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Patents, Thickets and the Financing of Early-Stage Firms: Evidence from the Software Industry

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Abstract

Legal changes in the patentability of software since the mid 1990s have resulted in a substantial increase in the number of patents on software inventions. We focus here on the impact of transactions costs associated with patent “thickets” on new entrants' interactions with the capital markets. Using data on the financing of entrants into 27 narrowly defined software markets, we show that start-up software companies operating in markets characterized by denser patent thickets saw their initial acquisition of VC funding delayed relative to firms in markets less affected by patents after the mid 1990s. The relationship between patent thickets and subsequent financing activity such as IPO or acquisition is more complex, but there is weak evidence that firms without patents became less likely to go public if they operated in a market characterized by patent thickets. Firms with patents are more likely to be funded or experience a liquidity event. However, the application for a patent appears to matter more than its grant.

1. Introduction

Patents and entrepreneurship are intimately linked. For many new ventures, intellectual property rights are an important asset that provides protection from imitation or a basis for contracting in the market for technology. At first blush, therefore, it may seem obvious that strengthening patent rights or expanding the scope of the patent system would stimulate entrepreneurship. Yet many economists and legal scholars have grown skeptical about whether the current U.S. patent system is promoting or hindering innovation. As one prominent researcher in the field, Adam Jaffe, has stated in testimony before Congress “the patent system—intended to foster and protect innovation—is generating waste and uncertainty that hinder and threaten the innovative process.” [1] These concerns are most acute in industries such as software and semiconductors, where products are highly complex, each embodying thousands of innovations, and where technological progress tends to be incremental and cumulative. In such circumstances, critics argue, any "stimulating" effect of stronger patents on incentives to innovate will be offset, or even swamped, by the "stifling" effect of higher transactions costs, increased threat of litigation, and constraints imposed on the cumulative development of technologies by multiple blocking patents.

New enterprises that have limited resources and lack experience and managerial expertise in "working the patent system" are likely to be among those most severely affected by these stifling effects. Thus, far from supporting entrepreneurship, the current patent system may be choking innovation and hindering new venture formation in some sectors. In such circumstances, the enterprises that were the first to perceive these institutional changes and respond to them most effectively are likely to have been most successful in bringing their innovations to market. "Environmental awareness" and the ability to exploit the evolution of legal and regulatory institutions may therefore be an important complement to the innovative capability of new ventures.

1.1 Patents and the Software Industry

In this paper, we examine the impact of the changing IP landscape the interaction of entrant firms into a sample of software with external investors. The software industry provides an unusual and interesting opportunity to evaluate the impact of changes in patent rights on innovation and entrepreneurship. Software has been an important locus of innovation in the U.S. economy, and one where entrepreneurial ventures have played a particularly important role in driving technological change. Yet much foundational innovation occurred in the absence of strong patent protection, and until relatively recently many leading innovators in the industry, including highly visible firms like Microsoft, filed relatively few patents. Only after changes in patent law and USPTO practice in the mid 1990s generated a surge in patenting in software (that continues unabated) did patents become an important aspect of competition. The industry thus presents a "quasi-experiment" in which these policy changes may allow the impact of patents on new ventures to be much more clearly distinguished than in contexts where high levels of patenting have always been present.

The nature of software products and of the innovation process in this technology also means that industry participants face an increasingly forbidding "thicket" of IP. Software products are highly complex, with even quite modest products containing millions of lines of code and thousands or tens of thousands of interrelated component modules, any of which could potentially infringe one or more patents. With several hundred thousand software patents issued in the United States since 1990, [2] and ever-greater complexity and scale of software products, the cost of "clearing" new products for potential infringement can be very large. Even where an innovator can identify which patents it may need to license or invent around, if very large numbers of patents are potentially infringed the total "tax" on entry to the market may be prohibitively high. Where, as Shapiro suggests, these patents form "a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology" [3] or where the entrant has to bargain with large numbers of licensors, additional transactions costs associated with clearing a path to market may be very substantial.

These problems may have been exacerbated by poor patent "quality" in the sense that the validity, enforceability, and scope of claims of some software patents is unusually difficult to assess. Allegedly poor standards of patent examination in this area in the past may have generated large numbers of issued patents with inadequate disclosure, and excessively broad claims, raising the costs of determining the scope of existing IP, and increasing uncertainty about possible future litigation from competitors and noncompetitors alike.

Figure 1 shows how dramatic the increase in software patenting has been. The figure plots the total number of patents in force that are relevant to 27 distinct software product markets between 1980 and 2006. Over this period the CAGR (compound annual growth rate) of the total number of patents outstanding was 29.8%. Over the decade from 1994 to 2004 alone, the number of patents in the average market in our sample grew by almost 600%, while the number of active firms grew by less than 300%. By 2006, the average market in this sample had 5,858 patents in force, collectively asserting more than 127,000 claims.

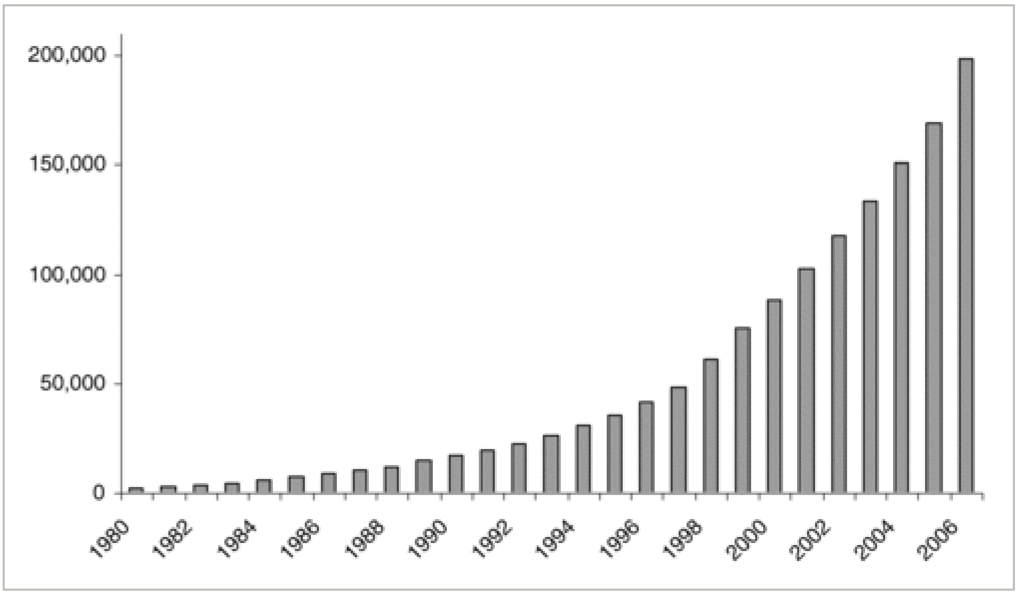

Figure 1

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TOTAL PATENTS IN FORCE IN 27 SOFTWARE MARKETS

Data such as these suggest that costs associated with patents—searching prior art, building patent portfolios, and defending against the threat of patent litigation—have grown very substantially, and may now be having a significantly negative impact on the pace of innovation in the industry. To cite just two authoritative observers, Donald Knuth, author of *The Art of Computer Programming* and inventor of TeX, has stated that "I don't think I would have been able to create TeX if the present [patent] climate had existed in the 1970s," while erstwhile entrepreneur Bill Gates has opined that "If people had understood how patents would be granted when most of today's ideas were invented and had taken out patents, the industry would be at a complete standstill today." [4]

