity by firms	(Hall et al. 2005)
Patent Scope	Overall space of exclusion rights covered by the patent	(Novelli 2015)
Technological Scope (Dimension of Patent Scope)	Extent of system specification for a software innovation documented in patent claims.	(Novelli 2015)
Application Diversity (Dimension of Patent Scope)	Extent of applicability for a software innovation in different patent technological classes	(Lerner 1994; Novelli 2015)

Reputation for IP Toughness	Expectations of rival firms about the behavior of patent owner in defending against patent rights infringement	(Agarwal et al. 2009; Carlton and Perloff 2005)

3.2. Hypotheses Development

Prior research on patent scope generally takes the policy perspective and conceptualizes patent scope as the level of leniency that the patent examiner provides the innovator in claiming protection for their innovation. It argues that patents with larger scope should be more protected against the risk of imitation. This is due to the larger number of variations of the invention that are provided protection by the patent disclosure and therefore the innovator would want to claim the broadest possible extent of the invention that the examiner would allow. Conversely, the examiner would want to narrow down the scope before granting a patent. Recent theoretical development of the patent scope construct suggests that though the innovator may have an incentive to claim the broadest possible protection, they are limited in identifying the scope based on the extent of knowledge available in the organization boundary (Novelli 2015). As discussed earlier, there are two distinct dimensions of patent scope which denote two different attributes of a patent in relation to the inventive space. The first dimension is the number of variations of the core invention which is indicated by the number of claims made in the patent application. This dimension indicates the size of the inventive space occupied by the patent and therefore denotes the technological scope of the invention. The second dimension reflects the positioning of the patent in the inventive space. This dimension is indicated by the number of technological classes over which the claims are spread and therefore diversity of applications possible for the invention across technological domains. The second dimension is therefore indicative of the application diversity of the invention over more technological domains. The two dimensions together define the total scope of protection provided by the patent to the invention and also influence the innovator's ability to appropriate the returns to their invention (Novelli 2015)

The first dimension of patent scope, the number of variations of the core idea, outlines the overall technological scope of the invention identified and documented by the inventor in the patent application. A higher number of identified variations reflected in a higher number of claims, inhibits other firms from building on the disclosed knowledge as there is a higher likelihood that the competitors innovation would still fall within the purview of the claims in the patent (Novelli 2015). Higher number of claims also signal the deep understanding of the elements of the innovation by the inventor and their advantage in being able to develop subsequent inventions related to that knowledge. Therefore, there is greater possibility for the inventor to appropriate the returns for their invention and realize greater firm value.

For software innovations, the greatest risk for denial of patent rights could be due to the claimed invention being adjudicated as being directed to abstract ideas, that is generic processes merely implemented using software. An example of this was the *Alice Corp vs CLS Bank International (2014)* decision which ruled electronic escrow service was not patentable because it was an electronic implementation of an abstract idea, viz escrow service. Therefore, the documentation of claims in a software patent filing need to fully describe the technological challenge facing the inventor and the unique solution that was implemented by them using software. As such, the claims need to document both the requirement specification as well as detailed information about the design of the information system where the innovation has been done. To be able to properly protect the innovation, the innovator needs to have the capability to convert codified and tacit knowledge about the information system document it in a proper system design. If this capability is not available with the innovator, then the patent scope claimed in the patent filing would not be a proper representation of the innovation. Thus, documenting a larger technological scope may be consequential for value appropriation in several ways.

First, the risk of the invention being ruled as a software implementation of an abstract idea would be lower due to the more detailed documentation of the requirement specification and design specification of the innovative system. Second, extent of protection provided by the patent filing would be a greater barrier for imitation by rival firms as it is more likely that the features of an imitating system could be shown as infringing based upon the system description in the patent filing. Third, higher number of claims indicates the innovator's understanding of the codified and tacit knowledge elements of their software innovation and therefore an ability to generate follow on innovations and capture higher generative appropriability (Ahuja et al. 2013). Therefore, if the technological scope for a firm's software patent stock is larger, it indicates a higher capability of the firm to appropriate value from the current and follow-on innovations and more effectively deter competitors from using the disclosed knowledge in the patent. Thus, we propose the following hypothesis on the relationship between the average number of claims of the patent stock and firm value.

H1: The technological scope of a firm's software patent stock positively moderates the effect of the patent stock on firm value.

Extant literature also suggests that the second dimension of patent scope, the diversity of technological classes over which the technological scope is positioned may have negative consequences for follow-on innovations by the firm (Novelli 2015). Instead of providing increased protection from imitation, such positioning would mean that the inventor may not be able to pursue all opportunities to develop its invention due to the lack of internal capabilities or complementary assets. For software patents such a broader applicability of the software innovation over many technological classes, increases the risk of the patent being designated as directed to an abstract idea based on the notion that such a widely applicable process should be a generic process that has only been implemented in software by the innovator. More broadly defined software patents have been subject to intense criticism and therefore more likely to invite negative interest from patent examiners and competitors. In that case the patent even if granted may either be not enforceable easily or be open to challenge from competitors for invalidation. Alternately, claims spread over diverse technological classes may bring the invention to the notice of a larger number of firms through exposing the invention to their search processes. This entails the attendant risks of imitation or generation of follow-on innovations from a larger number of potential competitors. The innovating firm itself may not be able to pursue development of the innovation in such diverse domains and it is more likely that other firms would appropriate some of the value for the innovation. This suggests that a greater diversity in the technological classes where the technological scope is classified decreases the potential for the innovator to appropriate returns for their innovation and makes it easier for competitors to either imitate or utilize the disclosed knowledge in the patent and gain value at the expense of the innovator. For software patents, broader technological span increases the enforcement risk for the invention as well as invites increased attention from patent examiners and potential competitors who could benefit from the knowledge disclosure in the patent filing. Therefore, we propose the following hypothesis on the relationship between the average number of technological classes across which a firm's software patent stock is spread and firm value.

H2: The application diversity of a firm's software patent stock negatively moderates the effect of the patent stock on firm value.

As patents are only rights to exclude others from using the disclosed innovation, enforcement of the rights is an important strategic action undertaken by the patent owner (Somaya 2012). Enforcement of patent rights through litigation, a costly and time-consuming process (Lanjouw and Schankerman 2001) represents the value appropriation strategy of patent owners in two ways. First, they enable direct extraction of returns through injunctions from the party infringing on their rights. Therefore, patent owners appropriate the entire benefit of successful infringement action. Given the cost of this approach, litigated patents tend to be more valuable to the patent owner or represents the base of a cumulative chain of innovations (Lanjouw and Schankerman 1999, 2001). Second, aggressive litigation action can be used as a reputation building strategy by the innovator (Agarwal et al. 2009; Lanjouw and Schankerman 2001).

Patent enforcement through litigation is a costly and visible action that signals commitment of the innovator to aggressively defend against infringement of the firm's patent rights. Therefore, patent litigation is useful for building a reputation of being tough on infringement of intellectual property (Agarwal et al. 2009). Reputation building through costly actions that signal a credible commitment by firms to build a reputation for toughness, helps them achieve superior performance (Carlton and Perloff 2005). A reputation for toughness on IP infringement defined as the expectations of rivals on the likely behavior of the patent owner on infringement has important benefits for the patent owner. It will be less likely for competitors to attempt infringement, since there would be a credible threat that such activities will invite punitive action from the patent owner. It will deter future knowledge spillover directly through the patent filing or indirectly through employee mobility, due to the uncertainty whether a follow on innovation could be unambiguously designed such that it does not infringe on the patent owners' intellectual property (Agarwal et al. 2009). Software based innovations, like other technological fields have sequential and cumulative accumulation (Noel and Schankerman 2013) and therefore, a reputation of IP toughness with respect to the portfolio of software patents held by a firm, enables a greater opportunity to defend the value of its intellectual property and reduce chances of utilization of spilled over knowledge. Therefore, a stronger reputation of the patent owner for being tough on IP infringement, reduces the potential of loss of value appropriation for its entire patent portfolio and generates better firm performance. Conversely, not defending its patent portfolio aggressively, would either imply that the value of the patent stock is not worth the cost and effort to engage in costly enforcement action through litigation or the firm may not have the resources to prosecute infringement due to size, market position or high litigation costs (Agarwal et al. 2009). In such cases there is greater chance of low appropriation of value for the firm's patent stock with the consequent negative effect on firm performance. Therefore:

H3: The firm's reputation for IP toughness positively moderates the effect of a firm's software patent stock on firm value.

CHAPTER 4

RESEARCH DESIGN AND METHODOLOGY

4.1. Data and Sample Selection

To investigate firm level relationships using patent data, the most important factor is the identification of the firm to which each individual patent is assigned. Initial assignment of patents always happens to the individual inventors to whom the innovation is attributed and subsequently they are reassigned to a firm, so that the firm can exercise the patent rights. By using this association between a firm and the patents assigned to it, firm level variables for testing the research model can be constructed. The assignee name information in the patent data is the name of the organization (not individual inventors, of which there may be multiple), to which the patent rights are assigned. Therefore, patent assignees can exercise the patent rights on behalf of the inventors. Such exercise of rights would be in the form of patent strategy actions like licensing or litigation, aimed at appropriating the value of the assigned patent (Somaya 2012). All issued patents must have at least one inventor associated, but they may or may not be assigned to an organization. However, patents which have not been assigned to an organization cannot be included in a firm level analysis because there will be no firm level data associated for those patents. The presence of an assignee would therefore be an important criterion to include a patent into the sample for this study. The assignee information in patent data however is a free text field and does not directly correspond to firm name listings in important firm level data sets such as Compustat. To ensure such a correspondence between patents and assignment of their ownership to Compustat firm entities, there are two approaches available.

One approach utilizes the NBER patent data project data set created by (Hall et al. 2001) which contains information on all utility patents granted between 1976 and 2006 by the USPTO. The main patent level information contained in this data set includes the grant and application dates, U.S. patent class, assignee information (organization and organization type), individual inventors' information and the number of claims. Apart from the basic patent level information, two other important data sets are available. The first is patent citation information linking all the patents cited by a focal patent. This information enables the construction of backward and forward citation measures, i.e., the number of citations made by the patent and the number of citations received during the data set period. The next data set is a comprehensive match of the assignee names in the patent data set to corporation names in Compustat. This enables linking detailed patent level information with financial performance information of publicly traded U.S. companies. This data set provides the necessary firm assignment information with additional mapping to Compustat identifiers, so that firm level data can be easily obtained. Therefore, the advantage of this data set is a reliable mapping of patent ownership that has been used in subsequent studies. The disadvantages of this data set are that it provides patent data only up to 2006 with the corresponding patent ownership information. Additionally, this study also requires integration of USPTO research data sets containing the patent classification information for technology class assignments and patent litigation data to create the full data set required.

Another approach is based on relying completely on USPTO research data sets (Webb et al. 2018). This approach would however require several steps to create the patent ownership information that was provided by NBER patent data project. First, due to data quality issues with the assignee information with misspellings, abbreviations etc. in raw USPTO data, a name harmonization step is required to ensure consistency of assignee names. Next, as the initial assignees are always the inventors, reassignments to employers need to be extracted from a separate patent assignment data set and associated. Finally, the patent assignee firms need to be matched to Compustat to extract the firm information required. After this, patent classification and litigation data can be integrated in the same way as for the NBER data set. The advantage of this approach is the availability of more recent data and the data set will not be restricted till 2006 as the NBER patent data set is. The main disadvantage of this approach is that the patent assignee information does not consider firm ownership patterns where patents could be assigned to subsidiary entities for large firms. The other disadvantage is that this approach would also not account for changes in patent ownership through mergers and acquisitions. NBER data set does not have these disadvantages as the construction of the data set accounted for these issues. In using either of these approaches, an important consideration for choosing the starting year of the data set is the *State Street vs Signature Financial* litigation adjudicated in 1998 which clarified the validity of patents on business methods implemented in Software. The utilization of patenting for software innovations saw a massive increase after this judgment and therefore serves as a starting timeline for the data set.

To select the software patents from the full patents data set, there are two major approaches used in extant literature which are based upon the techniques used to assign patents to a technology field. The first approach is based on classification of individual patents by looking at their text. This could be a manual process of reading and classification by experts, but an algorithmic approach also has been used based on an initial training set of patents classified manually (Bessen and Hunt 2004). Keywords such as “software”, “computer” and “program” are used for this approach. The second approach is based on the patent classification system developed by the patent office and assigned to all patents. For this approach, patent classes are chosen by examining where the patents of large software publishers are assigned (Hall and MacGarvie 2010). The patent classes could either be the USPTO class-subclass combinations or based on International Patent Classification (IPC) classes and subclasses. The approach based on patent classes has been used more frequently in extant literature as there have been questions on the accuracy of the algorithmic approach for correctly classifying software patents (Graham & Mowery 2006; Layne-Farrar 2006). Since the context of this study is the increase in software patenting after the appropriability regime changes in the US, the USPTO classification system would be more appropriate for selecting software patents as the classification system would be more consistently applied in this jurisdiction. There are about 400 main patent classes and many subclasses. The classification is updated continuously to keep pace with technological changes. One such important change is the introduction of the 3-digit class series 7xx where data processing and computer technology related patents are classified. Apart from this series there are a few other technology classes where software inventions could be potentially patented. Together there are about 20 such technology classes that have been used in previous literature to identify software patents (Chung et al. 2019). The NBER patent data set incorporates the 3-digit original patent class for every patent based on USPTO's 1999 classification scheme. Selecting the patents belonging to the 20 technology classes identified as software patent classes (Chung et al. 2019) will provide us the sample of software patents out of the overall utility patent data set. Additionally, USPTO published guidelines for software patentability in 1996, so though NBER data is available from 1975, focusing on software patents would require narrowing down the sample data to after 1996 to account for the guidelines from USPTO. This approach is also in line with recent research on patents where technological classification is important from a theory perspective (Novelli 2015) and the study of software patents in the US context (Chung et al.

2019). A potential issue for classifying software patents is the presence of patent sharks or trolls. These entities do not commercialize innovations themselves and typically use the threat or use of litigation to extract rents for their patent holding. To address this issue, the SIC code information from Compustat data is useful to remove entities assigned to the 6797 code (patent owners and lessors) as their primary business (Agarwal et al. 2009). This will only leave entities which generate innovation utilizing internal knowledge or commercialize innovations through technology development internally or in partnership with other firms.

The data sampling process results in firms from 89 industries at the 4-digit NAICS code level from the years2000 to 2006[2]. Out of this set, 10 industries correspond to IT and related sub industries as utilized in extant literature (Chung et al. 2019). The other major industries included in the sample are non-IT related manufacturing (automotive, aerospace, industrial machinery, construction machinery, medical equipment, and pharmaceuticals). From non-IT related services, finance, professional and technical services are included. The sample also includes primary industry in the form of support services for mining. While IT and related industries have traditionally been studied in relation to software patents (Chung et al. 2019; Cockburn and MacGarvie 2011; Hall and MacGarvie 2010), software-driven innovation has become increasingly important in other sectors too. Examples from the manufacturing sector indicate the central role software-driven innovation plays in the innovation activities of traditional industries (Branstetter et al. 2019). Therefore, we do not limit the sample to IT and related industries as in extant research and include non-IT manufacturing and service industries to account for the importance of software-driven innovation in general.

[2] The timeframe of this dataset, albeit not recent, matched with the timeframe used in recent IS studies (Chung et al. 2019). Moreover, as we discuss later (in Limitations section), we believe that our theoretical arguments and insights drawn from the study can still be considered valid despite the relatively older nature of the dataset.

In addition to patent data, we also need the information on litigation activity associated with patents for testing the model. This information is available from Lex Machina derived from the IP litigation clearing house project at Stanford University. The data set associates all the court cases filed for USPTO patents starting from the year 2000 with detailed information for each case such as status, resolution, damages, plaintiffs, defendants, and findings etc. The use of NBER patent data set to construct the dependent and other independent variables of this study, limits us to use litigation data till 2006. We discuss in detail, the potential implications of this timeframe, for this study, in the limitations section.

4.2. Variables

Tobin's q - Firm Value is measured by Tobin's q, a measure capturing both short term financial performance and long-term prospects based on market value. Tobin's q as a measure of firm value is well supported in IS literature (Bharadwaj et al. 1999; Xue et al. 2012). This measure has been used to account for a firm's tangible and intangible value in relation to its innovation performance (Xue et al. 2012). Market valuation alone has also been used as a firm performance measure as an outcome of innovation performance (Lerner 1994). However, that measure was suggested to be appropriate for start-up firms in those industries where alternative intellectual property protection methods are ineffective compared to patents. In that context, there is a much larger effect of innovation on firm performance. Therefore, Tobin's q provides a more well-rounded indicator of firm performance than market valuation alone.

Tobin's q is computed using financial and accounting data available from Compustat. The main data points required to calculate this measure required from Compustat are the closing price of company stock at the end of the year, liquidating value of the firm's outstanding preferred stock, level of debt holding and the book value of total assets. There would be one observation of Tobin's q for each firm-year and can be used as the measure for the dependent variable firm value.

Software Patent Stock – The software patent stock of a focal firm could include the innovation output of the firm's R&D spending (Chung et al. 2019) as well as assets acquired from outside the firm (Ahuja and Katila 2001) and is an indicator of the firm's knowledge stock (Hall et al. 2005). The stock of software patents held by a firm represents the disclosed software innovation output owned by it, whose value could be potentially appropriated. The basic measure of a firm's software patent stock is the number software patents applied for by a firm each year added to the cumulative stock of patents from the previous years depreciated at 20%. (Hall et al. 2005; Lerner 1994; Liu and Wong 2011). This value is scaled using R&D stock calculated in the same way using R&D spending information, also depreciated at 20% to isolate the additional information value of patents exclusive of R&D spending (Chung et al. 2019; Hall et al. 2005). The scaling using R&D spending also makes this measure of patent stock an indication of the productivity of the firm in converting its knowledge stock into observable innovation output (Chung et al. 2019; Hall et al. 2005).

Number of Claims – The number of claims made by the innovator in the patent filing represents the novel features of the innovation and describes all the variations of the innovation. It is a measure of the "bits of information" about the software innovation contained in a patent (Lanjouw and Schankerman 2001) and therefore the technological scope. The evaluation of patents by examiners revolve around the novel features of the invention as documented in the claims and whether it is a sufficient advancement over the prior art. From policy perspective, the number of claims allowed by examiners in awarded patents depends on the overall leniency of patent protection in a particular jurisdiction. More lenient jurisdiction will allow larger number of claims and therefore broader technological scope while stringent jurisdiction would require number of claims to be narrowed down. At a firm level, this implies that the firm has an incentive to have the maximum number of claims a jurisdiction could allow (Lanjouw and Schankerman 2001). However, recent research indicates that there is firm level heterogeneity in identifying the number of claims that depends on the firms scientific knowledge and related inventive experience in its knowledge base (Novelli 2015). Therefore, technological scope reflects differences in the innovation generating knowledge and skills that is exposed through a firm's granted patents. The total number of claims data is available as a part of patent data sets as a count of the numbered claims listed in a patent. To account for potential skewness in the variable, its natural log is used in the estimation model, following the practice in extant literature (Novelli 2015)..

Number of Technological Classes - The number of technological classes in which the claims are classified represents the positioning of the patent claims across different knowledge domains and therefore is an indicator of application diversity. This dimension of patent scope however has different implications depending on whether IPC classes or USPTO classes are used for operationalization. In case of IPC classes, the positioning of claims occurs based on industry and therefore, the innovation is claimed to belong to those industries' knowledge domains. USPTO classes position claims across technological knowledge domains and are more appropriate for the relationship between firm knowledge base and the development of technological knowledge represented in its patent claims (Novelli 2015). For this variable, again to address potential skewness, its natural log is used in the estimation model (Lerner 1994; Novelli 2015).

Both patent scope measures (*Number of Claims*, and *Number of Technological Classes*) are patent level measures with a value for each individual patent. To roll up these measures to the firm level, these measures must be transformed as indicators for the patent stock of the firm. For the number of technological classes, the mean of the technological classes for the patent stock is used in prior literature (Lerner 1994). Following this operationalization, the two dimensions of patent scope will be operationalized as two variables. The first variable would be the mean number of technological classes for the patents applied by the firm each year. Using the same model, the mean number of technological classes for the patents applied by the firm each year would also be calculated. These two variables will represent the two dimensions of patent scope, viz. the technological scope and application diversity.

Litigiousness - Following prior literature, Reputation for IP toughness will be operationalized by Litigiousness. Litigiousness is a firm level time varying measure defined as the cumulative count of the number of unique patent infringement suits launched by the focal firm in a five year window preceding the focal year (Agarwal et al. 2009). As lawsuits are a costly mechanism of patent enforcement, their initiations by a patent owner are an important signal of the intent to build a reputation for toughness towards intellectual property challengers (Agarwal et al. 2009) as well as a risky action to appropriate value for their innovation (Lanjouw and Schankerman 2001). Utilizing a five-year time window allows for accounting of the hangover effect of litigation action which shows up in ways consequential for firm performance such as increased citations for litigated patents, immediately following the publicizing of litigation action. Following extant literature, log transformation is not used for this variable (Agarwal et al. 2009).

Control variables - We include control variables to control for firm and industry heterogeneity. For controlling firm specific, industry and year effects, the required control variables are – Firm size, R&D Intensity (R&D expenditure to Sales), firm market share, advertising intensity, Industry Tobin's Q and year fixed effects(Chung et al. 2019). At the firm level, there is a requirement to control for firm size, R&D expenditure, and market share as these would be consequential for firm performance. Firm size and market share denote the dominant position that the firm would enjoy in economies of scale and market position. Therefore, these firm level variables would have a direct relationship to firm value. Firm size is measured using the number of employees' information from Compustat for each year. Market share information is calculated as the ratio of the total sales of the firm to the total sales at the industry SIC code level each year (Xue et al. 2012). R&D intensity represents the potential creation of growth opportunities and as we measure the dependent variable firm value in this study using Tobin's q that also accounts for the future prospects, R&D intensity would have an impact on the future growth of the firm. R&D expenditure and total sales per year data from Compustat allow scaling of the firm's R&D expenditure to enable comparison between firms of different sizes in terms of R&D intensity. We control for Advertising Intensity because a firm's brand strength may impact its intangible value and therefore its Tobin's q (Xue et al. 2012) Industry Tobin's q defined as the median Q for the firm's industry measured at the end of year t is utilized to account for industry specific variations in Tobin's q (Bardhan et al. 2013). Year fixed effects for the sample years, i.e., year dummies from 2000 to 2006, needs to be included to control for year specific effects. To control for industry specific effects, industry dummies for NAICS four-digit codes are added to the estimation model. We will also include control variables for Regulation and Industry Capital Intensity (Bharadwaj et al. 1999). Presence of regulation impacts firm value through potential barriers to entry in the industry, increasing profits for incumbents or by counteracting anti-competitive practices and reducing potential profits. Similarly, capital intensive industries may represent a barrier of entry for new firms and raise profits or the requirement for capital spending may reduce intangible investments and reduce *q* value (Bharadwaj et al. 1999). Therefore, it is important to also account for these important sources of industry level heterogeneity in a study focusing on firm value. Tables 3 and 4 provides a summary of all the variables that will be included in the research model:

Table 4: Description and measurement of dependent and independent variables

Dependent and Independent Variables				
Construct	**Variable**	**Measurement**	**Data Source**	**Citations**
Firm Value	Tobin's q	Ratio of market value to replacement cost of assets of a firm. Calculated using Chung-Pruitt approximation as used in IS literature.	Compustat	(Bharadwaj et al. 1999; Chung and Pruitt 1994; Hall et al. 2005)
Firm Knowledge Stock	Software Patent Stock	Cumulative software patent counts, scaled by R&D stock	NBER Patent Data Project	(Hall et al. 2005)
Technological Scope	Average Number of Claims	Average number of claims for patents applied by firm *i* in year *t*	NBER Patent Data Project	(Novelli 2015)
Application Diversity	Average Number of Technological Classes	Average number of USPTO 3-digit classes assigned to patents applied by firm *i* in year *t*	USPTO Research Dataset	(Lerner 1994; Novelli 2015)

Reputation for IP Toughness	Litigiousness	Moving five-year cumulative count of infringement lawsuits initiated by firm *i*	USPTO Research Dataset	(Agarwal et al. 2009)

Table 5: Description and measurement of control variables

Variable	**Measurement**	**Data Source**	**Citations**
Firm-Level Control Variables			
Firm Size	Number of employees of firm *i* in year *t (log form)*	Compustat	(Bharadwaj et al. 1999)
R&D Intensity	Ratio of firm *i*'s R&D expenditure to Sales in year *t*	Compustat	(Bharadwaj et al. 1999)
Advertising Intensity	Ratio of firm *i*'s advertising expenditure to sales in year *t*	Compustat	(Chung et al. 2019)
Market Share	Ratio of sales of firm *i* in year *t* to industry sales at 4-digit NAICS level	Compustat	(Bharadwaj et al. 1999; Chung et al. 2019)
Industry-Level Control Variables			
Industry Capital Intensity	Ratio of capital investment to sales for the firm's industry at 4-digit NAICS level	Compustat	(Bharadwaj et al. 1999; Capon et al. 1990)
Industry Mean q	Average q for the for the firm's industry at 4-digit NAICS level at end of year *t*	Compustat	(Bharadwaj et al. 1999)

4.3. Estimation Models and Econometric Considerations

The empirical estimation model is based on similar models from extant literature (Chung et al. 2019; Hall et al. 2005). For investigating hypothesis H1, the association of software patent stock with firm value, the software patent stock of a firm i in year t is scaled by R&D stock which isolates the value of patent stock from the overall value of R&D stock that would be accounted for in the firm's market value. Further, the natural log of the dependent variable Tobin's q is taken following extant literature (Chung et al. 2019; Hall et al. 2005) and for the independent variables Software Patent Stock, Litigiousness and Patent Scope to address their skewness and magnitude. To test the hypotheses, interaction terms will be required to be added to the baseline model testing the relationship between software patent stock and firm value. We estimate:

Tobin's $q_{i,t}$ = Intercept + α_1 Software Patent $Stock_{i,t}$ + β_1 $Litigiousness_{i,t}$ + γ_1 $NumberofClaims_{i,t}$ + π_1 $NumberofClasses_{i,t}$ + τ_1 $Litigousness_{i,t}$ + σ_1 (Software Patent $Stock_{i,t}$ * $NumberofClaims_{i,t}$) + σ_2 (Software Patent $Stock_{i,t}$ * $NumberofClasses_{i,t}$) + σ_3 (Software Patent $Stock_{i,t}$ * $Litigiousness_{i,t}$) + Firm Controls + Year Fixed Effects

We will first test the models using Fixed-Effects and Random-effects models. To choose the more appropriate model for the analysis, some preliminary steps can be performed. We can compute the intra-class correlations (ICC) for the data to check for within firm versus between firm variation. An ICC value of less than 0.5 would imply more within unit variation and the fixed effects model would be more appropriate as it will explicitly model within firm variation. Random effects model would also be inappropriate if the error term is correlated with the independent variables. To check for this issue, we will run a Hausman test with the null hypothesis that the error is not correlated with the independent variables. If the null is rejected, then random effects model would be biased and therefore fixed effect model would be preferred. A fixed effects model would control for all time-invariant effects, both observed and unobserved, and therefore, reduce potential bias from unobserved heterogeneity. There is also possibility of auto-correlated error terms due to the panel nature of the data set. This issue could be investigated by using the Wooldridge test for serial correlation of errors and if found to be an issue, the corresponding correction needs to be applied when estimating the model.

While estimating these models, it is also required to account for the endogeneity of software patent stock as described in extant literature or the potential endogeneity of the moderators, patent scope and litigiousness. Patenting decisions are likely to be made depending on the expectation of future returns and therefore, an impact on firm value (Chung et al. 2019). Similarly, pursuing an aggressive reputation-building strategy using patent litigation may be done with the intention of creating or maintaining a competitive advantage by dissuading competition as well as defending high-value intellectual property from unauthorized use (Agarwal et al. 2009; Lanjouw and Schankerman 2001). Therefore, patent stock and litigiousness could be endogenous and bias the estimation results. System GMM estimation is an option to address the endogeneity of the explanatory variables if instrument variables are not easily identifiable. This approach is also used to address endogeneity concerns and bias due to unobserved heterogeneity in recent IS innovation and software patents literature (Bardhan et al. 2013; Chung et al. 2019). System GMM allows the use of lagged levels and differences between independent variables as internal instruments. Due to the large number of firms and time periods in the panel, system GMM is a feasible approach to address endogeneity for this study due to the availability of large number of internal instruments. There is, however, a potential issue of over-identification due to too many instruments. This can be addressed by choosing the appropriate lags for the endogenous variables in the system GMM estimation such that the number of instruments does not exceed the number of firms in the panel.

CHAPTER 5

RESULTS AND DISCUSSION

5.1. Findings

The final data set for analysis consists of 2,146 firm year observations over a diverse set of industries as depicted in Table 6. Over two-thirds of the observations pertain to the IT and related industries as suggested by the NAICS code assignments of the relevant firms. Another 27% of observations come from non-IT manufacturing industries and the remaining 6% belong to non-IT service firms. Therefore, within the sample period from 2000 to 2006, IT and related industries were highly active in acquiring software patents. Within the observations for IT and related industries, the hardware sector accounts for a larger portion which follows from the traditional preference for patents as an intellectual property protection mechanism especially in semiconductor related industries. Further information about the variables used in the estimation model are provided in the following tables. Table 7 provides the descriptive statistics for the dependent variable, independent and moderator variables, and the controls used, and Table 8 shows the correlation coefficients for the pair wise correlations for all the variables.

To choose the appropriate estimator to evaluate the empirical model, we first use the fixed effects panel estimator on the full model for testing whether firm-specific heterogeneity of the constant term is necessary. The result of the F test of the null hypothesis that the constant terms are equal across firms, ($F = 4.91$, $p < 0.001$) indicates that pooled OLS will be inconsistent and either a fixed effects or random effects estimator needs to be used. For comparing the fixed and random effects estimator, we use the Durbin-Wu-Hausman test on the results of the fixed effects and random effects estimator. The result of the test (Durbin $\chi^2(19) = 143.49$, $p < .001$) indicates that the orthogonality assumption of the random effects estimator is violated and therefore it will not be consistent.

Table 6: Distribution across industries for the data sample

Sector (NAICS)	Sector Description	N (Firm-Years)
IT & Related Industries		
3341	Computer and Peripheral Equipment Manufacturing	175
3342	Communications Equipment Manufacturing	147
3343	Audio and Video Equipment Manufacturing	7
3344	Semiconductor and Other Electronic Component Manufacturing	339
3345	Navigational, Measuring, Electro medical, and Control Instruments Manufacturing	192
5112	Software Publishers	273
5171	Wired Telecommunications Carriers	12
5181	Internet Service Providers and Web Search Portals	12
5182	Data Processing, Hosting, and Related Services	5
5191	Other Information Services	50
5415	Computer Systems Design and Related Services	96
Other Primary & Manufacturing Industries		
11xx	Agriculture, Forestry, Fishing and Hunting	5
2131	Support Activities for Mining	28
21xx	Mining, Quarrying, and Oil and Gas Extraction	5
3254	Pharmaceutical and Medicine Manufacturing	62
3331	Agriculture, Construction, and Mining Machinery Manufacturing	19
3332	Industrial Machinery Manufacturing	49
3333	Commercial and Service Industry Machinery Manufacturing	63
3361	Motor Vehicle Manufacturing	29
3363	Motor Vehicle Parts Manufacturing	34
3364	Aerospace Product and Parts Manufacturing	31
3391	Medical Equipment and Supplies Manufacturing	23
31xx-33xx	Other Manufacturing	189
Other Non-IT related Services		
42xx	Wholesale Trade	8
4541	Electronic Shopping and Mail-Order Houses	7
48xx	Transportation and Warehousing	4
51xx	Information Services	24

52xx	Finance and Insurance	14
53xx	Real Estate Rental and Leasing	8
54xx	Professional, Scientific, and Technical Services	21
56xx	Administrative and Support Services	5
62xx	Health Care and Social Assistance	3
71xx	Arts, Entertainment, and Recreation	5
9999	Others	18

Table 7: Descriptive statistics of variables (N = 2,146 Firm-Years)

Variable	**Description**	**Mean**	**Standard Dev**	**Min**	**Max**
Tobin's q	Tobin's q by firm-year	2.622	2.860	0.232	55.729
SW Patent Stock	Cumulative software patent count by firm-year scaled by R&D stock	0.265	2.279	0.000	83.333
Mean Claims	Mean of patents' number of claims by firm-year	23.201	16.559	0.000	176.000
Mean Classes	Mean of patents' number of assigned classes by firm-year	3.951	2.722	0.000	31.000
Litigiousness	Number of patent related court cases in a 4-year window depreciated 20% every year	2.051	7.758	0.000	119.662
Employees	Total number of employees	27.933	75.352	0.002	1383.000
R&D Intensity	Ratio of R&D expenses to sales by firm-year	0.540	4.643	0.000	133.786
Advertising Intensity	Ratio of firm *i*'s advertising expenditure to sales in year *t*	0.040	0.676	0.000	26.058
Market Share	Ratio of sales of firm *i* in year *t* to industry sales at NAICS4 level	0.066	0.151	0.000	1.000
Industry Capital Intensity	Ratio of capital investment to sales for the firm's industry at NAICS4 level	0.069	0.056	0.002	0.603
Industry Tobin's q	Average q for the firm's industry based on NAICS4 code at fiscal year end	15.882	31.608	0.891	854.203

Table 8: Correlation among variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1. Tobin's q	1.000										
2. SW Patent Stock	0.085***	1.000									
3. Technological Scope	0.063**	0.024	1.000								
4. Application Diversity	0.037	0.008	0.214***	1.000							
5. Litigiousness	-0.033	-0.008	0.014	0.018	1.000						
6. Employees	-0.115***	-0.036	-0.032	-0.007	0.252***	1.000					
7. R&D Intensity	0.128***	0.008	0.013	-0.025	-0.023	-0.038	1.000				
8. Advertising Intensity	-0.001	-0.001	0.043*	0.010	-0.011	-0.017	0.145***	1.000			
9. Market Share	-0.105***	-0.034	-0.012	0.000	0.210***	0.441***	-0.040	-0.017	1.000		
10. Ind. Cap. Intensity	-0.005	-0.016	-0.012	-0.013	-0.044*	-0.013	0.026	0.053*	-0.083***	1.000	
11. Ind. Tobin's q	0.025	-0.003	0.012	-0.008	-0.009	0.045*	-0.008	-0.014	-0.029	-0.097***	1.000

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Therefore, we continue the analysis using the fixed effects estimator. While using the fixed effects estimator will not allow us to investigate between firm relationships, it will ensure that there is no bias from time-invariant observed factors potentially driving both the independent and the dependent variables. Next, we test for the need for time fixed effect in the model specification, presence of heteroscedasticity and cross-sectional dependence. The F-test of dummies for all years being zero (F = 39.88, $p < 0.001$) indicates the need for time dummies to be included. A significant modified Wald test for group-wise heteroscedasticity means the use of robust Huber-White standard errors are required to address the issue in the data.