1.2 Patent Thickets, Innovation, and Entrepreneurship

Ideally, we would want to evaluate the impact of patents and "thicketing" on innovation and entrepreneurship in software with reference to direct economic outcomes such as indicators of the pace of technical change or the prices prevailing in innovation markets. Unfortunately these data are generally poor, and measurement challenges are particular severe in software. Data on licensing transactions, for example, is very sparse and highly selective, [5] though see Cockburn et al. (2008) which examines the relationship between patent thickets and the extent to which small and medium enterprises in German manufacturing engage in licensing. Research on these issues has therefore tended to focus on indirect measures of the impact of patents, such as the stock market value of companies (see e.g., Hall and MacGarvie, 2006). In software, one useful indicator of technical change—recognizing the important role of new ventures in driving innovation in this industry—is market entry and the founding and financing of new firms. Here we focus on the effect of thickets on the ability of new entrants to finance market entry by secure external funding from various sources, a critical economic mechanism in this and other sectors, and one through which patents play an important role in determining incentives to launch new products and new ventures. [6]

We hypothesize that patent thickets affect the ability of software start-ups to raise money from outside investors in two main ways. First, the *transaction costs* of entering a market may be higher when that market has a patent thicket. Patents that block a would-be entrant from producing or selling its product mean that the entrant must either bear additional costs of “inventing around” such patents, pay licensing fees to the patent holder, or accept potentially severe *ex post* penalties from launching its product “at risk” of infringement litigation. [7] One dimension of a patent thicket is thus the number of the patents that an entrant may potentially infringe, where more patents impose a proportionately higher “tax” on entrants. Suppose an entrant was to obtain licenses to all of the patents that it infringes. All else equal, we expect that the more patents that must be licensed, the higher the total cost of entry. However, particularly in complex technologies, patents are frequently bundled or pooled, or jointly licensed, thus total costs of entry may not have a simple linear relationship to the number of patents blocking the would-be entrant. In particular, costs imposed by a thicket may also reflect the structure of ownership of these patents (Ziedonis, 2004). For example, transactions costs associated with bargaining with licensors may be lower when ownership of patents is more concentrated. To the extent that there are fixed costs of conducting a negotiation, having to conduct fewer negotiations will lower costs. A licensee may be able to get better terms per patent when negotiating with a relatively small number of licensors who each control large bundles of patents. Conversely, where the entrant has to conduct a complex bargaining process with many licensors, each of whom has some holdup power, higher total costs may be incurred—that is., the height of the “royalty stack” may rise nonlinearly in the number of its components. Noel and Schankerman (2006) provide evidence on the costs imposed by patent thickets from a sample of publicly traded software firms by showing that market value decreases when patent rights held by a firm's competitors are more fragmented, reflecting the higher costs of negotiating with more parties.

Second, the *uncertainty* of the firm's future profit stream may be higher when it faces a patent thicket. Lemley and Shapiro (2005) argue that there are two types of uncertainty associated with patents: uncertainty about the commercial value of the property right granted to the inventor, and uncertainty about the validity and scope of the property right. The latter form of uncertainty may be especially prevalent in software, a field in which patents were until recently not used to protect IP and which saw a dramatic growth of patenting following changes in the USPTO's patentability guidelines in the mid 1990s. The lack of experience with software patents at the USPTO, combined with the ambiguity associated with what is covered by many patents in this sector, has meant that software developers face significant uncertainty about existing prior art and the possibility of being sued for infringement. Bessen and Meurer (2008) find that software patents are more than twice as likely as other patents to have claim construction appealed to the Federal Circuit, and, which they take as an indicator of elevated uncertainty about the boundaries of patents in software. [8]

We look for evidence of the impact of increased transaction costs and greater uncertainty on new ventures in “thicketed” markets in the following ways. First, higher anticipated transaction costs should affect negatively affect investors' valuations of start-up companies, “raising the bar” for new entrants in terms of meeting minimum levels of profitability required by outside inventors, and thus reducing the number of entrants that receive funding from outside investors. Once a firm becomes an incumbent, the effect of thickets is less clear: thickets may offer protection from entrants, or result in future additional transaction costs, with an ambiguous effect on the value of the enterprise and the probability that a firm is able to create a “liquidity event” for early-stage investors by going public or being acquired. Second, higher uncertainty about future profits should affect the timing of investments. When investments are irreversible, the opportunity cost of current investment (versus investment at a later date) increases with uncertainty about future profits. Thus, all else equal, increases in uncertainty increase the value of delaying investment. [9]

We hypothesize that higher levels of uncertainty over the threat of litigation or other future patent-related costs increases the value of delaying investments in anticipation of information such as court rulings that clarify the scope of relevant patents, or the results of “field testing” licensing and enforcement strategies. As a result, we expect that, after controlling for firm- and investor-level characteristics, firms operating in markets characterized by larger or more fragmented patent thickets, or markets in which the relevant prior art is less well defined, will see investments delayed. We look for evidence of delay in duration models for the timing of investment at two points in the lifecycle of new ventures: the time elapsed from the birth of a new venture until it obtains its first round of funding from outside investors (both venture capitalists and corporate investors), and the time elapsed between the first round of funding and “exit” from the entrepreneurial phase via IPO or acquisition. This transition often marks a significant change in entrepreneurial ventures' ability to generate significant profits, and in their business model, capital requirements, scale of operation, and management. [10]

Third, we examine which strategies may help firms succeed when faced with patent thickets. Following Hall and Ziedonis (2003) and Ziedonis (2004), we hypothesize that start-up companies with patents will be able to use them in cross-licensing negotiations to defend themselves against litigation, or more generally to obtain better terms in any licensing negotiation. These patents may then act to reduce the transaction costs associated with operating in a “thicketed” market. These firms should also face less uncertainty, and thus we expect investment will take place earlier.

We believe this paper makes several contributions to the literature. First, we provide novel empirical evidence on several aspects of the impact of patent thickets on early-stage firms. Using a differences-in-differences methodology that uses shifts in the software patent regime to identify the effects of interest, we find that patent thickets make it more difficult for early-stage firms to obtain initial funding. The impact of patent thickets on the ability of firms to “exit” from the start-up phase via IPO or acquisition, is more ambiguous, however, there is evidence that the negative effect of thickets intensified following changes in patentability and that this effect was felt disproportionately by firms without patents of their own. We consistently find a positive correlation between the firm's own patent holdings and “success” in financing transactions. Interestingly, however, we observe that it is the number of patents *pending*, rather than the number of patents already granted, which matters in our regressions. This raises important questions about the value of patents as property rights relative to their value as signals of quality.

Second, we also contribute to the literature on entrepreneurship by analyzing a dataset that contains both venture- or corporate-funded firms from the SDC universe as well as pre-funding start-ups drawn from the CorpTech database. This allows us to examine how funded firms differ from firms that do not obtain funding, and to analyze determinants of the timing of first investment. While other research has looked at differences between venture-backed and non venture-backed firms in small samples, we are not aware of other papers that exploit as comprehensive a dataset as the one we use here.

1.3 Literature Review

A number of strands of literature are relevant to this paper. Studies of the impact of quasi-natural experiments associated with legal changes to patent regimes on innovation include Branstetter and Sakakibara (2001), Lanjouw and Cockburn (2001), Moser (2005), Scherer and Weisburst (1995), Branstetter et al. (2006), Lerner (2002), and Hall and Ziedonis (2001). On software patents in particular, negative effects of more-and-stronger patent rights have been found by Bessen and Maskin (2007) and Bessen and Hunt (2007). See also Noel and Schankerman (2006), Hall (2005) and Hall and MacGarvie (2006) for evidence on the impact of patents on market value of software firms, and Mann (2006) who shows that software start-ups holding patents receive more investment from venture capitalists than those without patents.

Arora et al. (2001), Gans and Stern (2000), Gans et al. (2002), and others have highlighted the role of patents and other formal IP rights in supporting a “market for technology,” which provides an avenue for new entrants to realize value from innovation by licensing, or selling themselves to incumbents. Hsu and Ziedonis (2007) show that a doubling in a start-up firm's patent stock is associated with a 24% increase on average in investors' valuations.

In contrast to the number of papers that use datasets comprising exclusively venture-backed firms, the literature that models the probability that start-up companies obtain external investment from other sources is relatively sparse. Hellmann and Puri (2002) provide evidence on the impact of VC funding on start-ups, using a sample of venture-backed and non venture-backed firms. See also Kortum and Lerner (2000) and Goldfarb et al. (2005).

Analyses of the role of uncertainty in the duration and timing of investment in start-ups include Gompers (1995) and Guler (2007). Empirical analyses of exits via IPO include Lerner (1994), Gompers (1995), Giot and Schwienbacher (2007), Ljungqvist et al. (2007), and Cockburn and Wagner (2007).

2. Data and Empirical Approach

Our approach here is to estimate reduced form regressions in which we look for evidence of an association between measures of patent thickets and indicators of entry and financing of new ventures, controlling for other market characteristics, such as demand, market structure, and the state of technology. We look at the impact of patent thickets at two levels. In the first set of regressions presented here we look at the market- level association between patents and aggregate volumes of entry and financing activity. A second set of regressions looks at the effect of the patent landscape on the timing of investment using much more detailed firm-level data.

One obvious potential problem is endogeneity: the nature of the patent thicket prevailing in these markets presumably reflects optimizing responses to the competitive environment. Motivations for firms to file patents are, however, complex. Incumbents may well apply for patents strategically to deter entry, to raise the costs of rivals already in the market, or to protect themselves from litigation (Ziedonis, 2004), thus making the size of the thicket in a given market endogenous with respect to competition. But patenting behavior may also reflect other factors such as the use of patents as part of internal systems for providing incentives or monitoring employees, or the firm's participation in other patent-intensive industries (such as hardware). [11] Other aspects of the institutional context of this study and of our estimation methods also suggest that any endogeneity bias is quite limited, and to the extent that it does affect our estimates it will bias coefficients toward zero, leading to underestimates rather than overestimates of any causal effect of patent thickets. In all of our regressions we use market fixed effects, so that our identification comes from within-market changes in the patent thicket and the outcomes of interest rather than from purely cross-sectional correlations. It is also important to recognize that the timing of incumbents' patent grants (or their ability to obtain patent protection at all) is in large part affected by exogenous changes in resources and policy at the patent office. The average time between patent application and grant in our dataset is close to 3 years. [12] Given the high speed of product cycles and turnover in the software industry, incumbents *filing* patents in response to threats from competitors will in most cases be unable to use the granted patents until well after entry has taken place, and the infringing product has been superseded. Because of this, a substantial portion of the thicket faced by entrants in any market is composed of patents obtained far in the past, and by noncompetitors. Thus, after controlling for time-invariant unobserved effects, and a variety of other potential sources of bias (such as confounding growth in the patent thicket with maturity of the technology in a market), endogeneity of our thicket measures created by incumbents' responses to time-varying shocks to the threat of entry appears not to be a major issue. [13]

Here we additionally exploit a series of changes in the legal regime that substantially expanded patentability of software inventions, and were accompanied by a dramatic increase in the number of software patents granted during the 1990s. These changes can be thought of as a quasi-experiment in which the strength of issued patents exogenously increased, raising barriers to entry in markets with more patents relative to markets with fewer patents. This allows us to examine patterns of entry and financing before and after changes in the legal regime using a differences-in-differences approach. In this model, for any there to any bias arising from a correlation between financing/entry and patents induced by omitted variables, the relationship between financing/entry and the omitted variable(s) in question would have to occur simultaneously with the changes in software patentability that took place during our sample. [14]

2.1 Data

2.1.1 Market and Firm Characteristics

The firms we study are drawn from the CorpTech directory of technology companies, which covers 19,717 public and private firms active in software markets over the period 1990–2004. [15] We know the founding date of the firm, revenues, and employment for most (but not all) of the firms in the dataset, the patents held by the firm, information on corporate parents, funding sources, and a number of other variables. To the CorpTech sample, we add data from SDC's VentureXpert database, matched by firm name using a name-matching algorithm augmented by manual inspection. [16] VentureXpert lists over 60,000 companies. Our matching algorithm found a match for 4,531 of the software firms listed on CorpTech in the list of VentureXpert firms. While there is obvious potential for both Type I and Type II errors in this matching process, our considerable effort spent on manual inspection of matches and nonmatches between these sources suggests that these are small.

For each matched firm we obtained information on the number of rounds of investment received, the amounts invested, the identities of investors, the stage of the investment, the founding date of the venture, [17] and whether the venture ultimately went public or was acquired, and the name of the acquirer when relevant. We also collect Compustat data on the sales, employment, and two-digit SIC codes of corporate investors.