To evaluate our hypotheses, we first estimate the fixed effects panel regression model using the model equation depicted in the previous section with only the controls and software patent stock included. Then the main effects of the moderators are included stepwise. The results of the estimation are shown in Table 9, models (2), (3) and (4). In all three models, the influence of software patent stock on firm value is positive and significant (β = approx. 0.075, $p < 0.001$). This result indicates that a 1% increase in software patent stock is associated with 0.075% increase in firm value. The main effect of technological scope in these models is not significant, but the main effect for application diversity is negative and significant (β = approx. -0.053, $p < 0.05$) indicating that higher application diversity is negatively associated with firm value. Models (5) and (6) introduce the interaction effects between the moderators and software patent stock to evaluate the moderation hypotheses. As both the models show, the main effect and interaction are significant for both technological scope and application diversity. For technological scope, the coefficient of the interaction effect is positive, indicating a positive moderation effect of the variable on the relationship between software patent stock and firm value and providing support for hypothesis 1. Similarly, the coefficient for the interaction effect of application diversity is negative and significant providing support for hypothesis 2. The main effect for litigiousness is not significant in both models (5) and (6) and the interaction effect is also not significant in model (6) indicating no support for hypothesis 3.

Table 9: Results of fixed effects model with robust standard errors

Variable Dep Var: Tobin's q	(1) ln(Y)	(2) ln(Y)	(3) ln(Y)	(4) ln(Y)	(5) ln(Y)	(6) ln(Y)
SW Patent Stock	0.0688*	0.0729	0.0770*	0.0769*	0.0856*	0.0849*
	[0.034]	[0.052]	[0.042]	[0.042]	[0.016]	[0.016]
Technological Scope		-0.00356	0.0185	0.0174	0.0747*	0.0721*
		[0.682]	[0.142]	[0.169]	[0.010]	[0.014]
Application Diversity			-0.0541*	-0.0533*	-0.188***	-0.186***
			[0.021]	[0.023]	[0.000]	[0.000]
Litigiousness				0.0187	0.0200	0.0553
				[0.246]	[0.218]	[0.093]
SW Patent Stock x					0.0184*	**0.0174***
Technological Scope					[0.013]	**[0.019]**
SW Patent Stock x					-0.0416**	**-0.0408****
Application Diversity					[0.003]	**[0.004]**
SW Patent Stock x						0.0106
Litigiousness						[0.130]
Employees	-0.240***	-0.238***	-0.240***	-0.236***	-0.225**	-0.227**
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
R&D Intensity	-0.210**	-0.209**	-0.208**	-0.208**	-0.211**	-0.211**
	[0.008]	[0.008]	[0.008]	[0.008]	[0.008]	[0.008]
Advertising Intensity	-0.276**	-0.277**	-0.288**	-0.291**	-0.293**	-0.293**
	[0.008]	[0.007]	[0.005]	[0.005]	[0.005]	[0.005]
Market Share	0.529	0.528	0.533	0.551	0.464	0.480
	[0.463]	[0.465]	[0.459]	[0.448]	[0.524]	[0.510]

Industry Capital Intensity	0.0210	0.0212	0.0205	0.0190	0.0226	0.0244
	[0.737]	[0.735]	[0.743]	[0.762]	[0.720]	[0.699]
Industry q	-0.00192	-0.00200	-0.00272	-0.00259	-0.00127	-0.00128
	[0.868]	[0.862]	[0.811]	[0.821]	[0.911]	[0.911]
Intercept	2.009***	2.030***	2.064***	2.050***	2.078***	2.083***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Year Dummies	Y	Y	Y	Y	Y	Y
R^2	0.216	0.216	0.219	0.220	0.225	0.226
Adjusted R^2	0.211	0.210	0.214	0.214	0.219	0.220
F-Value	28.77***	26.81***	25.04***	23.37***	21.33***	20.31***
Degrees of Freedom	(13, 758)	(14, 758)	(15, 758)	(16, 758)	(18, 758)	(19, 758)
N	2146	2146	2146	2146	2146	2146

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Due to potential endogeneity concerns with the independent variables, additional analysis is performed using the system GMM estimator. The endogeneity issue with software patent stock is the possibility that firms with more resources are likely to apply for and hold larger patent stocks, implying reverse causality in the relationship between software patent stock and firm value. For technological scope and application diversity it is possible that firms attempt to claim a larger boundary of protection by increasing the claimed technological scope and application diversity with expectations of a positive effect on firm value. Similarly, firms may also engage in a reputation building strategy with an expectation of positive effect on firm value. Therefore, the relationship between firm value and technological scope, application diversity and litigiousness may be systematically biased. Prior research on business value of IT (Bardhan et al. 2013) and software patents (Chung et al. 2019) address endogeneity using the system GMM estimator. System GMM estimator is a useful approach to address the endogeneity concerns for the independent variables where suitable instruments may be hard to find. The approach uses the lagged levels of the independent variables and the differences in controls as internal instruments (Roodman 2009). We, therefore, report the results of the system GMM estimation in table 10.

The initial model run is performed including only the controls and the independent variable and then the main effects of the moderators are added in model (2). Models (3) to (5) add the interaction terms stepwise to test the hypotheses. In all the model runs the second lag onwards of the endogenous moderators, first lag onwards for predetermined firm controls and the differences of all moderators, independent and control variables are employed as instruments. This approach is as recommended in literature for the usage of the estimator (Roodman 2009). Additionally, we also ensure that the number of instruments (119) is less than the number of firms in the panel (759) and check that the Hansen test for over-identification and Arellano-Bond

AR (2) tests are not significant indicating the robustness of the specification. We also employ the Windmeijer correction for potential finite sample bias because the panel of our data is of a small T and large N nature. The results of Model (1) including only the controls and software patent stock shows a positive and significant result for the relationship between software patent stock and firm value (β = approx. 0.09, $p < 0.01$), broadly in line with the results from the fixed effects model. Model (2) introducing the main effects of the moderators, however, indicates that after correcting for endogeneity, the significant results for the main effects in the fixed effects model (i.e., technological scope and application diversity) are no longer significant. Additionally, models (3) to (5) testing the moderation hypotheses show that hypothesis 1 is not supported and, while the main and moderating effects of application diversity are significant, they are opposite in direction to the hypothesis and the results of fixed effects model.

While we hypothesize a negative relationship for application diversity with firm value, prior literature has indicated mixed results with both a negative relationship (Novelli 2015) and a positive relationship (Lerner 1994). It is therefore plausible that correcting for endogeneity gives better support to the theoretical findings relating broader application diversity to increased firm value based on the argument that this increase in this dimension of patent scope increases the scope of protection provided by a patent and there is no potential problem in such an increased scope leading to a challenge based on the unenforceability of patents on abstract ideas. Moreover, while it may be difficult for the patent owner to derive value from usage of the patented technology from more diverse applications, for software patents it may be equally difficult for potential rivals in diverse industries to be able to use a widely applicable software patent without inviting the threat of legal action from the patent owner. Empirically, the system GMM uses internal instruments to account for the endogeneity of the independent variables. But if potential instruments could be found for the dimensions of patent scope and litigiousness, then they can provide more evidence and shed more light on the differences in results between the fixed effects and system GMM models. This can clarify the theoretical arguments that account for the results. For litigiousness, the results indicate no support for hypothesis 3, same as the results from using the fixed effects estimator as reported previously.

Table 10: Results of system GMM models with finite sample robust standard errors

Variable Dep Var: Tobin's q	(1) ln(Y)	(2) ln(Y)	(3) ln(Y)	(4) ln(Y)	(5) ln(Y)
SW Patent Stock	0.0910**	0.0789*	0.0618	0.0455	0.0396
	[0.002]	[0.020]	[0.262]	[0.443]	[0.495]
Technological Scope		0.0150	0.0330	-0.193	-0.181
		[0.736]	[0.679]	[0.095]	[0.180]
Application Diversity		0.0139	0.0319	0.526**	0.535**
		[0.873]	[0.714]	[0.007]	[0.009]
Litigiousness		0.0285	0.0310	0.0193	-0.00305
		[0.438]	[0.412]	[0.622]	[0.977]
SW Patent Stock x			0.00747	-0.0589*	-0.0546
Technological Scope			[0.699]	[0.025]	[0.092]
SW Patent Stock x				0.138**	**0.138***
Application Diversity				[0.005]	**[0.012]**
SW Patent Stock x					-0.00696
Litigiousness					[0.802]
Employees	-0.0564	-0.0851*	-0.0852*	-0.0740	-0.0760
	[0.105]	[0.015]	[0.021]	[0.155]	[0.156]
R&D Intensity	-0.224	-0.259*	-0.259	-0.271	-0.269
	[0.064]	[0.049]	[0.055]	[0.054]	[0.055]
Advertising Intensity	2.315	1.820	2.043	2.481	2.538
	[0.200]	[0.306]	[0.284]	[0.170]	[0.166]
Market Share	0.759	0.825	0.826	0.772	0.776
	[0.245]	[0.146]	[0.141]	[0.271]	[0.312]

Industry Capital Intensity	-0.102	-0.0790	-0.0980	-0.127*	-0.130
	[0.168]	[0.303]	[0.219]	[0.036]	[0.054]
Industry q	-0.00120	-0.00116	0.00280	0.0000716	-0.00244
	[0.930]	[0.926]	[0.814]	[0.996]	[0.873]
Intercept	1.229***	1.221***	1.107**	0.905**	0.869**
	[0.000]	[0.000]	[0.002]	[0.003]	[0.007]
Year Dummies	Y	Y	Y	Y	Y
Wald Statistics	5252.7***	5448.6***	5631.4***	5039.4***	4920.1***
Degrees of Freedom	13	16	17	18	19
Number of Instruments	119	119	119	119	119
Hansen Test of Over-ID	0.440	0.441	0.505	0.684	0.670
Arellano-Bond AR (2) test	0.467	0.595	0.614	0.570	0.564
N	2146	2146	2146	2146	2146

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

5.2. Robustness Checks

We performed robustness checks to assess whether the results for our hypotheses hold under various conditions. Table 11 summarizes the issues, and the remediation approaches we used to assess the robustness of our results. The results of robustness checks reported in this section use the fixed effects models for comparison with the main analysis. We also performed these checks using the system GMM estimator instead of the fixed effects models. The full results of the system GMM models are reported in the appendix C.

Table 11: Robustness issues and remediation approaches

Issue	**Remediation Approach**	**Citations**
Skewness of patent values	Test model using multiple *alternate measures of technological scope and application diversity* that better capture the skewness.	(Lerner 1994)
Endogenous independent variables	Use *System GMM estimator* with lagged independent variables as internal instruments	(Bardhan et al. 2013; Chung et al. 2019)
Industry Heterogeneity	Test model for *restricted sample with IT industry firms*	(Chung et al. 2019)

Firms with low patenting observations	Test models with *panels having multiple observations only*	
Bias due to log transformation of patent scope	Test models *without the log transformation*	(Novelli 2015)
Outliers in data	Test models with *outliers winsorized and trimmed*	

Alternative Measures of Patent Scope: First, we reran fixed effects models using three alternate measures each for technological scope and application diversity. The results are reported in table 12. While the main model runs were performed using the mean value of technological scope and application diversity, we build three alternate measures based on the maximum, cumulative and cumulative average value of the two scope dimensions. These measures are based on the idea that the distribution of patent values might be highly skewed in which case patents with the broadest scope will be the best measure of firm value (Lerner 1994)[3]. The three alternate measures for both dimensions of scope can better capture the skew in patent values than the mean which would instead attenuate the effect. With the measures constructed using maximum and cumulative values of the variables, the significant main effects, and the support of hypotheses 1 and 2 are consistent with the original fixed effects model reported earlier. For the cumulative mean measure however, the results are only supported for technological scope and not for application diversity. This may be due to the cumulative mean measure not fully accounting for the potential skewness in patent values that the other two alternate measures provide while the mean measure though attenuated is more responsive than the cumulative mean to the skewness.

[3] The maximum measure is the largest value of technological scope and application diversity for patents in a firm-year. Cumulative measures are calculated by accruing the total technological scope and application diversity values for each firm-year. Cumulative mean constructs a moving average of the two dimensions over firm-years.

Table 12: Fixed effects with alternate measures of patent scope

Dep Var: Tobin's q Patent Scope Measure	(1) ln(Y) Mean	(2) ln(Y) Max	(3) ln(Y) Cumulative	(4) ln(Y) Cumul. Mean
SW Patent Stock	0.0849*	0.0901*	0.0663	-0.0601
	[0.016]	[0.018]	[0.436]	[0.415]
Technological Scope	0.0721*	0.0742**	0.218**	0.272**
	[0.014]	[0.005]	[0.008]	[0.002]
Application Diversity	-0.186***	-0.166***	-0.379***	-0.242
	[0.000]	[0.000]	[0.000]	[0.057]
Litigiousness	0.0553	0.0477	0.0368	0.0497
	[0.093]	[0.151]	[0.244]	[0.131]
SW Pat Stock x Tech Scope	**0.0174***	**0.0180****	**0.0665****	**0.0638****
	[0.019]	**[0.009]**	**[0.004]**	**[0.006]**
SW Pat Stock x App Diversity	**-0.0408****	**-0.0347****	**-0.0531***	-0.0518
	[0.004]	**[0.002]**	**[0.025]**	[0.093]
SW Pat Stock x Litigiousness	0.0106	0.00899	0.00532	0.00895
	[0.130]	[0.208]	[0.457]	[0.209]
Employees	-0.227**	-0.221**	-0.128	-0.228***
	[0.001]	[0.001]	[0.077]	[0.001]
R&D Intensity	-0.211**	-0.206**	-0.176*	-0.207**
	[0.008]	[0.007]	[0.014]	[0.009]
Advertising Intensity	-0.293**	-0.297**	-0.308**	-0.306**
	[0.005]	[0.004]	[0.004]	[0.004]
Market Share	0.480	0.495	0.296	0.513
	[0.510]	[0.500]	[0.701]	[0.477]
Industry Capital Intensity	0.0244	0.0213	0.0343	0.0268
	[0.699]	[0.734]	[0.569]	[0.663]
Industry q	-0.00128	-0.000493	0.000828	0.000422
	[0.911]	[0.966]	[0.942]	[0.971]
Intercept	2.083***	2.088***	2.294***	1.480***
	[0.000]	[0.000]	[0.000]	[0.000]
Year Dummies	Y	Y	Y	Y

R^2	0.226	0.229	0.246	0.229
Adjusted R^2	0.220	0.222	0.239	0.222
F-Value	20.31***	20.38***	20.45***	20.59***
Degrees of Freedom	(19, 758)	(19, 758)	(19, 758)	(19, 758)
N	2146	2146	2146	2146

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

IT-Industry Sub-sample: Second, we ran the fixed effects models for a sub-sample of IT industry firms only. Though our sample contains approximately 67% observations from the IT industry, there is a significant percentage of observations from non-IT manufacturing and service industries. This increases the potential for unobserved heterogeneity from additional sources unique to different industries represented in the sample. Restricting the sample to only IT industry removes these factors from other industries and reduces potential bias due to them. The results for this analysis reported in table 13, indicate that for this sub-sample hypothesis 1 is supported for all alternate measures of technological scope, but hypothesis 2 is not supported for cumulative and cumulative mean measures of application diversity. As with previous results using these measures in the full sample, it appears that the cumulative measures may be less sensitive to patent value skewness and therefore not as good indicators for patent scope as the mean and max measures are. There is no support for hypothesis 3 in the IT industry sub-sample, consistent with the results of the main analysis.

Table 13: Fixed effects with sample restricted to IT industry

	(1)	(2)	(3)	(4)
Dep Var: Tobin's q	ln(Y)	ln(Y)	ln(Y)	ln(Y)
Patent Scope Measure	Mean	Max	Cumulative	Cumul. Mean
SW Patent Stock	0.107*	0.112*	0.0373	-0.0947
	[0.030]	[0.037]	[0.763]	[0.458]
Technological Scope	0.114**	0.112**	0.317**	0.378**
	[0.008]	[0.003]	[0.007]	[0.001]
Application Diversity	-0.285***	-0.244***	-0.531***	-0.350
	[0.001]	[0.000]	[0.000]	[0.063]

Litigiousness	0.0462	0.0320	0.00903	0.0349
	[0.268]	[0.445]	[0.817]	[0.394]
SW Pat Stock x Tech Scope	**0.0289***	**0.0284***	**0.0997***	**0.0892***
	[0.025]	**[0.012]**	**[0.010]**	**[0.015]**
SW Pat Stock x App Diversity	**-0.0698***	**-0.0575****	-0.0649	-0.0745
	[0.012]	**[0.006]**	[0.078]	[0.199]
SW Pat Stock x Litigiousness	0.00953	0.00564	-0.00379	0.00613
	[0.339]	[0.561]	[0.697]	[0.527]
Employees	-0.211*	-0.197*	-0.0116	-0.209*
	[0.018]	[0.026]	[0.893]	[0.012]
R&D Intensity	-0.197*	-0.193*	-0.132	-0.185*
	[0.039]	[0.036]	[0.081]	[0.045]
Advertising Intensity	-0.279*	-0.286*	-0.274**	-0.299**
	[0.016]	[0.012]	[0.004]	[0.009]
Market Share	1.133	1.074	0.287	1.143
	[0.406]	[0.433]	[0.806]	[0.388]
Industry Capital Intensity	0.00523	0.00663	-0.0143	0.00989
	[0.961]	[0.950]	[0.888]	[0.927]
Industry q	0.00181	0.00174	0.00648	0.00207
	[0.922]	[0.926]	[0.718]	[0.911]
Intercept	2.019***	2.031***	2.164***	1.227*
	[0.000]	[0.000]	[0.000]	[0.026]
Year Dummies	Y	Y	Y	Y
R^2	0.245	0.249	0.286	0.250
Adjusted R^2	0.235	0.238	0.276	0.240
F-Value	17.71***	17.71***	18.45***	18.63***
Degrees of Freedom	(19, 477)	(19, 477)	(19, 477)	(19, 477)
N	1412	1412	1412	1412

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Removing Single Firm-Year Observation Firms: Third, we ran another restricted sample analysis, by removing firms with only a single firm-year observation from the data set. This approach was taken to remove firms which do not actively use patents as an appropriation mechanism, and therefore potentially also did not engage in using patent litigation as a reputation building strategy. Conversely firms generating software patents more frequently have a higher opportunity and incentive to consider litigation to deter competitors from using spilled-over knowledge and litigiousness could influence firm value for such firms. The results of the analysis are presented in table 14. The results are like other fixed effects results presented earlier, and even in the subset of firms using software patenting more frequently, hypothesis 3 on the influence of litigiousness on firm value is not supported.

Table 14: Fixed effects with sample restricted to firms with multiple firm-year observations

Dep Var: Tobin's q Patent Scope Measure	(1) ln(Y) Mean	(2) ln(Y) Max	(3) ln(Y) Cumulative	(4) ln(Y) Cumul. Mean
SW Patent Stock	0.0849*	0.0901*	0.0663	-0.0601
	[0.017]	[0.019]	[0.436]	[0.416]
Technological Scope	0.0721*	0.0742**	0.218**	0.272**
	[0.014]	[0.005]	[0.009]	[0.002]
Application Diversity	-0.186***	-0.166***	-0.379***	-0.242
	[0.000]	[0.000]	[0.000]	[0.057]
Litigiousness	0.0553	0.0477	0.0368	0.0497
	[0.093]	[0.152]	[0.245]	[0.132]
SW Pat Stock x Tech Scope	**0.0174***	**0.0180****	**0.0665****	**0.0638****
	[0.019]	**[0.009]**	**[0.004]**	**[0.006]**
SW Pat Stock x App Diversity	**-0.0408****	**-0.0347****	**-0.0531***	-0.0518
	[0.004]	**[0.002]**	**[0.026]**	[0.093]
SW Patent Stock x Litigiousness	0.0106	0.00899	0.00532	0.00895
	[0.131]	[0.209]	[0.457]	[0.209]
Employees	-0.227**	-0.221**	-0.128	-0.228***
	[0.001]	[0.001]	[0.077]	[0.001]
R&D Intensity	-0.211**	-0.206**	-0.176*	-0.207**
	[0.008]	[0.008]	[0.014]	[0.009]

Advertising Intensity	-0.293**	-0.297**	-0.308**	-0.306**
	[0.005]	[0.004]	[0.004]	[0.004]
Market Share	0.480	0.495	0.296	0.513
	[0.510]	[0.501]	[0.702]	[0.477]
Industry Capital Intensity	0.0244	0.0213	0.0343	0.0268
	[0.699]	[0.734]	[0.569]	[0.664]
Industry q	-0.00128	-0.000493	0.000828	0.000422
	[0.911]	[0.966]	[0.942]	[0.971]
Intercept	2.108***	2.116***	2.364***	1.506***
	[0.000]	[0.000]	[0.000]	[0.000]
Year Dummies	Y	Y	Y	Y
R^2	0.226	0.229	0.246	0.229
Adjusted R^2	0.219	0.221	0.239	0.221
F-Value	20.27***	20.34***	20.41***	20.55***
Degrees of Freedom	(19, 490)	(19, 490)	(19, 490)	(19, 490)
N	1878	1878	1878	1878

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

No (1+Patent Scope) Transformation: We ran two additional robustness checks based on the properties of the variables. First, as there were observation years for patent scope with no patents filed in specific years, the main models were run using log (1+patent scope) transformation to handle the patent scope values for those years. To investigate if this transformation has an influence on the results, we reran the fixed effects and system GMM models without this transformation. Table 15 shows the results for this robustness check for the fixed effects models. With this transformation removed, while hypothesis 1 is supported, hypothesis 2 is not supported except for the indicator using cumulative classes. Testing the three hypotheses using system GMM (shown in the appendix C) showed no significant effects. That is, there was no support for any of the three hypotheses and, unlike the main model, results were also not significant in the opposite direction for hypothesis 2.

Table 15: Fixed effects without log (1+patent scope) transformation

Dep Var: Tobin's q Patent Scope Measure	(1) ln(Y) Mean	(2) ln(Y) Max	(3) ln(Y) Cumulative	(4) ln(Y) Cumul. Mean
SW Patent Stock	-0.123	-0.141	-0.171	-0.182
	[0.126]	[0.091]	[0.180]	[0.079]
Technological Scope	0.210**	0.197***	0.386**	0.437**
	[0.001]	[0.000]	[0.003]	[0.001]
Application Diversity	-0.104	-0.109*	-0.360**	-0.314
	[0.168]	[0.030]	[0.003]	[0.121]
Litigiousness	0.0588	0.0666	0.0463	0.0593
	[0.147]	[0.109]	[0.247]	[0.143]
SW Pat Stock x Tech Scope	**0.0445***	**0.0443****	**0.0935****	**0.0961****
	[0.012]	**[0.004]**	**[0.009]**	**[0.008]**
SW Pat Stock x App Diversity	-0.0254	-0.0258	**-0.0689***	-0.0798
	[0.201]	[0.064]	**[0.047]**	[0.118]
SW Patent Stock x Litigiousness	0.0141	0.0158	0.00593	0.0124
	[0.115]	[0.091]	[0.498]	[0.155]
Employees	-0.259*	-0.259*	-0.234*	-0.237*
	[0.015]	[0.015]	[0.032]	[0.032]
R&D Intensity	-0.328***	-0.330***	-0.299**	-0.322***
	[0.001]	[0.001]	[0.001]	[0.001]
Advertising Intensity	-0.303*	-0.299*	-0.362**	-0.363**
	[0.027]	[0.028]	[0.002]	[0.002]
Market Share	-0.0897	-0.0943	-0.0959	-0.112
	[0.396]	[0.378]	[0.364]	[0.291]
Industry Capital Intensity	0.0385	0.0404	0.0403	0.0348
	[0.704]	[0.692]	[0.654]	[0.699]
Industry q	0.00569	0.00450	-0.0000750	0.00212
	[0.705]	[0.765]	[0.996]	[0.881]
Intercept	-0.459	-0.507	-0.492	-0.948
	[0.629]	[0.598]	[0.670]	[0.366]

Year Dummies	Y	Y	Y	Y
R^2	0.272	0.274	0.281	0.278
Adjusted R^2	0.265	0.267	0.275	0.272
F-Value	18.47^{***}	18.32^{***}	23.05^{***}	23.15^{***}
Degrees of Freedom	(19, 758)	(19, 758)	(19, 758)	(19, 758)
N	1961	1961	2145	2145

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Accounting for Outliers: Second, to rule out bias due to outlier values for the model variables, we winsorized the patent scope variables and reran the fixed effect and system GMM models. The results are shown in table 16. Models (1) and (2) were run with outliers of the pooled data set winsorized in model (1) and trimmed in model (2). Models (3) and (4) were based on winsorization and trimming within panels rather than for the pooled data set. In all the fixed effects models, hypotheses (1) and (2) are supported as in the main model. Using system GMM (reported in the appendix C), the results are consistent with the main model shown in table 10 with hypothesis 2 significant in the opposite direction. However, for the model with winsorized pooled data, hypothesis 1 is also significant in the opposite direction.

Table 16: Fixed effects with adjustment for outliers

Dep Var: Tobin's q Model	(1) ln(Y) Pool Winsorized	(2) ln(Y) Pool Winsorized	(3) ln(Y) Pool Trimmed	(4) ln(Y) Pool Trimmed	(5) ln(Y) Within Winsorized	(6) ln(Y) Within Winsorized	(7) ln(Y) Within Trimmed	(8) ln(Y) Within Trimmed
SW Patent Stock	0.101 [0.054]	0.115* [0.019]	0.102 [0.065]	0.127* [0.012]	0.101 [0.052]	0.113* [0.022]	0.101 [0.052]	0.113* [0.022]
Technological Scope	0.0282 [0.140]	0.105* [0.018]	0.0286 [0.176]	0.119* [0.025]	0.0270 [0.139]	0.0960* [0.019]	0.0270 [0.139]	0.0960* [0.019]
Application Diversity	-0.0728* [0.037]	-0.266*** [0.001]	-0.0715 [0.088]	-0.318** [0.001]	-0.0714* [0.027]	-0.246*** [0.001]	-0.0714* [0.027]	-0.246*** [0.001]
Litigiousness	0.0231 [0.299]	0.0828 [0.068]	0.0217 [0.339]	0.0806 [0.089]	0.0229 [0.304]	0.0818 [0.071]	0.0229 [0.304]	0.0818 [0.071]
SW Patent Stock x Technological Scope		**0.0247* [0.033]**		**0.0287* [0.035]**		**0.0220* [0.036]**		**0.0220* [0.036]**
SW Patent Stock x Application Diversity		**-0.0600** [0.006]**		**-0.0750** [0.005]**		**-0.0535** [0.008]**		**-0.0535** [0.008]**
SW Patent Stock x Litigiousness		0.0176 [0.063]		0.0174 [0.080]		0.0173 [0.068]		0.0173 [0.068]
Employees	-0.330*** [0.000]	-0.318*** [0.001]	-0.349*** [0.000]	-0.331*** [0.000]	-0.331*** [0.000]	-0.320*** [0.001]	-0.331*** [0.000]	-0.320*** [0.001]
R&D Intensity	-0.347** [0.004]	-0.351** [0.004]	-0.345** [0.004]	-0.358** [0.004]	-0.345** [0.004]	-0.348** [0.004]	-0.345** [0.004]	-0.348** [0.004]

Advertising Intensity	-0.326*	-0.324*	-0.487*	-0.473*	-0.331*	-0.334*	-0.331*	-0.334*
	[0.039]	[0.041]	[0.019]	[0.023]	[0.036]	[0.036]	[0.036]	[0.036]
Market Share	0.953	0.865	0.962	0.872	0.958	0.870	0.958	0.870
	[0.356]	[0.402]	[0.351]	[0.398]	[0.354]	[0.400]	[0.354]	[0.400]
Industry Capital Intensity	-0.0136	-0.00640	-0.0447	-0.0352	-0.0126	-0.00496	-0.0126	-0.00496
	[0.885]	[0.946]	[0.646]	[0.719]	[0.894]	[0.958]	[0.894]	[0.958]
Industry q	-0.00331	-0.00168	0.0116	0.0133	-0.00344	-0.00172	-0.00344	-0.00172
	[0.832]	[0.914]	[0.503]	[0.441]	[0.826]	[0.912]	[0.826]	[0.912]
Intercept	1.803***	1.857***	1.729***	1.821***	1.808***	1.859***	1.808***	1.859***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
R^2	0.228	0.234	0.226	0.233	0.228	0.235	0.228	0.235
Adjusted R^2	0.222	0.227	0.219	0.226	0.223	0.228	0.223	0.228
F-Value	24.23***	20.87***	21.14***	18.10***	24.22***	20.98***	24.22***	20.98***
Degrees of Freedom	(16, 758)	(19, 758)	(16, 701)	(19, 701)	(16, 758)	(19, 758)	(16, 758)	(19, 758)
N	2146	2146	1948	1948	2146	2146	2146	2146

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

5.3. Additional Analyses

We performed additional analyses, beyond testing our hypotheses, to investigate properties of our model constructs, and specifically of reputation for IP toughness and application diversity. Table 17 summarizes the additional analyses performed and the justification for those analyses. Table 24 provides a summary of the entire empirical analyses including the main analysis and robustness checks from the previous sections, additional analysis in this section, and the possible theoretical explanations of the results.

Table 17: Additional analyses and justification

Analysis	**Justification**	**Citations**
Three-Way Interactions	Potential attenuation or enhancement of the effect of patent scope on firm value due to the reputation of IP toughness of the patent owner	
Citations based application diversity measure based on patent generality	Possible differences between application diversity measured using *potential* applications based on patent classification versus *actual* applications in diverse classes based on citations received	(Flammer and Kacperczyk 2016)

Three-Way Interactions: First, we investigated the three-way interactions between software patent stock, technological scope, application diversity and litigiousness. As patent litigation could be used not only for reputation building but also as a strategy for appropriation of value (Lanjouw and Schankerman 2001), litigiousness of the patent owner could amplify or attenuate the effect of the dimensions of patent scope. For these fixed effects models, the results are as shown in Table 18. There are no significant three-way interaction effects using the max, cumulative and cumulative mean measures of patent scope. However, there is a negative and significant three-way interaction between software patent stock, litigiousness, and technological scope measured using mean claims (which is our original measure). This implies that a greater reputation for IP toughness attenuates the effect of technological scope of the firm's software patent portfolio on its value. It appears likely that firms using the reputation building strategy utilize their software patent stock for a leveraging strategy (Somaya 2012) where the additional scope of protection gained from increased knowledge disclosure is less important than as a defense against situations of patent thickets. This effect is likely significant only with the mean technological scope indicator as the max and cumulative indicators skewed towards high value patents only. For a leveraging strategy, the complete software patent stock, rather than individual high value patents would be more useful to defend against competitor actions and therefore mean value would be a better indicator for the technological scope of the overall patent stock rather than other measures which are based on high value patents.