The CorpTech data contain fine-grained information on the product classes in which the firm develops software (the "SOF category"). This self-reported variable can include products under development as well as products already launched. CorpTech reports more than 290 SOF categories; however, many of these are quite vaguely defined, or appear to be defined in terms of customer segments rather than in terms of a technology—for example, "secondary school software, dental practice management software, etc." Furthermore mapping patents to markets is a challenging and resource-intensive task. We therefore focus our analysis on 27 of these SOF-defined markets, listed in Table AI. These 27 markets were chosen primarily to facilitate subsequent mapping to patent data, primarily on the basis of our assessment as to whether the technology/product is reasonably distinctive, and we could define a set of keywords that could be fruitfully searched in the abstract of patent documents. [18]

Table I gives summary statistics for the number of firms of various types averaged over successive years and across markets. On average, 15.4 firms entered a market in the 2-year period between CorpTech sample years. The number of "*de novo*" entrants, as opposed to firms, which are new to the market in question, but already have an established presence in other markets, is quite small, averaging 3.05 per market per year. (This figure is likely to be an underestimate of the fraction of entrants into these markets that are "new," reflecting issues with the way that CorpTech collects data, and our screen for identifying new versus continuing ventures.) [19] Among these new entrants, 16% receive external funding from VCs prior to the year in which they enter the market, while 6% receive funding from a corporate investor at this point in their lifecycle. There is substantial variation in rates of entry in the cross-section and over time, with the number of entrants ranging from 0 to 104 per sample year.

Table I.

Descriptive Statistics

243 Market-Level Observations				
Variable	**Mean**	**Min**	**Max**	**Std. Dev.**
Market Characteristics				
Number of incumbents	157.5	0	766	179.5
Number of entrants	15.2	0	104	18.4
Number of "*de novo*" entrants	3.06	0	45	5.4
Fraction of all entrants with VC funding (%)	24.9	0	100	22.1
Fraction of all entrants with corporate funding (%)	6.4	0	50	10.0

243 Market-Level Observations				
Variable	Mean	Min	Max	Std. Dev.
Number of firms receiving first round of financing	1.9	0	50	5.6
Number if firms experiencing IPO or acquisition	0.885	0	19	2.329
Proxy for total sales in market ($MM)	2,684	0	6,517	6,319
CR4 of sales proxy	0.80	0	1	0.17
Growth rate of sales proxy (in logs)	0.576	−2.9	4.3	0.97

We do not have data on market-specific sales, but we construct a proxy for total sales based on the sales of firms that are active in a market. [20] On average, markets in this sample have a total of $2.7bn in annual sales, with substantial growth over time. Markets vary widely in size, from less than $70MM per year in sales to over $6.5BN.

2.1.2 Patents

Identifying the set of patents relevant for firms operating in a particular market is not a trivial task. Cockburn and MacGarvie (2007) describe in detail the process used to match USPTO patent classifications to the CorpTech SOF categories using an adaptive/iterative algorithm that combines keyword searching of the abstracts and titles of patents with the technology class codes applied by the USPTO. [21] Using the mapping between patent classes and CorpTech product markets described above, we obtained all the relevant patents in these classes from the NBER Patent Database. There is a striking increase in the volume of patenting over time: annual patent grants relevant to this set of 27 product markets increased more than 40-fold between 1980 and 2006, from 366 per year to 16,285 per year. We base our analysis on “patents in force” in any particular year, that is, net of patents that have reached the end of their term or were not renewed. These expirations represent a nontrivial fraction of the total number of patents in force: in the late 1990s, for example, new patents were being added to the sample at a rate of about 7,000 per year, while about 1200 were being removed from the “patent stock.”

Table I gives descriptive statistics for the patent landscape in the 27 product markets considered here. In total we identified 108,863 patents issued since 1977 that are relevant to the set of markets considered. (Some of these are relevant to more than one market.) There are very substantial changes over time in the observable characteristics of these patents. The average number of claims per patent doubled between 1980 and 2006, from 12.6 to 22.4, while the average number of backward citations per patent almost tripled over this period, rising from 7.2 to 19.1 and the average number of citations to nonpatent literature increased more than 10-fold from 0.5 per patent to 6.9. While some of the growth in citations reflects growth in the pool of references available to be cited, these figures also suggest significant changes in the nature of the patent rights being awarded and in the stringency of patent examination.

As Figure 2 shows, there is substantial variation the numbers of patents issued in different technology classes as well as in trends in patenting in different technology classes.

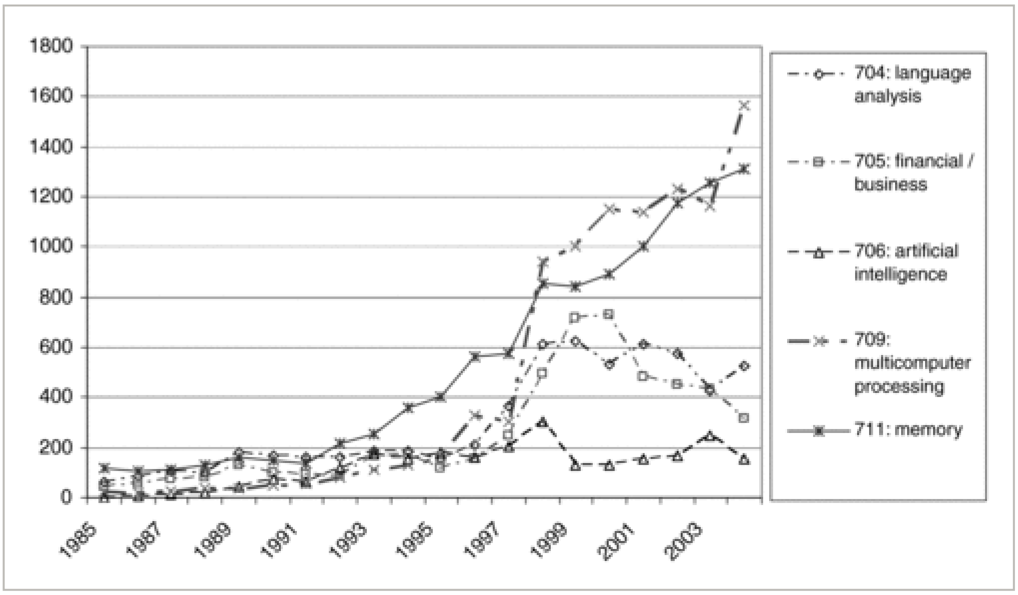

Figure 2

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PATENTS GRANTED BY YEAR, SELECTED USPTO CLASSES

After mapping these classes to product markets, this variation is reflected in substantial cross-sectional and time series differences between these markets in the number of patents granted. In some markets only a few hundred patents met our search criteria, while in others there are more than 16,000 patents issued over the sample period. Less substantial differences are also apparent in the average number of claims and in the amount of patent and nonpatent prior art that is cited. (Note though that ANOVA *F*-tests strongly reject the hypothesis of equality of means across markets for all of these measures.)