Table 18: Fixed Effects with three-way interactions between patent stock, scope, and litigiousness

Dep Var: Tobin's q Patent Scope Measure	(1) ln(Y) Mean	(2) ln(Y) Max	(3) ln(Y) Cumulative	(4) ln(Y) Cumul. Mean
SW Patent Stock	0.0792*	0.0827*	0.0682	-0.0278
	[0.025]	[0.032]	[0.431]	[0.726]
Technological Scope	0.101**	0.0939**	0.209*	0.264**
	[0.006]	[0.006]	[0.015]	[0.004]
Application Diversity	-0.223***	-0.185***	-0.387***	-0.287*
	[0.001]	[0.000]	[0.000]	[0.033]
Litigiousness	0.163	0.167*	0.301*	-0.0288
	[0.056]	[0.033]	[0.038]	[0.927]
SW Pat Stock x Tech Scope	0.0281**	0.0260**	0.0672**	0.0609*
	[0.009]	[0.008]	[0.008]	[0.013]
SW Pat Stock x App Diversity	-0.0571**	-0.0456**	-0.0568*	-0.0702
	[0.006]	[0.005]	[0.028]	[0.050]
SW Pat Stock x Litigiousness	0.0296	0.0291	0.0599	-0.0336
	[0.088]	[0.077]	[0.093]	[0.573]
Litigiousness x Tech Scope	-0.0406	-0.0293	-0.0106	0.00781

	[0.052]	[0.190]	[0.836]	[0.912]
Litigiousness x App Diversity	0.0112	-0.00117	-0.0293	0.0420
	[0.801]	[0.973]	[0.575]	[0.769]
SW Pat Stock x Tech Scope x Litigiousness	**-0.0122***	-0.00961	-0.00725	0.00248
	[0.020]	[0.080]	[0.588]	[0.868]
SW Pat Stock x App Diversity x Litigiousness	0.0118	0.00863	0.000360	0.0262
	[0.273]	[0.313]	[0.978]	[0.380]
Employees	-0.225**	-0.222**	-0.131	-0.231***
	[0.001]	[0.001]	[0.072]	[0.001]
R&D Intensity	-0.211**	-0.206**	-0.176*	-0.207**
	[0.008]	[0.008]	[0.013]	[0.009]
Advertising Intensity	-0.291**	-0.294**	-0.304**	-0.304**
	[0.005]	[0.004]	[0.005]	[0.005]
Market Share	0.511	0.505	0.245	0.521
	[0.486]	[0.496]	[0.753]	[0.472]
Industry Capital Intensity	0.0192	0.0151	0.0330	0.0249
	[0.761]	[0.810]	[0.586]	[0.687]
Industry q	-0.00142	-0.0000439	0.000435	0.000404
	[0.901]	[0.997]	[0.970]	[0.972]
Intercept	2.038***	2.038***	2.346***	1.565***
	[0.000]	[0.000]	[0.000]	[0.000]
Year Dummies	Y	Y	Y	Y
R^2	0.229	0.232	0.252	0.230
Adjusted R^2	0.221	0.224	0.243	0.222
F-Value	17.72***	17.83***	17.33***	17.57***
Degrees of Freedom	(23, 758)	(23, 758)	(23, 758)	(23, 758)
N	2146	2146	2146	2146

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Classification- vs. Citation-Based Measures of Application Diversity – Patent Generality:

Second, we investigated an alternate measure for application diversity that can be built using the citation information available for software patents in the NBER patent data. The measure, labeled as generality of a patent (Hall et al. 2001), is constructed using the Herfindahl concentration index of patent classes from which a focal patent receives its citations. The measure is higher if a patent receives citations from a wider range of patent classes and, therefore, indicates *actual* diverse application of a patent compared to the measure based on patent classification, which denotes *potential* applicability. Therefore, with the patent generality measure, we could look at application diversity based on additional information of actual diversity of applications of a software patent. Like all citation-based measures, this measure does have the limitation of being right censored for which a statistical correction needs to be applied. Also, unlike the classification-based measure of application diversity, the citation-based measure is only available for patents that receive citations during the observation period. The correlation matrix for this variable in Table 19 shows that the measure does not correlate with other measures of patent scope and only correlates with software patent stock. The results of the fixed effects and system GMM models using the generality measure are depicted in tables 21 and 22. In both the fixed effects and system GMM models, hypotheses 1 and 3 are not supported. For hypothesis 2 with the generality measure, the results in both models are opposite to the hypothesized relationship and are significant. Therefore, the results using the generality measure are consistent after accounting for endogeneity, whereas for the patent classification-based measures the fixed effects results supported hypothesis 2, and the system GMM results were in the opposite direction.

Table 19: Correlation among model variables and generality measure

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1. Tobin's q	1.000											
2. SW Patent Stock	-0.023	1.000										
3. Technological Scope	0.040	-0.033	1.000									
4. Application Diversity	-0.011	-0.027	0.051	1.000								
5.Patent Generality	-0.051	0.077*	-0.010	-0.014	1.000							
5. Litigiousness	-0.022	0.040	-0.044	-0.038	-0.044	1.000						
6. Employees	-0.130***	-0.076*	-0.111**	-0.031	0.092**	0.188***	1.000					
7. R&D Intensity	0.043	-0.012	0.093**	0.022	-0.001	-0.054	-0.098**	1.000				
8. Advt. Intensity	-0.010	-0.004	0.096**	0.017	0.007	-0.015	-0.024	0.597***	1.000			
9. Mkt. Share	-0.113**	-0.074*	-0.084*	-0.015	0.071*	0.176***	0.483***	-0.099**	-0.023	1.000		
10. Ind. Cap. Intensity	0.003	-0.033	-0.078*	-0.101**	0.015	-0.047	-0.036	0.063	0.070*	-0.082*	1.000	
11. Ind. Tobin's q	0.016	0.018	0.056	0.093**	-0.070*	-0.018	0.067	-0.023	-0.023	-0.014	-0.150***	1.000

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 20: Correlation among model variables and all patent scope measures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1. Tobin's q	1.000											
2. SW Patent Stock	0.007	1.000										
3. Mean Claims	0.037	-0.029	1.000									
4. Max Claims	0.067	0.002	0.517***	1.000								
5. Cumul Claims	-0.001	-0.001	-0.032	0.337***	1.000							
6. Cumul Mean Claims	0.051	-0.022	0.909***	0.465***	-0.022	1.000						
7. Mean class	-0.013	-0.026	0.060	-0.024	-0.018	0.045	1.000					
8. Max Class	-0.020	-0.018	-0.059	0.428***	0.377***	-0.065	0.462***	1.000				
9. Cumul Class	-0.009	-0.003	-0.046	0.309***	0.994***	-0.039	-0.011	0.372***	1.000			
10. Cumul Mean Class	-0.006	-0.033	0.056	-0.035	-0.022	0.051	0.918***	0.404***	-0.013	1.000		
11. Patent Generality	-0.047	0.074*	-0.009	-0.072*	-0.079*	0.002	-0.009	-0.058	-0.077*	0.001	1.000	
12. Litigiousness	0.033	0.063	-0.033	0.138***	0.366***	-0.026	-0.038	0.180***	0.376***	-0.041	-0.051	1.000

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 21: Results of fixed effects models with patent generality measure

Variable Dep Var: Tobin's q	(1) ln(Y)	(2) ln(Y)	(3) ln(Y)	(4) ln(Y)	(5) ln(Y)	(6) ln(Y)
SW Patent Stock	0.0688*	0.0729	0.0795	0.0805	0.210	0.206
	[0.034]	[0.052]	[0.140]	[0.135]	[0.096]	[0.117]
Technological Scope		-0.00356	-0.0229	-0.0198	-0.169	-0.167
		[0.682]	[0.644]	[0.688]	[0.188]	[0.206]
Application Diversity			0.0289	0.0265	0.337*	0.348*
			[0.647]	[0.674]	[0.038]	[0.040]
Litigiousness				0.0240	0.0242	0.0119
				[0.339]	[0.322]	[0.765]
SW Patent Stock x					-0.0533	-0.0525
Technological Scope					[0.124]	[0.143]
SW Patent Stock x					0.106*	0.111*
Application Diversity					[0.014]	[0.017]
SW Patent Stock x						-0.00518
Litigiousness						[0.615]
Employees	-0.240***	-0.238***	-0.162	-0.154	-0.167	-0.169
	[0.001]	[0.001]	[0.120]	[0.141]	[0.107]	[0.105]
R&D Intensity	-0.210**	-0.209**	-0.0104	-0.00880	0.0108	0.0121
	[0.008]	[0.008]	[0.936]	[0.947]	[0.931]	[0.922]
Advertising Intensity	-0.276**	-0.277**	-0.477***	-0.485***	-0.483***	-0.484***
	[0.008]	[0.007]	[0.000]	[0.000]	[0.000]	[0.000]

Market Share	0.529	0.528	1.009	1.043	1.146	1.161
	[0.463]	[0.465]	[0.146]	[0.135]	[0.117]	[0.111]
Industry Capital Intensity	0.0210	0.0212	0.0970	0.104	0.117	0.118
	[0.737]	[0.735]	[0.371]	[0.341]	[0.278]	[0.276]
Industry q	-0.00192	-0.00200	0.00245	0.00254	-0.000710	0.000125
	[0.868]	[0.862]	[0.908]	[0.905]	[0.974]	[0.995]
Intercept	2.009***	2.030***	2.115***	2.106***	2.522***	2.513***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Year Dummies	Y	Y	Y	Y	Y	Y
R^2	0.216	0.216	0.234	0.235	0.248	0.249
Adjusted R^2	0.211	0.210	0.221	0.221	0.232	0.232
F-Value	28.77***	26.81***	.	.	.	.
Degrees of Freedom	(13, 758)	(14, 758)	(13, 428)	(14, 428)	(16, 428)	(17, 428)
N	2146	2146	826	826	826	826

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Table 22: Results of System GMM model runs with patent generality measure

Variable Dep Var: Tobin's q	(1) ln(Y)	(2) ln(Y)	(3) ln(Y)	(4) ln(Y)	(5) ln(Y)
SW Patent Stock	0.106***	0.0922	0.0575	0.248	0.405
	[0.000]	[0.240]	[0.889]	[0.574]	[0.399]
Technological Scope		-0.207	-0.00462	-0.403	-0.526
		[0.251]	[0.992]	[0.450]	[0.330]
Application Diversity		-0.102	-0.277	1.144	1.131
		[0.581]	[0.281]	[0.132]	[0.118]
Litigiousness		-0.0383	0.0321	-0.0575	-0.121
		[0.535]	[0.744]	[0.357]	[0.278]
SW Patent Stock x			-0.00761	-0.0874	-0.130
Technological Scope			[0.954]	[0.545]	[0.373]
SW Patent Stock x				0.391	**0.388***
Application Diversity				[0.054]	**[0.045]**
SW Patent Stock x					-0.0260
Litigiousness					[0.447]
Employees	-0.0513	-0.0748	-0.140	-0.0693	-0.0690
	[0.139]	[0.403]	[0.150]	[0.375]	[0.315]
R&D Intensity	-0.188	-0.487**	-0.525**	-0.482***	-0.483***
	[0.134]	[0.003]	[0.004]	[0.001]	[0.000]
Advertising Intensity	3.487	2.630	-1.511	1.267	1.226
	[0.092]	[0.426]	[0.410]	[0.681]	[0.640]
Market Share	0.656	0.0424	1.336	0.535	0.560
	[0.261]	[0.976]	[0.301]	[0.683]	[0.606]
Industry Capital Intensity	-0.112	-0.233	0.0567	-0.127	-0.128
	[0.104]	[0.271]	[0.683]	[0.588]	[0.527]
Industry q	-0.00244	-0.0372	-0.00359	-0.0536	-0.0554
	[0.860]	[0.329]	[0.920]	[0.152]	[0.125]
Intercept	1.228***	1.618	1.879	2.149	2.599
	[0.000]	[0.053]	[0.224]	[0.168]	[0.095]
Year Dummies	Y	Y	Y	Y	Y
Wald Statistics	5265.1	2212.0	2514.6	2204.8	2225.3

Number of Instruments	119	59	59	59	59
Hansen Test of Over-ID	0.400	0.711	0.164	0.917	0.927
Arellano-Bond AR (2) test	0.375	0.892	0.985	0.948	0.828
N	2146	826	826	826	826

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

As the data set used for investigating the patent generality-based measure of application diversity was restricted due to a much smaller subset compared to the main model due to no citation information, we reran the main fixed effects models with this restricted sample to check whether the differences in results were due to systematic differences in this subsample. The results for the fixed effects models are shown in Table 23 and system GMM in appendix C. In both models, all three hypotheses are not supported indicating that the results may indeed be due to systematic differences in the subsample.

Table 23: Fixed effects for subsample without missing generality measure

Dep Var: Tobin's q Patent Scope Measure	(1) ln(Y) Mean	(2) ln(Y) Max	(3) ln(Y) Cumulative	(4) ln(Y) Cumul. Mean
SW Patent Stock	0.358^{**}	0.0611	0.348^{*}	0.299
	[0.004]	[0.492]	[0.016]	[0.051]
Technological Scope	-0.168	0.0323	-0.0769	-0.146
	[0.196]	[0.689]	[0.623]	[0.413]
Application Diversity	-0.213	-0.0637	-0.274	-0.210
	[0.080]	[0.443]	[0.167]	[0.376]
Litigiousness	0.0199	0.0259	0.0131	0.0252
	[0.644]	[0.540]	[0.749]	[0.554]
SW Pat Stock x Tech Scope	-0.0509	0.0137	0.00380	-0.0476
	[0.147]	[0.544]	[0.923]	[0.331]
SW Pat Stock x App Diversity	-0.0608	-0.00622	-0.00226	-0.0466
	[0.075]	[0.792]	[0.959]	[0.399]
SW Pat Stock x Litigiousness	-0.00471	0.0000102	0.00157	-0.000342
	[0.684]	[0.999]	[0.900]	[0.977]

Employees	-0.135	-0.140	-0.0104	-0.143
	[0.190]	[0.174]	[0.919]	[0.173]
R&D Intensity	0.0251	-0.00224	0.0388	0.00685
	[0.843]	[0.986]	[0.700]	[0.958]
Advertising Intensity	-0.499***	-0.497***	-0.538***	-0.506***
	[0.000]	[0.000]	[0.000]	[0.000]
Market Share	0.978	1.001	0.828	0.966
	[0.165]	[0.136]	[0.200]	[0.161]
Industry Capital Intensity	0.116	0.0990	0.109	0.107
	[0.282]	[0.364]	[0.298]	[0.324]
Industry q	0.000150	0.00352	0.00310	0.000450
	[0.995]	[0.870]	[0.886]	[0.984]
Intercept	2.974***	2.076***	3.859***	2.809***
	[0.000]	[0.000]	[0.000]	[0.000]
Year Dummies	Y	Y	Y	Y
R^2	0.245	0.238	0.268	0.239
Adjusted R^2	0.228	0.221	0.251	0.222
N	826	826	826	826

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Table 24: Summary of results including robustness checks and additional analyses.

	Hypothesis 1		**Hypothesis 2**		**Hypothesis 3**		**Explanation**
	Fixed Eff.	Sys GMM	Fixed Eff.	Sys GMM	Fixed Eff.	Sys GMM	
Main model							
	Supported	Not Supp	Supported	Opposite	Not Supp	Not Supp	There is indication of mixed results using fixed effects models for app diversity in general patents literature. Results with correction for endogeneity using system GMM imply that control of initial innovations of a technology chain are more valuable to firms.
Alternate measures of patent scope							
Max	Supported	Not Supp	Supported	Not Supp	Not Supp	Not Supp	Maximum values of patent scope measures are more sensitive to the skew in patent values where there are many patents with low value and few ones with a high value.
Cumulative	Supported	Not Supp	Supported	Not Supp	Not Supp	Not Supp	Cumulative values of patent scope measures are more sensitive to the skew in patent values where there are many patents with low value and few ones with a high value.
Cumulative Mean	Supported	Not Supp	Not Supp	Not Supp	Not Supp	Not Supp	Cumulative mean values of patent scope measures incorporate sensitivity to both the skew in patent values as well as the overall scope of the SW patent portfolio that a firm holds.