2.1.3 Quantitative Measures of Patent Thickets

Patents that block a would-be entrant from producing or selling its product can clearly be a significant barrier to entry. The entrant must either bear additional costs of "inventing around" such patents, pay licensing fees to the patent holder, or accept potentially severe *ex post* penalties. [22] As a first step toward characterizing the patent "landscape" in a market, we therefore compute the cumulative stock of patents in force in the markets in which each ventures operates as an indicator of the overall amount of intellectual property faced by the venture. [23] There was substantial growth over time in the size of the thicket, and substantial variation across markets, with the stock of patents ranging from 10 to over 11,000 patents.

However, as argued above, it may not be just the absolute *number* of patents in an area that can deter entry, but also the extent to which those patents constitute a "thicket" in the sense of generating transactions costs above and beyond simple blocking power. Following Ziedonis (2004) and Noel and Schankerman (2006) we hypothesize that a key factor driving transactions costs may be the degree to which ownership of patent rights is fragmented, and capture this second effect by measuring the concentration of IP ownership in each market using patent citations. [24] Patent citations are references to existing patented technologies, listed in the patent document. [25] Because these citations delimit the property rights represented by a patent by describing related claims contained in other patents, citations made by a patent give an indication of the extent to which a technological area is already covered by intellectual property rights and is thus (in principle) foreclosed to entrants who do not obtain a license. Assuming that the share of citations received by an assignee proxies the importance of negotiating with that assignee, we postulate that, in a market that has many cited assignees but where citations go disproportionately to a small number of firms, entry costs may actually be lower than in a market with fewer assignees each of which receives a similar share of total citations. To capture this effect, we calculate the Herfindahl index of citations over assignees for each market in each year. [26] The number of cited assignees is quite large, averaging 505 per market per year, and the Herfindahl indexes correspondingly low.

Some of these patent measures will be correlated with the maturity of the technology. Gort and Klepper (1982), for example, document an increase in patenting as technologies reach the late stages of the product life cycle. We want to separate the effects of increased patenting at any given stage of the technology life cycle from the natural accumulation of larger patent stocks as time passes. To control for the average maturity of technology in the product market, we use the modal citation lag. Because the number of citations to a patent is a function of the number of potential citations, we estimate the modal lag using a framework that adjusts for this effect. For each product class and citing-cited year pair, we compute the citation frequency, or ratio of actual to potential citations (see Jaffe and Trajtenberg, 1999), and then identify the citation lag (citing year—cited year) with the highest citation frequency for a given product class and citing year. [27] If the modal lag in a product category is short, it implies that the most highly cited patents in that market were granted recently, which suggests that the market is at a relatively early stage of the product cycle. [28]

2.1.4 Quantitative Measures of Uncertainty About Patent Rights

Capturing market participants' ex ante degree of uncertainty about the scope and validity of the patents that they face is clearly a substantial challenge. Based on discussions with practitioners and our reading of the ongoing debates about “patent quality” we identify two aspects of patents that may signal that their scope and validity may be difficult to assess. First, we look at the number of nonpatent references cited as prior art. Software patent applications (and their review by the patent office) have been widely criticized for failing to recognize or consider relevant prior art in the form of articles in professional journals, trade press, widely circulated product manuals and the like, which could potentially have sharply reduced the scope of claims allowed. According to this view, patents with very few citations to this type of prior art are more likely to be held invalid if subjected to legal challenge. (Of course, it may be that such patents reflect truly innovative inventions for which no prior art existed.) Arguably, therefore, markets with many such patents are ones in which the degree to which the technology space is “covered” is particularly hard to assess. For patents in the average market, the mean share of nonpatent citations in the count of total backward citations per patent was 17.6%, with substantial variation across markets (1.7% to almost 50%) and over time.

Second, we compute the average number of claims per patent in a market. Arguably, the difficulty of assessing the scope of a patent is increasing in the number of claims. One of the USPTO's recent initiatives to improve patent quality has been to limit the number of claims in a patent to no more than 25 (with no more than 5 independent claims.) Further, Allison et al. (2004) show that patents with larger numbers of claims are more likely to be litigated, and while the likelihood of litigation is undoubtedly related to the value of the patent, it is also more likely to occur when parties disagree over the validity or scope of the patent—that is, when there is greater uncertainty. [29] As a measure of this type of uncertainty about the strength of a patent we calculate the ratio of the number of claims allowed on a patent to the number of patents (both U.S. and foreign) cited. Our reasoning is that patents with a very large number of claims and very few citations to prior art are whose validity and scope are likely to be particularly difficult to assess. (Such patents are sometimes referred to by practitioners as "problem patents.") One difficulty with this measure is that low numbers of backward cites may simply reflect the "newness" or novelty of the invention rather than poor examination (or strategic behavior by the applicant). However, it is uncorrelated with the model citation lag, which we believe more directly captures "newness," suggesting that it is capturing an independent dimension of the data.

For patents in the average market, the mean number of claims per backward citation is 2.14, with industry averages ranging from 1.67 to 2.72. Variation in this ratio across markets is statistically significant: an ANOVA F-test strongly rejects the hypothesis of equal industry means ($p < 0.0001$).

3. Results

3.1 Impact of Patent Thickets at the Market Level

Tables II and III give estimates of the impact of patent thickets on market-level measures of activity by new software ventures. In Table II, the dependent variable in the regressions is the number of new entrants in each market in each sample year. In Table III we look at the impact of patent thickets on three measures of financing activity: the number of firms receiving an initial round of funding from external investors in that market-year, the median amount invested per firm in that market-year, and the number of IPOs or acquisitions of sample firms in that market per year.

Table II.
Market-Level Results on Entry

Poisson Regressions with Year and Market Fixed Effects and Standard Errors Clustered by Market							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Entrants			*De Novo*		Diversifiers	
Key Patent Variables							
Ln(Market's patents)	−0.628 (0.276)**	−0.774 (0.268)***	−0.657 (0.272)**	−0.097 (0.651)	−0.139 (0.646)	−0.671 (0.263)**	−0.702 (0.265)**
Average claims per cite in market		−0.466 (0.182)***					
Nonpatent share of prior art		−0.874 (2.234)					
D(Regime change)			0.735 (0.287)**		1.721 (0.882)		0.470 (0.236)*

Poisson Regressions with Year and Market Fixed Effects and Standard Errors Clustered by Market							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Median Marginal Effects of Interaction Terms							
D(Regime change) × ln(market's patents)					−2.135	−0.435	−1.45
median standard error					1.316	0.444	1.06
median *p*-value					0.090	0.308	0.147
Average effect below 25th percentile of market size					−0.984	−0.300	−0.642
Average effect above 75th percentile of market size					−8.317	−1.70	−5.93

Robust standard errors clustered by market in parentheses.

* Significant at 10%; ** significant at 5%; *** significant at 1%.

Table III.

Market-Level Results on Financing and IPOs

Estimation Method	Poisson			Tobit			
Dependent Variable	Number of Firms in Market *j* Receiving Initial Funding in Year *t*			Median Amount Invested in Market *j* in Year *t*			# (
	(1)	(2)	(3)	(4)	(5)	(6)	(
Patent Variables							
Ln(Market's patents)	−1.263 (0.710)*	−0.809 (0.807)	−0.590 (0.743)	−11,608.122 (12,091.284)	−10,981.753 (11,099.054)	−10,084.730 (10,695.009)	−1.: (0.6(
D(regime change)		1.358 (1.219)	2.249 (1.176)*		10,658.633 (8,585.367)	14,718.818 (8,974.368)	
D(regime change) × ln(patents in market)		−0.299 (0.169)*	−0.402 (0.158)**		−1,590.659 (1,343.024)	−2,040.591 (1,319.938)	
Average claims per cite			−0.907 (0.616)			−6,765.088 (4,807.813)	
Average			−10.618			−14,295.353	

All regressions include market and year fixed effects.

Robust standard errors clustered by market in parentheses.

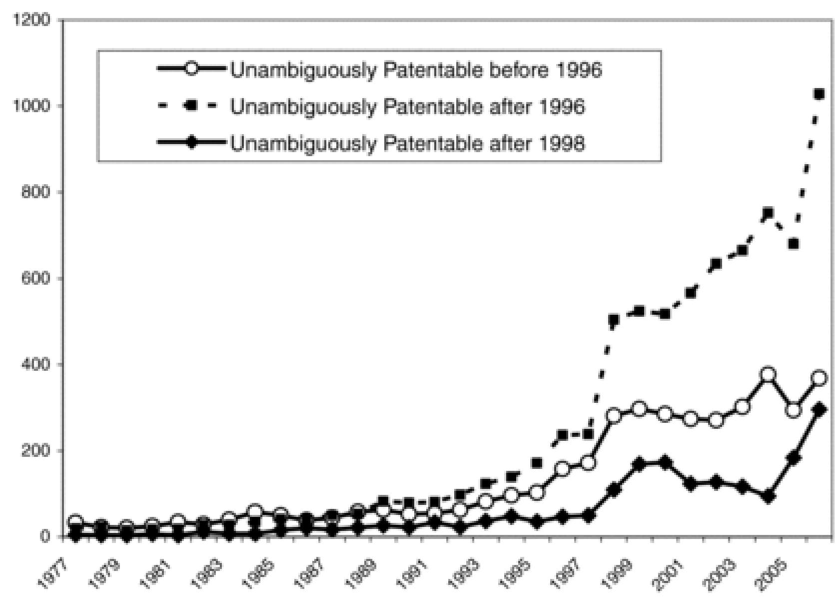
* Significant at 10%; ** significant at 5%; *** significant at 1%.

In each of these regressions we focus on the total number of patents in force in each market at a given point in time as an explanatory variable. We control for market size, market structure and demand using market and year fixed effects, the number of incumbents (and its square), and the growth rate of sales. We further control for the quality of patents in the market using the average number of forward citations received per patent in force, and for the maturity of the technology in the market using the modal citation lag.

As discussed above, we also present "differences-in-differences" estimates that make use of the fact that the expansion of software patentability took place at different times for different types of software. Though driven to some extent by pressure from patent applicants, arguably these changes are exogenous to the extent of the patent thicket in a particular market. Briefly, these regime changes were as follows. In 1972, the Supreme Court's ruling in *Gottschalk v. Benson* held that because software is essentially a collection of algorithms, it could not be patented. However, in 1981 in the *Diamond v. Diehr* ruling, the court allowed for patenting of software tied to physical or mechanical processes, such as the program implemented in the method for curing rubber at issue in the case. While patents were granted during the 1980s for inventions with a substantial software component, and the distinction between patentable and nonpatentable subject matter in this area was progressively shifted and weakened by various court decisions and creative drafting of patent claims, the effectiveness of patent protection for software was far from clear, with many leading software companies filing only limited numbers of applications, or eschewing software patents altogether. This uncertainty was resolved in the mid 1990s, when the 1994 Federal Circuit decision *In re Alappat* drew a definitive distinction between unpatentable software in the form of "a disembodied mathematical concept…which in essence represents nothing more than a 'law of nature,''natural phenomenon,' or 'abstract idea'" and patentable software that is "rather a specific machine to produce a useful, concrete, and tangible result." [30] A series of further court decisions in 1994 and 1995 following *Alappat* culminated in a new set of guidelines, issued by the Commissioner of Patents in May of 1996, which allowed inventors to patent any software embodied in physical media. [31] Further expansion of software patentability came in 1998 with the *State Street Bank & Trust vs. Signature Financial Corp. ("State Street")* decision, which eliminated the requirement that the software algorithm be tied to a "physical transformation."

This evolution of legal and administrative doctrine means that some categories of software patents became more clearly obtainable, and more easily enforceable before others. While software used in manufacturing or "embedded" in hardware devices was covered prior to the 1996 change in guidelines, software more generally was covered after 1996, and financial or business methods software became clearly patentable after *State Street* in 1998. The markets in our sample fall into three groups that were affected by these "regime changes" at different times: those for which software was patentable before 1996 (manufacturing software), those for which it became patentable in 1996 (other types of software not including those affected by *State Street*), and those for whom patentability increased in 1998 (financial software and business methods algorithms). Using the standard differences-in-differences specification, we therefore include in the regression the log of the number of patents in a market, the regime-change dummy, and the interaction of the latter two variables. The coefficient on this interaction term gives the change in the effect of the market's patents on the dependent variable following the expansion of the strength of patents that are relevant to the market.

Figure 3 shows the average number of patents granted in each market, grouped by the applicable regime change. As the figure shows, changes in the volume of patenting and the timing of these changes behave quite differently across the three groups, reflecting the differential impact of the regime changes in 1996 and 1998. Group 1, the set of software markets characterized by manufacturing applications, shows a stable increase over time. Group 2, the set we classify as primarily affected by the legal decisions following *Alappat* and the change in USPTO guidelines as of 1996, sees a dramatic jump after 1996 followed by a return to trend. [32] Markets in the third group, which were affected by *Alappat* but also by *State Street* in 1998, see an increase after 1996 and continue to grow until 2000, when the USPTO began performing more rigorous examinations of business methods patents (the "second pair of eyes"). This change may account for the dip in the number of patents granted in Group 3 after 2000, though other factors such as backlogs and resource constraints at the USPTO may also be at work. [33]



Unambiguously patentable before 1996: Automatic teller machine software, Robotic software, Quality control software, Peripheral device drivers
Unambiguously patentable after 1996: Voice technology software, Natural language software, Neural network software, Fax software, Internet tools, Wide area network software, Local area network software, File management software, Hierarchical DBMS software, Relational DBMS software, Database query language software, 3D representation software, Electronic message systems software, Desktop publishing software, Artificial intelligence R&D, Geographic information systems software, Disaster recovery software, Security/auditing software, Performance measuring software
Unambiguously patentable after 1998: Invoicing/Billing Software, Tax preparation and reporting software, Inventory management software, Order entry/processing software