Sample Restricted to IT industry							
	Supported	Not Supp	Supported	Opposite	Not Supp	Not Supp	Similar results for the full sample and IT industry restricted sample indicates they are robust to industry heterogeneity and software patents are similar from a knowledge-based view across different industries.
Patent Scope with no log (1+var) transformation							
	Supported	Not Supp	Not Supp	Not Supp	Not Supp	Not Supp	Removing log(1+var) transformation and therefore dropping observation years without patent filings by a firm reduces the within firm information available to estimate the hypothesized relationships
Outlier adjustments							
Winsorization	Supported	Opposite	Supported	Opposite	Not Supp	Not Supp	
Trimming	Supported	Not Supp	Supported	Opposite	Not Supp	Not Supp	Dropping outlier observations do not influence the results obtained using the full sample.
Sample restricted to multi-year panels							
	Supported	Not Supp	Supported	Opposite	Not Supp	Not Supp	
Patent Generality Indicator for App Diversity							
	Not Supp	Not supp	Opposite	Opposite	Not Supp	Not Supp	Using a measure of actual instead of potential app diversity, reinforces the result of system GMM estimator for the main model that software patents for general advances in technology are more valuable.

Three-Way Interactions							
	Fixed Eff	Sys GMM					
SW Pat Stock X Tech Scope X Litigiousness	Negative	No Support					Higher reputation for IP toughness indicates usage of leveraging strategy where the entire SW patent stock is more important than individual high value patents.
SW Pat Stock X App Diversity X Litigiousness	No Support	No Support					

5.4. Discussion

Software patents are one of the several value appropriation mechanisms available to firms. However, firms control the disclosure of knowledge and enforcement of the patent rights granted to them and need to consider how these levers can be used to appropriate value for their innovation. The technological scope and application diversity of a firm's software patent stock are knowledge disclosure related factors which firms can manipulate. While the results of the fixed effects models indicate that there is a positive moderating effect of technological scope and a negative moderating effect of application diversity, these results do not hold with endogeneity correction using system GMM. The results with respect to litigiousness are consistent across the two models. Therefore, in this section, we use the results of the system GMM estimator to discuss the implications of our findings with respect to the relationship between patent scope and firm value.

For technological scope, the results of the fixed effects estimator for the main model and the robustness checks show support for hypothesis 1; that is, technological scope moderates the relationship between software patent stock and firm value positively. While the fixed effects models do account for time invariant unobserved heterogeneity, there remain other endogeneity concerns for the model variables such as relationships in the opposite direction. Inconsistent with the fixed-effects model, results of the system GMM estimator with internal instruments, show no support for hypothesis 1. This may suggest that there are potential time variant unobserved factors that may have been the reason for the support to the hypothesis with fixed effects. While we draw from the general patents literature to theorize the relationship for hypothesis 1, for the time frame of our observations from 2000 to 2006, when software patents were in their early stages as an appropriation mechanism. There is evidence from this time frame to suggest that there wasn't enough clarity on precisely determining the scope of protection that software patents offered (Bessen and Hunt 2004) due to the lack of extensive prior art for software patents.

Therefore, higher technological scope may not have been very effective means of increased appropriation of patent value during that period. Therefore, it is possible that our data does not support the relationships theorized from general patents literature, which draw upon more mature understanding of mechanisms of patent protection. Additionally, the theoretical argument for the positive moderation effect for technological scope is also based on the ability to generate follow-on innovation. The lack of such an effect implies that despite obtaining patents for software innovations, firms may not have the internal knowledge management mechanisms to be able to generate follow-on innovations based on the patented innovation.

For application diversity, the fixed effects results supported hypothesis 2 of a negative moderating effect on the relationship between software patent stock and firm value. Accounting for endogeneity again, using the system GMM estimator with internal instruments, we instead find the opposite result that application diversity has a positive moderating effect. A positive moderation effect implies that software innovations with wider applicability might still be valuable, even if the firm generating this innovation itself does not develop all the potential applications, but the firm's control of the initial patents of a technology chain and enables monetization of its innovation in other ways. This may also be due to gaining a first mover advantage that is important in cases such as the IT industry (Graham and Mowery 2003) or the difficulty in being able to utilized spilled over knowledge of software innovations by rivals would require significant amount of resources in commercialization.

In the case of patent enforcement, we find no support for using patent litigation as a reputation building mechanism to deter spillover of knowledge from software patents to rivals. There may be several reasons for this result. It has been shown that firms have engaged in creation of patent thickets for software patents which reduces the potential of using litigation as a strategy (Somaya 2012). Also, the nature of software as a technology, even when disclosed through a patent, requires an firm building on it to devote significant resources in developing a potential product or service to bring it to market (Graham and Mowery 2003). This would ensure that the patent-owning firm retains a first mover advantage over their rivals to benefit from their software innovation and knowledge spillover may not have any significant downsides in relation to the advantages to be gained from patent protection. In such situations, reputation building strategy would be less effective in providing a competitive advantage. Finally, patent litigation remains a rare and costly exercise (Lanjouw and Schankerman 2001) and if knowledge spillover from software patents does not have any significant negative consequences, firms may not prefer to use that method of enforcement at all, and may instead use other enforcement mechanisms available to them.

CHAPTER 6

CONTRIBUTION AND LIMITATIONS

6.1. Theoretical Contributions

There is an ongoing debate on the value of software patents on their utility for both social welfare (Bessen and Hunt 2004; Graham and Mowery 2006) and to innovators seeking to protect and monetize software based intellectual property (Hall and MacGarvie 2010). Recent scholarship on software patents utility to firms has addressed the broad question of the influence of software patents portfolio on firm value (Hall and MacGarvie 2010), the effect of firm innovation orientation and market environment (Chung et al. 2019) and knowledge spillovers (Noel and Schankerman 2013) on this relationship. However, the main criticism from practitioners towards software patents are that they are fuzzy and ambiguous (Chung et al. 2019). As software patents are abstract representations of intangible knowledge assets such uncertainty over their attributes and boundaries creates difficulties in ensuring intellectual property protection and the development of markets to enable sale and licensing of such knowledge and the consequent appropriation of value (Graham and Mowery 2006; Teece 1998). Additionally, evidence suggesting that software patents did not create incentive for innovation and is only used for strategic purposes (Bessen and Hunt 2004) implies that the strategic perspective taken so far on firm level investigations of the value of software patents, do not fully address the knowledge-based aspects of software patenting. Therefore, this study utilizes the knowledge-based view of the firm to investigate the value of software patents at the firm level. This approach also moves beyond the patent level investigations situated in the knowledge-based view of the firm that has been used in general patents literature (Novelli 2015). Therefore, this study contributes in two ways to the literature on software patents.

First, the study focuses on the knowledge disclosure required for software patents and its influence on the relationship between software patent portfolios and firm value. Knowledge disclosure is an important characteristic of patents as an appropriability mechanism that differentiates it from other mechanisms for value appropriation from innovation, such as copyrights, secrecy, or lead time to market (James et al. 2013). Given the criticism of software patents as being fuzzy and ambiguous implies that the knowledge disclosure for software patents may or may not be effective in enabling the patent owner to appropriate value for that knowledge as explained by theories connecting patents with firm value. Therefore, for software innovators, the question of what characteristics of knowledge disclosure required for software patents they can control, so that they can effectively appropriate the returns from their software innovation needs to be addressed.

In this study, we draw upon the theoretical development of patent scope as consisting of two distinct dimensions (Novelli 2015) that together define the full extent of protection that patents provide to software innovation. The two dimensions, technological scope and application diversity, delineate the extent of the software innovation documented by the patent owner and the application contexts that they identify as to where the software innovation can be applied. Based on theoretical arguments from general patents literature and the nature of software patents, we theorized a positive moderation effect of technological scope which was supported by fixed effects empirical models. However, accounting for the potential endogeneity of technological scope using system GMM, we found that there was no moderation effect of this dimension. Therefore, within the time frame of our study which covers the early use of software patents, increased documentation of software innovation in patent applications does not appear to be helpful in appropriating the value of software patents.

For the second dimension of patent scope, application diversity, our findings suggest that identifying more application contexts for the software innovation is beneficial for value appropriation. For this dimension, the results from general patents literature indicated mixed results in both positive and negative directions. The reasons for expecting negative moderation effect were based on the idea that software innovations with wide applicability would bring increased competition, spillover of knowledge and potential challenges to validity of the patents. However, as our empirical findings showed a positive moderation effect of application diversity, the unique characteristics of software patents and their usage comes into focus. Given the significant first mover advantages with software innovations (Graham and Mowery 2003), protecting such innovations which are indicated by high application diversity is beneficial as it enables the control of the innovation chain. Additionally, it may not be very easy for rivals to build upon that knowledge even though it is disclosed in the patent as developing market solutions based on software innovations is a resource and time intensive process. Therefore, it is much more likely for the patent owner to retain their first mover advantage.

Second, the study looks at another aspect specific to patents as an appropriation mechanism for innovations. This aspect is related to the fact that patents are only rights to exclude other parties from unauthorized use of the knowledge described in the patent filing (Somaya 2012). Therefore, for software patents to be effective for innovators to appropriate value, enforcement of the rights in case of infringement is an important factor. Going back to the criticism that software patents are fuzzy and ambiguous, may again have consequences for effective enforcement of rights for software patents and therefore influence their value. Therefore, the nature of software patents as disclosing abstract knowledge assets is important in studying the relationship between software patents and firm value based on whether those assets can be effectively protected using patents as the appropriation mechanism. In this study, we specifically looked at whether software patent litigation could be used for a reputation building strategy to deter competitors from using spilled over knowledge from patents. The lack of support for the effectiveness of reputation building with software patents, indicates that the traditional advantages of early market access remain more important for value appropriation from software innovation and methods of patent enforcement other than litigation might be more useful.

6.2. Managerial Contributions

For managerial practice, this study contributes by clarifying some important aspects for the use of patents to protect software based intellectual property. In comparison to other appropriability mechanisms such as copyright, secrecy or time to market, patents incur rights creation and enforcement costs (James et al. 2013) and need a coherent strategy for the value appropriation to happen for the innovating firm (Somaya 2012). Therefore, using patents for software innovation requires practice to consider the aspects of patent rights creation and enforcement strategy levers that they control, so that the value appropriation goals for the innovation are met. Patent rights creation requires specification of patent scope which defines the boundary of protection provided. By distinguishing the effect of two distinct dimensions of patent scope, along which innovators position their application, on the realization of value, the study provides insight into the patent creation strategy that would be beneficial for software-based innovations. As our results indicate that the dimension of application diversity is important for the value of software patents, and technological scope not so, firms intending to patent software innovations would have to closely analyze their innovation on its applicability in a variety of contexts. A software innovation with wider applicability would represent a potential seminal technological breakthrough worth protecting by patenting.

For patent enforcement, the cost and time of litigation is an important factor and therefore the strategy for appropriating value of innovations using litigation needs to be carefully considered by practice (Lanjouw and Schankerman 2001). Patent related litigation has an important role in building a reputation for aggressive defense of patent rights infringement (Agarwal et al. 2009) as well as an value appropriation strategy by itself (Lanjouw and Schankerman 2001). As we looked at the role of reputation building through patent related litigation for software patents and found that this strategy is not useful for value appropriation enforcement strategies other than litigation might be more useful.

6.3. Limitations, Future Work and Conclusion

The limitations of this study are closely related to the nature of patents as an appropriability mechanism and their correspondent use by firms in pursuit of intellectual property protection. Patent law and protection varies with legal jurisdiction, and therefore there are differences in how patents are awarded and upheld between jurisdictions with otherwise similar business environments such as the United States, Europe and Japan (Graham and Mowery 2003). This is especially important for software patents as there are important differences in the validity of patents on business methods implemented in software, the leniency towards examination of patent scope and the legal processes for challenging their awards, between jurisdictions such as the United States and Europe. As business method patents have been an important component of the growth of software patenting (Allison and Tiller 2003), the close relation between legal jurisdiction and software patents implies that studies conducted within one jurisdiction cannot be generalized to other jurisdictions. As this study is situated in the United States legal jurisdiction with firms domiciled within the country, the results will not generalize for other jurisdictions with different appropriability regimes (Teece 1998). However, these differences also present an opportunity to study the differential role of patent scope and enforcement in other important jurisdictions such as Europe or Japan.

Another important limitation of the study derives from the sample of firms selected. As the study investigates the relationship of patent scope and enforcement to firm performance, the usage of publicly listed firms in the U.S. due to the availability of firm performance data implies that two important categories of firms are not considered. The first group is privately held firms, which also include the important category of start-up firms. As technology start-ups are an important source of innovation in technology, the potential availability of software patents as an appropriation mechanism would be a key consideration for realization of value for their innovation (Cockburn and MacGarvie 2011). Patents have been shown to be important for venture capital funding in other innovative industries such as biotechnology (Lerner 1994) and therefore it could be expected that studying the importance of patent scope and enforcement for software patents in the start-up ecosystem would yield additional knowledge on the role of these factors for appropriation of innovation value. Similarly, the sample of the study also does not consider foreign firms patenting in the U.S. jurisdiction and the corresponding effects for appropriability in an international business context. As the U.S.is a large technology market, with a developed intellectual property protection system including for software innovations, it is likely that firms located outside the U.S. might still consider patenting their software innovations in U.S. However, the realization of value for U.S. patent awards for such firms would have to additionally consider the challenges of negotiating international business environments and the differential utility of the patents in the U.S. versus their home markets. Therefore, looking at a different set of firms as compared to this study holds an opportunity for additional insights into software patents.

Further, an important limitation pertains to the timeframe of the data of the study. The NBER patent data set which is used to construct the dependent and two main independent variables contains patent data till the year 2006. Our choice to use the NBER patent data despite this limitation was guided by two important considerations. First, the NBER data provides a match from patent assignees in USPTO patent data to corporate entities from Compustat by year (Hall et al. 2001). This match enables linking of each patent to specific corporate ownership, accounting for corporate ownership structure or reassignments due to events such as mergers and acquisitions. As we study the implications of patent knowledge disclosure and enforcement on firm value, accurately assigning patents to the right owner is important. Patent ownership may be assigned to subsidiaries to maintain secrecy about innovation activities, for tax advantages or due to acquisitions (Webb et al. 2018). Not accounting for the ownership structure and changes to it would not give a complete picture of the relationship between patent measures and firm value.

Second, the NBER data set provides unambiguous linkage between patents and Compustat identifiers. This linkage enables accurate construction of both firm level and industry level variables required to fully test our empirical model. Although this data is not recent, we believe that the theoretical insights derived from this study is still relevant even with this limitation. This study is based upon the knowledge-based view of the firm and strategic deterrence arguments. It would be unlikely that a firm's value derived through knowledge-based advantages will change with time as a firm with superior store and application of internal knowledge can be expected to perform better as the knowledge-based view of the firm informs us. Similarly, the deterrence value of a strategic action based upon costly signaling mechanisms is unlikely to change over time, due to the rarity with which such actions are used. Moreover, recent research that is situated in the knowledge-based view, both in general patents literature (Ahuja et al. 2013), as well as software patents (Chung et al. 2019), use the NBER patent data and hence use similar timeframes. Nevertheless, future research could construct more recent patent ownership mapping data to further build on our findings.

Finally, though the study limits to the U.S. jurisdiction for software patents, the nature of such patents and the clarification of their boundaries of protection have evolved over the years. From *State Street vs Signature Financial* to more recent judgments such as *Alice Corp vs CLS Bank* and *Enfish vs Microsoft*, various aspects of software patents have been defined or clarified. A consequence of such evolution is the difficulty in conceptually and empirically defining software patents (Graham and Mowery 2006). Event studies approach has been utilized in some cases to assess the effect of such events for software patents (Hall and MacGarvie 2010). Such an approach might be useful to gain additional insight on the role of patent scope and enforcement arising out of important court judgements related to software patents and therefore a future opportunity.

To conclude, software patents are an important appropriation mechanism for software-based innovation. Though they have been criticized for not promoting innovation or not having an impact on firms' profits, they continue to be utilized as an important alternative to other intellectual property protection mechanisms. Recent scholarship has clarified the value of software patent stocks to its owners, their use for strategic purposes and the effect of innovation orientation and market environment on their value. However, there is less clarity on the key attributes of patents that define and differentiate them from other appropriability mechanisms. This study by investigating the effect of patent scope and enforcement on their value, addresses these attributes that are highly relevant for firms' use of patents for intellectual property protection of their software innovations.