Figure 3

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PATENTS GRANTED BY YEAR AND TYPE OF SOFTWARE

3.1.1 Patents and Entry

To provide some context, we begin by examining rates of entry into these markets. Table II reports coefficient estimates from Poisson regressions on the number of entrants in each market-year. Standard errors are clustered by market. Column (1) of Table II confirms the findings reported in Cockburn and MacGarvie (2007)—after controlling for market structure, demand, and so forth, [34] the number of patents in force in the market has a substantial negative and significant effect on the number of entrants with an elasticity of −0.6. In column (2) we include measures of uncertainty about the scope of patent rights, with the negative and significant coefficient on the number of claims per patent citation suggesting that markets in which there are a preponderance of such “problem patents” see less entry. [35]

Column (3) of Table II gives the “differences-in-differences” estimates. The negative and significant coefficient on the interaction term indicates that markets with more patents saw larger reductions in entry following the regime change when compared with other post-regime-change markets with fewer patents as well as preregime-change markets. (The positive and significant coefficient on the regime change dummy indicates that there was more entry into markets post-regime-change, but this likely reflects confounding with other factors that are not picked up with by our controls rather than a causal effect of the regime shift.) In columns (4) through (7) we report results estimated separately for “*de novo*” entrants versus “diversifiers” that is, entry into new product markets by firms that are already established in other markets. The marked difference in the estimated coefficients on the number of patents in force and on the interaction term with the regime shift dummy suggest that the negative effect of patent thickets on entry is largely driven by the impact on the *de novo* entrants.

This finding is provocative because it suggests that small, specialized firms were more affected by increases in the strength of IP rights than established firms. As argued above, one mechanism through which this effect may operate is the financing of early-stage firms. If increases in barriers to entry reduce the expected profitability of entrants, they will also reduce their attractiveness to investors and may make it more difficult for *de novo* entrants to raise capital. Note that coefficient on the interaction term with the regime shift dummy (the “treatment effect” from strengthening patent rights in the market) is the *average* treatment effect measured in terms of elasticities. Though it is negative and statistically significant at the 5% level, this coefficient conceals substantial differences across individual market-year observations the marginal “treatment effect” measured in numbers of entrants. Table II reports estimates of the marginal effect of the interaction term at the 25th, 50th, and 75th percentiles of the market size distribution. [36] Individual estimated treatment effects are all negative, although some are quite small and not statistically distinguishable from zero. Larger marginal effects tend to be found in markets with more incumbent firms, suggesting a more complex relationship between the patent landscape and competition than is captured by this simple regression model.

3.1.2 Patents and Initial Funding

Turning to the impact of patent thickets on financing, the first three columns of Table III present results from Poisson regressions on the number of new ventures receiving their first round of financing from external investors. As before, standard errors are clustered by market, and all regressions have market and year fixed effects. The dependent variable is the number of firms in market j that have not previously received external financing and which obtain such investment for the first time in year t. (The following section describes in greater detail how this indicator is constructed, and performs a firm-level analysis of the probability that a firm receives initial investment by a given year. Here we present a preview of these findings by examining the broad market-level association between in initial financing episodes and patenting in the market.) The regressions are run on a balanced panel of observations on our 27 markets between 1994 and 2002, for a total of 243 observations.

The number of firms in a market receiving investment for the first time in year t will depend on the number of firms “at risk” (i.e., the number of early-stage firms that have not previously received investment). We therefore include in the regression a count of the total number of new ventures identified as being present in the previous sample year. Additional controls include the stage of development of firms in the market (the average age of the firms), and the same variables as in the entry regressions to control for demand and market structure, which affect the anticipated profitability of entrants. In column (1) the coefficient on the number of patents in force is large and negative, implying that software ventures that enter markets with larger patent thickets see are less likely to receive funding from outside investors. In this regression the estimated coefficient is negative and significant at the 10% level. [37]

In columns (2) and (3) we use the differences-in-differences specification, and here a significant negative coefficient is estimated on the interaction term with dummy for change in regime. This indicates that patent-intensive markets saw a significant reduction in initial investment by external parties in early-stage firms relative to low-patent markets following the expansion of software patentability in the 1990s.

In column (3) we include measures of the uncertainty of patent rights. We find a negative effect on entry of the mean share of nonpatent references in the citations made by patents in the market. This result is consistent with idea that markets in which patents have relatively more references to the technical literature—that is, are more clearly distinguished from the prior art, and perhaps more likely to be held valid—appear to make new ventures less attractive to outside investors. In specifications where we include interaction terms of the regime shift dummy with the uncertainty variables they are not significant.

3.1.3 Patents and Funding Levels

Columns (4), (5) and (6) of Table III report regression results where the dependent variable is the median amount of financing received by firms active in each market in each year as reported by VentureXpert. [38] We use tobit to estimate the model, because this variable is truncated at zero. These regressions perform rather poorly, with very few variables found to be significant. We believe this reflects the very high level of measurement error in the amount of financing received at the transaction level, which creates some very large and influential outliers, as well as difficulties in adequately capturing heterogeneity across different rounds and unobserved aspects of individual transactions.

The estimated coefficient on patents in the market is negative, as is the coefficient on the interaction of patents with the regime change dummy. However, these estimates are not statistically significant. Similarly, the uncertainty variables have no significant effect on funding amounts, and controlling for these subtler aspects of the patent landscape in each market has little impact on the estimated effect of the number of patents in force. Note that the impact of increased uncertainty on funding has at least two potential effects: uncertainty may affect both the timing of investment and the amount invested and our measure conflates the two effects.

3.1.4 Patents and “Exit”

Finally, columns (7) and (8) and (9) in Table III present results from a Poisson regression on the number of sample firms “exiting” via either IPO or acquisition in each market per year. The coefficient estimates suggest that relative to markets with fewer patents, markets with a large number of patents in force are associated with a lower volume of “exits.” Strengthening patents appears to make software enterprises less attractive to public markets or other outside investors, though the coefficient is only significant at the 10% level. (Adding or dropping control variables, or relying exclusively on market and year fixed effects, can make some of these estimates statistically significant.) We also recognize that there may be difficulties in identifying this effect separately from other factors affecting IPOs. For example, the "tech stock" bubble of the late 1990s is somewhat coincident with the changes in legal regime. We experimented with using the level of the NASDAQ index and the book-to-market ratio in the ICT industry as control variables but found that their inclusion did not substantially alter the main findings and we concluded that the influence of aggregate forces such as these were better captured by the year dummies included in these regressions.

We find similar results for the association of the uncertainty measures with the volume of IPO and acquisition activity. While the estimated effects of some of the uncertainty measures are large, they are not statistically significant.