Additionally, this study also opens the opportunity to look at other important aspects of the usage of software patents. A lot of software innovation is generated by start-up firms and they would be an important context for investigating the value of patenting to protect their innovations. There is also variation in treatment of software patents between legal jurisdictions providing the opportunity for additional theoretical contribution. Finally, as the policy changes and firm strategy for innovation are interlinked, such changes in software patenting provides a useful way to study the impact of software patenting over time and opportunity for additional nuance to our understanding of gaining competitive advantage using software innovation.

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APPENDICES

A. SOFTWARE PATENT CLAIMS EXAMPLE

What is claimed is:

1. A method for tracking, from a central location, status of an order for a food item prepared at one of a plurality of decentralized food-preparation locations in a chain of food-service establishments for delivery to a customer at a customer location, the method comprising:

accepting, from the customer, an order for a food item at either a central computer system for the central location or an order processing computer system at any of the decentralized food-preparation locations, without requiring a login by the customer;

assigning the order for the food item to a first decentralized food-preparation location of the plurality of decentralized food-preparation locations in the chain of food-service establishments, the first decentralized food-preparation location being selected based on a respective customer attribute;

storing, in a respective order processing computer system for the first decentralized food-preparation location, status data for the order for the food item, and an identifier associated with the customer for the order and obtained during the accepting of the order, wherein the status data comprises data indicating at least one of real-time status of preparation at the first decentralized food-preparation location or real-time location of the food item prior to delivery;

communicating periodically between the central computer system at the central location and the order processing computer system for the first decentralized food-preparation location to send order status data to the central location;

accepting, at the central computer system at the central location, a status inquiry from the customer regarding the order without requiring a login by the customer and without requiring specification by the customer of the first decentralized food-preparation location, the status inquiry including the identifier associated with customer; and

providing, by the central computer system at the central location, retrieved order status data to the customer, in response to the inquiry and based on the identifier associated with the customer, regardless of whether the order was accepted at the central location or at one of the plurality of decentralized food-preparation locations in the chain of food-service establishments.

Figure 2: Example of software patent claims describing system design

B. LITERATURE SUMMARY

General Patents			
Citation	**Key Findings**	**DV**	**IVs**
(James et al. 2013)	Firms face a trade-off between publicly disclosing technical details of an innovation through patents and maintaining trade secrets. This is due to paradox of disclosure, i.e., disclosure of technical details signals value of innovation, but receivers of the knowledge may appropriate its value without compensation to the innovator	Theoretical Analysis	
(Ahuja et al. 2013)	There are two forms of appropriability, primary appropriability of using innovation as problem-solving mechanisms and generative appropriability of using innovations to generate follow-on innovations. Patenting an innovation generally increases primary appropriability. It may decrease generative appropriability due to the disclosure requirement of patent law	Theoretical Analysis	
(Somaya 2012)	Using patents in a proprietary, defensive, or leveraging strategy by firms influences appropriability outcomes and subsequently affects firm value	Theoretical Analysis	
(Encaoua et al. 2006)	Patent length and scope are policy instruments that can be used by regulators to provide incentive for development of innovations with high social value	Theoretical Analysis	
(Hall et al. 2005)	Forward citations of a patent are a measure of importance of the firm’s patents indicated by the stock market valuation of a firm’s intangible stock of knowledge	Firm Value	Ratio of R&D to Assets, Patents to R&D and Citations to Patents
(Anton and Yao 2004)	When intellectual property rights provide limited protection, the value of disclosure of enabling knowledge of an innovation (e.g., to obtain a patent) is offset by increased threat of imitation	Analytical Analysis	

Patent Scope			
Citation	**Key Findings**	**DV**	**IVs**
(Novelli 2015)	Two distinct dimensions of patent scope (1) the number of variations to the core inventive idea reflected in the number of its claims and (2) the positioning of such variations in the inventive space, reflected in the number of technological classes When the scope of a patents spans across a higher number of technological classes, follow-on innovation by the inventing firm with the knowledge underlying its own patent is lower	Forward self-citations	Number of claims, Number of classes
(van Zeebroeck and van Pottelsberghe de la Potterie 2011)	The number of claims in a patent has a stable influence on indicators of patent value independent of country, industry, or sample size	Firm Value	Number of Claims
(Lanjouw and Schankerman 2001)	Probability of patent litigation rises with the increase in value of the patent right and any indirect benefits to the litigation (such as to strengthen reputation and bargaining power)	Probability of litigation	Patent citations, Number of claims, Number of classes,
(Lerner 1994)	Broader patent scope is associated with higher forward citations, probability of litigation and market value for start-up firms	Forward citations, Probability of litigation, Firm value	Number of classes
(Merges and Nelson 1990)	Broader patent scope diminishes incentive for building improvements on the invention by other firms	Theoretical Analysis	

Patent Enforcement			
Citation	**Key Findings**	**DV**	**IVs**
(Weatherall and Webster 2014)	28% to 40% patented innovations were perceived to have been copied during their patent terms. However, less than 1%-2% patents incur litigation	Theoretical Analysis	

(Agarwal et al. 2009)	Corporate reputation for toughness in patent enforcement significantly reduces spillovers otherwise anticipated from departures of employee inventors	Total citations to firm's patents (Firm Level)	Litigiousness, Employee Mobility

Software Patents			
Citation	**Key Findings**	**DV**	**IVs**
(Chung et al. 2019)	Software patent stock with higher levels of explorative orientation associated with a higher firm value in environments with low dynamism and high competitiveness. Software patent stock with higher levels of exploitative orientation associated with a higher firm value in environments with high dynamism and low competitiveness	Firm Value	Software Patent Stock, Innovation Orientation, Environmental Uncertainty
(Branstetter et al. 2019)	Manufacturing industry firms with higher software intensity in innovation activity, generate more patents per R&D and their R&D investment is highly valued in equity markets	Number of Patents, Firm value	R&D expenditure, Software Intensity
(Noel and Schankerman 2013)	Strategic patenting and spillovers affect market value of software firms	Firm Value	Patent Portfolio Size, Patent Rights Fragmentation, Knowledge Spillovers
(Huang et al. 2013)	Independent Software Vendors with greater stock of formal IPR (Patents and Copyrights) and stronger downstream capabilities (trademarks and consulting services) are more likely to enter complementary markets to a proprietary platform as these mechanisms are effective in protecting them from expropriation of value by the platform owner	ISV partnership with platform owner	Software Patent Stock, Number of copyrights, Number of trademarks, Software consulting services

(Cockburn and MacGarvie 2011)	Increase in number of patents relevant to a market reduces the rate of entry of new entrants into the market for software industry. This negative impact is mitigated for entrants who have their own patents relevant to the market.	Market entry decision	Number of patents in the market, Firm's granted patents
(Hall and MacGarvie 2010)	Stock market evaluated software patents as a negative development prior to easing patentability of software. Subsequently, firms with software patent stocks had higher market values than those without	Firm Value	Software Patent Stock, Industry
(Allison and Tiller 2003)	Internet business method patents are similar to general patents on measures of patent quality and value	Statistical Comparison of IVs	Prior art citations, Number of claims, Number of inventors, Pendency time to approval

Business Value of IT			
Citation	**Key Findings**	**DV**	**IVs**
(Bardhan et al. 2013)	Investments in IT interact with a firm's R&D investment, enhancing firm value	Firm Value	R&D Expenditure, IT Expenditure
(Bharadwaj et al. 1999)	IT investments influence firm value as measured by Tobin's q, after controlling for industry and firm specific characteristics	Firm Value	Ratio of IT expenditure to total sales

C. ADDITIONAL ROBUSTNESS CHECK RESULTS

Table 25: System GMM with alternate measures of patent scope

Dep Var: Tobin's q Patent Scope Measure	(1) ln(Y) Mean	(2) ln(Y) Max	(3) ln(Y) Cumulative	(4) ln(Y) Cumul. Mean
SW Patent Stock	0.0396	0.000438	0.231	-0.284
	[0.495]	[0.995]	[0.376]	[0.650]
Technological Scope	-0.181	-0.0642	-0.303	0.190
	[0.180]	[0.590]	[0.482]	[0.758]
Application Diversity	0.535**	0.321	0.284	0.847
	[0.009]	[0.072]	[0.489]	[0.072]
Litigiousness	-0.00305	0.0183	0.00125	-0.0193
	[0.977]	[0.808]	[0.989]	[0.821]
SW Pat Stock x Tech Scope	-0.0546	-0.0197	-0.0610	0.0228
	[0.092]	[0.509]	[0.603]	[0.898]
SW Pat Stock x App Diversity	0.138*	0.0879	0.0723	0.222
	[0.012]	[0.050]	[0.515]	[0.135]
SW Pat Stock x Litigiousness	-0.00696	0.00186	-0.0137	-0.00872
	[0.802]	[0.927]	[0.508]	[0.688]
Employees	-0.0760	-0.0819	-0.0313	-0.0535
	[0.156]	[0.129]	[0.601]	[0.226]
R&D Intensity	-0.269	-0.239	-0.219	-0.101
	[0.055]	[0.122]	[0.125]	[0.512]
Advertising Intensity	2.538	2.609	1.384	2.965
	[0.166]	[0.164]	[0.430]	[0.202]
Market Share	0.776	0.768	0.541	0.207
	[0.312]	[0.097]	[0.201]	[0.709]
Industry Capital Intensity	-0.130	-0.161*	-0.0683	-0.127
	[0.054]	[0.020]	[0.430]	[0.083]
Industry q	-0.00244	0.00137	0.00225	-0.00554
	[0.873]	[0.902]	[0.877]	[0.771]

Intercept	0.869**	0.764*	2.015*	-0.627
	[0.007]	[0.015]	[0.042]	[0.766]
Year Dummies	Y	Y	Y	Y
Wald Statistics	4920.1	5155.9	4668.3	4697.1
Number of Instruments	119	119	119	119
Hansen Test of Over-ID	0.670	0.455	0.723	0.464
Arellano-Bond AR (2) test	0.564	0.542	0.753	0.575
N	2146	2146	2146	2146

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Table 26: System GMM with three-way interactions of patent stock, scope, and litigiousness

	(1)	(2)	(3)	(4)
Dep Var: Tobin's q	ln(Y)	ln(Y)	ln(Y)	ln(Y)
Patent Scope Measure	Mean	Max	Cumulative	Cumul. Mean
SW Patent Stock	-0.0114	-0.0264	-0.0184	-0.628
	[0.865]	[0.793]	[0.955]	[0.487]
Technological Scope	-0.188	-0.0500	0.0872	0.670
	[0.447]	[0.823]	[0.883]	[0.463]
Application Diversity	0.733	0.346	-0.0435	0.376
	[0.057]	[0.376]	[0.940]	[0.514]
Litigiousness	0.226	0.182	1.010	0.892
	[0.397]	[0.365]	[0.367]	[0.622]
SW Pat Stock x Tech Scope	-0.0566	-0.0184	0.0347	0.187
	[0.368]	[0.760]	[0.823]	[0.487]
SW Pat Stock x App Diversity	0.189	0.0904	-0.00927	0.0991
	[0.064]	[0.406]	[0.952]	[0.578]
SW Pat Stock x Litigiousness	0.0374	0.0271	0.302	0.367
	[0.593]	[0.636]	[0.257]	[0.477]
Litigiousness x Tech Scope	-0.00556	-0.0194	-0.399	-0.510
	[0.960]	[0.844]	[0.484]	[0.373]
Litigiousness x App Diversity	-0.146	-0.0326	0.350	0.493
	[0.429]	[0.860]	[0.532]	[0.371]
SW Pat Stock x Litigiousness	0.00261	-0.000664	-0.135	-0.188
x Tech Scope	[0.925]	[0.981]	[0.305]	[0.228]
SW Pat Stock x Litigiousness	-0.0376	-0.00530	0.124	0.157

x App Diversity	[0.408]	[0.915]	[0.338]	[0.260]
Employees	-0.0856*	-0.0702	-0.00760	-0.0530
	[0.035]	[0.104]	[0.912]	[0.227]
R&D Intensity	-0.270	-0.234	-0.169	-0.0804
	[0.101]	[0.168]	[0.208]	[0.612]
Advertising Intensity	2.740	2.796	1.544	2.858
	[0.216]	[0.168]	[0.421]	[0.215]
Market Share	0.795	0.705	0.350	0.311
	[0.071]	[0.134]	[0.608]	[0.612]
Industry Capital Intensity	-0.175*	-0.182*	-0.105	-0.142
	[0.015]	[0.020]	[0.253]	[0.058]
Industry q	-0.00457	0.00216	0.0112	-0.00378
	[0.771]	[0.880]	[0.414]	[0.840]
Intercept	0.533	0.561	0.967	-1.536
	[0.243]	[0.251]	[0.428]	[0.617]
Year Dummies	Y	Y	Y	Y
Wald Statistics	5851.9	5488.5	5388.4	4815.6
Number of Instruments	119	119	119	119
Hansen Test of Over-ID	0.766	0.654	0.875	0.794
Arellano-Bond AR (2) test	0.706	0.587	0.621	0.516
N	2146	2146	2146	2146

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Table 27: System GMM with sample restricted to IT industry

	(1)	(2)	(3)	(4)
Dep Var: Tobin's q	ln(Y)	ln(Y)	ln(Y)	ln(Y)
Patent Scope Measure	Mean	Max	Cumulative	Cumul. Mean
SW Patent Stock	0.0361	0.0502	-0.190	-0.402
	[0.522]	[0.637]	[0.504]	[0.448]
Technological Scope	0.0600	0.123	0.381	0.567
	[0.586]	[0.394]	[0.416]	[0.228]
Application Diversity	0.119	-0.0803	-0.353	0.154
	[0.542]	[0.714]	[0.452]	[0.777]
Litigiousness	-0.0246	-0.0193	-0.0558	-0.0161
	[0.823]	[0.856]	[0.617]	[0.886]

SW Pat Stock x Tech Scope	0.00895	0.0309	0.162	0.154
	[0.766]	[0.511]	[0.208]	[0.289]
SW Pat Stock x App Diversity	0.0361	-0.0243	-0.152	-0.00207
	[0.520]	[0.730]	[0.253]	[0.990]
SW Pat Stock x Litigiousness	-0.0182	-0.0263	-0.0367	-0.0268
	[0.494]	[0.406]	[0.303]	[0.410]
Employees	-0.0631	-0.0899	-0.0847	-0.0963
	[0.362]	[0.239]	[0.344]	[0.111]
R&D Intensity	-0.0552	-0.0688	-0.0770	0.00270
	[0.512]	[0.445]	[0.381]	[0.980]
Advertising Intensity	3.291	3.725	3.356	3.158
	[0.096]	[0.133]	[0.144]	[0.089]
Market Share	0.801	0.795	0.769	0.903
	[0.513]	[0.582]	[0.619]	[0.510]
Industry Capital Intensity	-0.0870	-0.0435	-0.00902	-0.0560
	[0.331]	[0.692]	[0.914]	[0.523]
Industry q	0.0116	0.0138	0.0269	0.0121
	[0.661]	[0.617]	[0.326]	[0.699]
Intercept	0.960**	1.173*	0.821	-0.590
	[0.003]	[0.017]	[0.396]	[0.701]
Year Dummies	Y	Y	Y	Y
Wald Statistics	5243.0	4914.2	3937.6	4841.0
Number of Instruments	109	109	109	109
Hansen Test of Over-ID	0.406	0.268	0.465	0.662
Arellano-Bond AR (2) test	0.333	0.350	0.363	0.412
N	1412	1412	1412	1412

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Table 28: System GMM with sample restricted to firms with multiple firm-year observations

	(1)	(2)	(3)	(4)
Dep Var: Tobin's q	ln(Y)	ln(Y)	ln(Y)	ln(Y)
Patent Scope Measure	Mean	Max	Cumulative	Cumul. Mean
SW Patent Stock	0.0356	-0.00544	0.229	-0.332
	[0.527]	[0.940]	[0.366]	[0.603]
Technological Scope	-0.173	-0.0563	-0.291	0.239
	[0.202]	[0.637]	[0.502]	[0.702]

Application Diversity	0.523*	0.313	0.271	0.837
	[0.013]	[0.086]	[0.514]	[0.075]
Litigiousness	0.00202	0.0241	-0.0135	-0.0111
	[0.985]	[0.750]	[0.888]	[0.899]
SW Pat Stock x Tech Scope	-0.0527	-0.0178	-0.0574	0.0366
	[0.106]	[0.551]	[0.625]	[0.840]
SW Pat Stock x App Diversity	0.136*	0.0854	0.0695	0.222
	[0.015]	[0.065]	[0.535]	[0.135]
SW Pat Stock x Litigiousness	-0.00625	0.00254	-0.0174	-0.00745
	[0.819]	[0.902]	[0.431]	[0.736]
Employees	-0.0795	-0.0866	-0.0140	-0.0563
	[0.134]	[0.117]	[0.828]	[0.204]
R&D Intensity	-0.270	-0.240	-0.201	-0.0990
	[0.054]	[0.121]	[0.139]	[0.516]
Advertising Intensity	2.720	2.772	1.818	3.435
	[0.160]	[0.165]	[0.337]	[0.181]
Market Share	0.785	0.794	0.406	0.208
	[0.293]	[0.086]	[0.436]	[0.711]
Industry Capital Intensity	-0.114	-0.139	-0.0688	-0.103
	[0.117]	[0.071]	[0.461]	[0.207]
Industry q	-0.00235	0.000530	0.00141	-0.00533
	[0.878]	[0.963]	[0.922]	[0.787]
Intercept	0.977**	0.868**	2.105*	-0.660
	[0.002]	[0.006]	[0.034]	[0.759]
Year Dummies	Y	Y	Y	Y
Wald Statistics	4098.9	4332.4	4334.2	3939.8
Number of Instruments	119	119	119	119
Hansen Test of Over-ID	0.667	0.441	0.748	0.487
Arellano-Bond AR (2) test	0.511	0.512	0.579	0.526
N	1878	1878	1878	1878

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Table 29: Descriptive Stats for firms with multiple firm-year observations (N = 1,878 firm-years)

Variable	**Description**	**Mean**	**Std**	**Min**	**Max**

			Dev		
Tobin's q	Tobin's q by firm-year	2.621	2.773	0.232	55.729
SW Patent Stock	Cumulative software patent count by firm-year scaled by R&D stock	0.195	1.391	0.000	40.351
Mean Claims	Mean of patents' number of claims by firm-year	22.459	15.335	0.000	176.000
Mean Classes	Mean of patents' number of assigned classes by firm-year	3.900	2.693	0.000	31.000
Litigiousness	Number of patent related court cases in a 4-year window depreciated 20% every year	2.359	8.340	0.000	119.662
Employees	Total number of employees	29.795	73.824	0.002	901.238
R&D Intensity	Ratio of R&D expenses to sales by firm-year	0.457	4.043	0.000	133.786
Advt. Intensity	Ratio of firm *i*'s advertising expenditure to sales in year *t*	0.042	0.731	0.000	26.058
Mkt. Share	Ratio of sales of firm *i* in year *t* to industry sales at NAICS4 level	0.068	0.150	0.000	1.000
Ind. Cap. Intensity	Ratio of capital investment to sales for the firm's industry at NAICS4 level	0.068	0.051	0.002	0.603
Ind. Tobin's q	Average q for the firm's industry based on NAICS4 code at fiscal year end	16.183	32.856	0.891	854.203

Table 30: Descriptive Statistics for firms with single firm-year observations (N = 373 firm-years)

Variable	Description	Mean	Std Dev	Min	Max
Tobin's q	Tobin's q by firm-year	2.629	3.354	0.342	37.609
SW Patent Stock	Cumulative software patent count by firm-year scaled by R&D stock	0.719	5.123	0.000	83.333
Mean Claims	Mean of patents' number of claims by firm-year	27.486	21.891	1.000	173.000
Mean Classes	Mean of patents' number of assigned classes by firm-year	4.244	2.869	1.000	26.000
Patent Generality	Generality of patent based on classes of citing patents	0.537	0.356	0.000	1.000
Litigiousness	Number of patent related court cases in a 4-year window depreciated 20% every year	0.276	1.554	0.000	19.000
Employees	Total number of employees	16.541	83.314	0.004	1383.00

					0
R&D Intensity	Ratio of R&D expenses to sales by firm-year	1.080	7.437	0.000	120.333
Advt. Intensity	Ratio of firm *i*'s advertising expenditure to sales in year *t*	0.027	0.119	0.000	1.655
Mkt. Share	Ratio of sales of firm *i* in year *t* to industry sales at NAICS4 level	0.055	0.157	0.000	1.000
Ind. Cap. Intensity	Ratio of capital investment to sales for the firm's industry at NAICS4 level	0.077	0.082	0.002	0.571
Ind.Tobin's q	Average q for the firm's industry based on NAICS4 code at fiscal year end	14.140	23.074	1.027	276.880

Table 31: Results of T-tests between single year versus multiyear panels sample

	(1)	
Tobin's q	-0.00766	(-0.05)
SW Patent Stock	-0.525***	(-3.76)
Mean Claims	-5.027***	(-5.44)
Mean Classes	-0.344*	(-2.25)
litigiousness	2.082***	(4.81)
Patent Generality	-0.0381	(-1.10)
N	2527	

t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 32: Results of system GMM without log (1+patent scope) transformation

Dep Var: Tobin's q Patent Scope Measure	(1) ln(Y) Mean	(2) ln(Y) Max	(3) ln(Y) Cumulative	(4) ln(Y) Cumul. Mean
SW Patent Stock	-0.111	-0.0304	0.153	0.520
	[0.701]	[0.889]	[0.634]	[0.383]
Technological Scope	-0.00212	0.0352	-0.650	-0.926
	[0.994]	[0.868]	[0.296]	[0.163]
Application Diversity	0.418	0.146	0.826	1.302*
	[0.119]	[0.446]	[0.182]	[0.027]
Litigiousness	0.164	0.0968	0.00333	0.0670
	[0.212]	[0.434]	[0.976]	[0.676]
SW Pat Stock x Tech Scope	0.00259	-0.0114	-0.133	-0.258

	[0.972]	[0.826]	[0.421]	[0.200]
SW Pat Stock x App Diversity	0.103	0.0330	0.160	0.253
	[0.094]	[0.480]	[0.317]	[0.118]
SW Pat Stock x Litigiousness	0.0194	0.00516	-0.00490	0.0127
	[0.515]	[0.876]	[0.873]	[0.737]
Employees	-0.190*	-0.215***	-0.254*	-0.171
	[0.047]	[0.001]	[0.029]	[0.059]
R&D Intensity	-0.113	-0.101	-0.152	-0.113
	[0.155]	[0.149]	[0.213]	[0.212]
Advertising Intensity	0.139	-1.094	0.112	-0.845
	[0.949]	[0.667]	[0.941]	[0.673]
Market Share	0.0654	0.0888	0.102	0.0795
	[0.448]	[0.200]	[0.311]	[0.390]
Industry Capital Intensity	-0.0765	-0.0320	-0.113	-0.00116
	[0.498]	[0.800]	[0.265]	[0.993]
Industry q	0.0113	0.0143	0.00286	-0.00193
	[0.572]	[0.513]	[0.873]	[0.930]
Intercept	0.217	0.655	1.664	2.301
	[0.848]	[0.513]	[0.263]	[0.250]
Year Dummies	Y	Y	Y	Y
Wald Statistics	1203.0	1206.0	997.0	826.7
Number of Instruments	117	117	119	119
Hansen Test of Over-ID	0.519	0.158	0.479	0.389
Arellano-Bond AR (2) test	0.550	0.688	0.599	0.199
N	1961	1961	2145	2145

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Table 33: Results of system GMM with adjustment for outliers

	(1)	(2)	(3)	(4)
Dep Var: Tobin's q	ln(Y)	ln(Y)	ln(Y)	ln(Y)
Patent Scope Measure	Mean	Max	Cumulative	Cumul. Mean
SW Patent Stock	0.0761	0.0654	0.0535	0.0535
	[0.299]	[0.492]	[0.524]	[0.524]
Technological Scope	-0.324	-0.313	-0.252	-0.252
	[0.091]	[0.153]	[0.186]	[0.186]

Application Diversity	0.897**	0.884	0.770**	0.770**
	[0.008]	[0.058]	[0.008]	[0.008]
Litigiousness	0.0173	-0.00510	-0.000789	-0.000789
	[0.888]	[0.973]	[0.996]	[0.996]
SW Pat Stock x Tech Scope	-0.0951*	-0.0897	-0.0765	-0.0765
	[0.049]	[0.095]	[0.098]	[0.098]
SW Pat Stock x App Diversity	0.229**	0.225*	0.196*	0.196*
	[0.006]	[0.035]	[0.013]	[0.013]
SW Pat Stock x Litigiousness	0.00304	-0.0161	-0.00943	-0.00943
	[0.927]	[0.652]	[0.806]	[0.806]
Employees	-0.0881	-0.144	-0.114	-0.114
	[0.165]	[0.084]	[0.139]	[0.139]
R&D Intensity	-0.443*	-0.510*	-0.431*	-0.431*
	[0.046]	[0.022]	[0.041]	[0.041]
Advertising Intensity	4.346	2.703	3.625	3.625
	[0.099]	[0.335]	[0.164]	[0.164]
Market Share	0.730	1.075	1.099	1.099
	[0.418]	[0.176]	[0.284]	[0.284]
Industry Capital Intensity	-0.226*	-0.121	-0.185	-0.185
	[0.014]	[0.242]	[0.055]	[0.055]
Industry q	-0.00821	-0.0142	-0.00703	-0.00703
	[0.670]	[0.547]	[0.739]	[0.739]
Intercept	0.169	0.548	0.238	0.238
	[0.674]	[0.223]	[0.607]	[0.607]
Year Dummies	Y	Y	Y	Y
Wald Statistics	1171.2	1030.7	1093.9	1093.9
Number of Instruments	119	116	119	119
Hansen Test of Over-ID	0.890	0.460	0.713	0.713
Arellano-Bond AR (2) test	0.372	0.121	0.442	0.442
N	2146	1948	2146	2146

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Table 34: Results of fixed effects for main effect of application diversity

Dep Var: Tobin's q Patent Scope Measure	(1) ln(Y)	(2) ln(Y) Mean	(3) ln(Y) Max	(4) ln(Y) Cumulative
SW Patent Stock	0.0688*	0.0857*	0.0991*	0.213**
	[0.034]	[0.021]	[0.012]	[0.001]
Application Diversity		-0.0313	-0.0383*	-0.200**
		[0.051]	[0.011]	[0.002]
Employees	-0.240***	-0.236***	-0.227**	-0.141
	[0.001]	[0.001]	[0.001]	[0.058]
R&D Intensity	-0.210**	-0.207**	-0.205**	-0.181*
	[0.008]	[0.007]	[0.007]	[0.012]
Advertising Intensity	-0.276**	-0.285**	-0.289**	-0.295**
	[0.008]	[0.005]	[0.004]	[0.005]
Market Share	0.529	0.527	0.544	0.340
	[0.463]	[0.468]	[0.458]	[0.659]
Industry Capital Intensity	0.0210	0.0213	0.0197	0.0277
	[0.737]	[0.734]	[0.753]	[0.650]
Industry q	-0.00192	-0.00264	-0.00220	-0.00125
	[0.868]	[0.818]	[0.849]	[0.912]
Intercept	2.009***	2.102***	2.144***	2.783***
	[0.000]	[0.000]	[0.000]	[0.000]
Year Dummies	Y	Y	Y	Y
R^2	0.216	0.218	0.220	0.234
N	2146	2146	2146	2146

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Table 35: Results of system GMM for main effect of application diversity

Dep Var: Tobin's q Patent Scope Measure	(1) ln(Y)	(2) ln(Y) Mean	(3) ln(Y) Max	(4) ln(Y) Cumulative
SW Patent Stock	0.112	0.0882**	0.0935*	0.139*
	[0.060]	[0.002]	[0.032]	[0.026]
Application Diversity		0.0190	0.00133	-0.0299
		[0.527]	[0.969]	[0.531]

Employees	-0.0452	-0.0632	-0.0617	-0.0314
	[0.436]	[0.094]	[0.130]	[0.737]
R&D Intensity	-0.174	-0.174	-0.153	-0.199
	[0.258]	[0.219]	[0.258]	[0.218]
Advertising Intensity	3.857	2.782	3.126	1.971
	[0.237]	[0.177]	[0.211]	[0.524]
Market Share	0.403	0.605	0.613	0.524
	[0.683]	[0.370]	[0.312]	[0.621]
Industry Capital Intensity	-0.151	-0.0989	-0.122	-0.0607
	[0.206]	[0.232]	[0.137]	[0.498]
Industry q	0.00189	-0.00194	-0.00167	0.00106
	[0.910]	[0.881]	[0.908]	[0.928]
Intercept	1.139***	1.230***	1.201***	1.554***
	[0.001]	[0.000]	[0.000]	[0.000]
Year Dummies	Y	Y	Y	Y
Wald Statistics	5466.4	6139.6	5498.4	4962.0
Number of Instruments	67	86	86	86
Hansen Test of Over-ID	0.481	0.586	0.640	0.554
Arellano-Bond AR (2) test	0.514	0.495	0.492	0.690
N	2146	2146	2146	2146

p-values in brackets * $p < .05$, ** $p < .01$, *** $p < .001$

Table 36: Variation inflation factors with mean measures of patent scope

Dep Var: Tobin's q	(1) ln(Y)	vif
SW Patent Stock	0.00692	1.49
	(0.56)	
Technological Scope	0.0506***	1.90
(Mean)	(3.65)	
Application Diversity	-0.0273	1.87
(Mean)	(-1.09)	
Litigiousness	0.0272	1.29
	(1.85)	
Employees	-0.0284*	2.56
	(-2.03)	
R&D Intensity	0.0651	1.24
	(0.76)	
Advt. Intensity	0.0416	1.09
	(0.45)	
Mkt. Share	-0.268*	1.60

	(-2.21)	
Ind. Cap. Intensity	0.0125	1.12
	(0.52)	
Ind. Tobin's q	0.0470***	1.13
	(3.84)	
Intercept	1.042***	
	(11.80)	
N	2146	

Table 37: Variation inflation factors with max measures of patent scope

Dep Var: Tobin's q	(1) ln(Y)	vif
SW Patent Stock	0.00104	1.69
	(0.08)	
Technological Scope (Max)	0.0527***	2.25
	(4.09)	
Application Diversity (Max)	-0.0185	2.38
	(-0.87)	
Litigiousness	0.0265	1.29
	(1.82)	
Employees	-0.0354*	2.85
	(-2.42)	
R&D Intensity	0.0625	1.24
	(0.72)	
Advt. Intensity	0.0448	1.09
	(0.48)	
Mkt. Share	-0.256*	1.60
	(-2.10)	
Ind. Cap. Intensity	0.00908	1.13
	(0.38)	
Ind. Tobin's q	0.0461***	1.13
	(3.79)	
Intercept	1.000***	
	(11.32)	
N	2146	

Table 38: Variation inflation factors with cumulative measures of patent scope

Dep Var: Tobin's q	(1) ln(Y)	vif
SW Patent Stock	0.00381	1.89
	(0.27)	
Technological Scope (Cumulative)	0.0447*	9.74
	(2.24)	
Application Diversity (Cumulative)	-0.0288	9.89
	(-1.41)	

Litigiousness	0.0181	1.49
	(1.07)	
Employees	-0.0359*	3.43
	(-2.13)	
R&D Intensity	0.0605	1.25
	(0.68)	
Advt. Intensity	0.0408	1.09
	(0.42)	
Mkt. Share	-0.243*	1.63
	(-1.98)	
Ind. Cap. Intensity	0.0155	1.12
	(0.65)	
Ind. Tobin's q	0.0462***	1.13
	(3.77)	
Intercept	1.032***	
	(11.24)	
N	2146	

Table 39: Variation inflation factors with cumulative mean measures of patent scope

	(1)	
Dep Var: Tobin's q	ln(Y)	vif
SW Patent Stock	0.0115	1.42
	(0.95)	
Technological Scope	0.0860***	1.02
(Cumulative Mean)	(3.56)	
Application Diversity	0.0326	1.02
(Cumulative Mean)	(1.07)	
Litigiousness	0.0267	1.29
	(1.81)	
Employees	-0.0241	2.50
	(-1.75)	
R&D Intensity	0.0633	1.24
	(0.74)	
Advt. Intensity	0.00907	1.10
	(0.10)	
Mkt. Share	-0.268*	1.60
	(-2.29)	
Ind. Cap. Intensity	0.0205	1.12
	(0.87)	
Ind. Tobin's q	0.0448***	1.13
	(3.63)	
Intercept	0.870***	
	(7.82)	
N	2146	