3.2 Impact of Patent Thickets at the Firm Level

The market-level results, though provocative, do not permit any investigation of our other hypotheses about the impact on uncertainty about patent-related costs on the timing of outside investment. By looking at firm-level data, we can measure the timing of investments at different stages in the growth of new ventures, and test for any impact of patent thickets and our other measures of uncertainty about the scope of patent rights. We can also control for the degree to which investors' concerns about patent thickets are mitigated by new ventures holding their own patents. Cockburn and MacGarvie (2007) find a substantial positive effect of own patent holdings on the probability of entry into a market, suggesting that this may also be an important factor in funding decisions.

3.2.1 Receipt of Initial Funding from VCs and Corporate Investors

We hypothesize that, if patent thickets reduce a venture's expected profits, investors faced with two otherwise identical companies will choose the one operating in a less "thicketed" market.

In order to test this, we would ideally have a dataset comprising firms that sought external funding and were either granted or denied such funding. While this type of data is very difficult to find, we have created what we believe to be a reasonable approximation of such a dataset using a subsample of firms extracted from the CorpTech directory. CorpTech lists more than 19,000 companies producing software that were active at some point between 1992 and 2004, but is unlikely to capture the entire population of software firms. To the extent that firms that appear on CorpTech have passed some threshold of success that warrants their inclusion in the directory, our sample may not be entirely representative of the universe of entrepreneurial companies. Inference based on firm-level census data would allow for unbiased estimates of the effects of patent thickets on investment in early-stage firms. Lacking such data, our estimates may therefore provide a lower bound for the effects of interest.

From the CorpTech sample we select firms founded in 1990 or later that are active in no more than one of our 27 product classes. For firms that appear in CorpTech more than 1 year after being founded, we extrapolate the firm-level data on firm size backward. We eliminate firms that have already gone public or been acquired.

CorpTech reports the initial source(s) of capital for the firm, for all smaller firms founded between 1992 and 2002. This variable allows us to construct a database comprising firms that obtain funding at an early stage from venture capitalists or corporate investors and firms that do not obtain such funding. We use CorpTech to identify the set of firms that did and did not receive funding, and we use VentureXpert to identify the *timing* of first investment. Kaplan et al. (2002) show that VentureXpert omits 15% of financing rounds and 20% of financing committed. To ensure that we do not mistakenly classify firms that receive external funding but are not listed on VentureXpert, we drop from the sample 290 firms that are listed on CorpTech as having VC or corporate investment prior to 2002 but that do not appear on VentureXpert. We also drop firms for which no information is available from CorpTech on initial sources of capital. We are left with a sample of 951 firms, of which 475 receive external funding for the first time between 1992 and 2002.

Using information on the first round of investment from VentureXpert, we create a dummy variable equal to 1 if firm *i* receives venture or corporate financing for the first time in year *t*, 0 before year *t*, and missing after year *t*. This variable takes on a value of zero in all years for firms that never receive funding before 2002. We then perform duration analysis using the Cox Proportional-Hazard model. [39]

Figure 4 gives the Kaplan–Meier survival curves estimated from these data for firms grouped by where their target market falls in the distribution of the numbers of patents in force per market. Here "survival" means failure to attract outside funding, and the survival functions plot the fraction of firms that have yet to receive funding as a function of time elapsed since they were founded. As can be seen from the figure, it takes about 5 years on average for 50% of firms to get their first round of funding. Separate survival functions are estimated for markets falling in various percentiles of the "thicketedness" distribution.

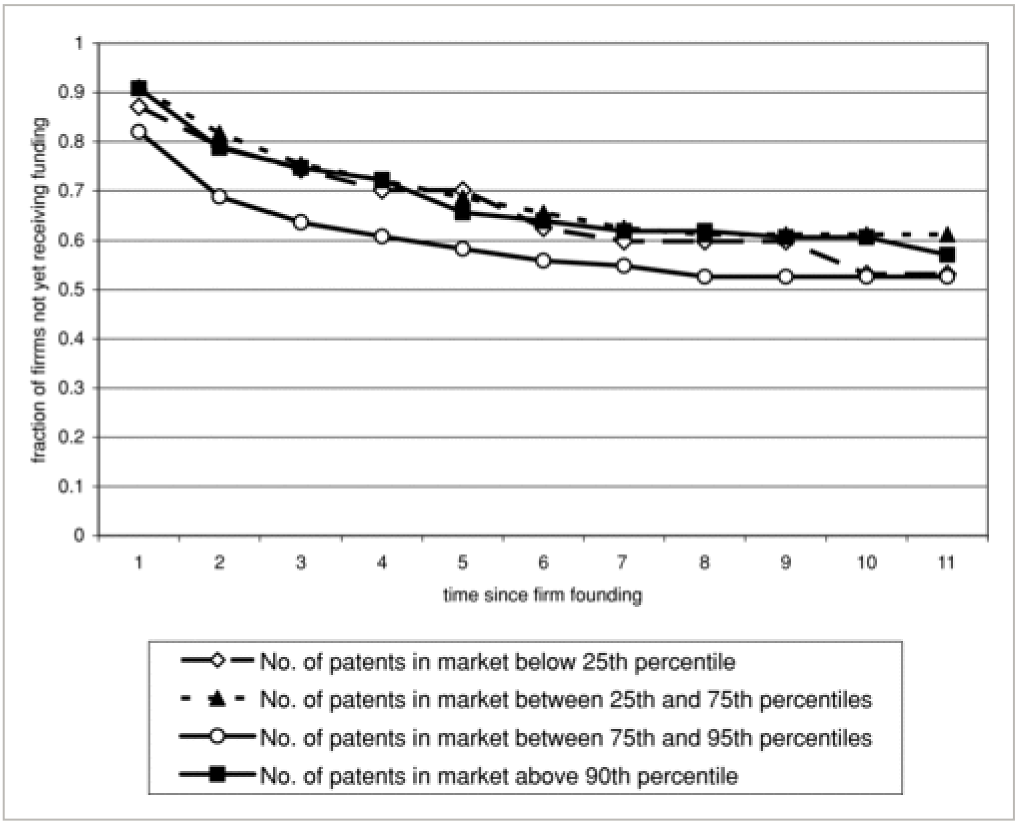

Figure 4

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SURVIVAL FUNCTIONS FOR THE HAZARD OF OBTAINING OUTSIDE FUNDING

There are no striking differences across these groups of markets. However, once the survival functions are adjusted for the size of the market (number of incumbents and number of incumbents squared), we see quite striking differences in the impact of patent thickets. [40] As can be seen in Figure 5, the estimated survival functions for different groups of markets show that software ventures in the most thicketed markets have a very small probability of obtaining outside funding in any given year and thus on average receive outside funding much later than firms operating in less thicketed markets. Moving from the most thicketed groups to the least, each survival function falls below that for the previous quartile: for any given duration since firm founding, the fraction of firms not received outside funding is lower in less thicketed markets.

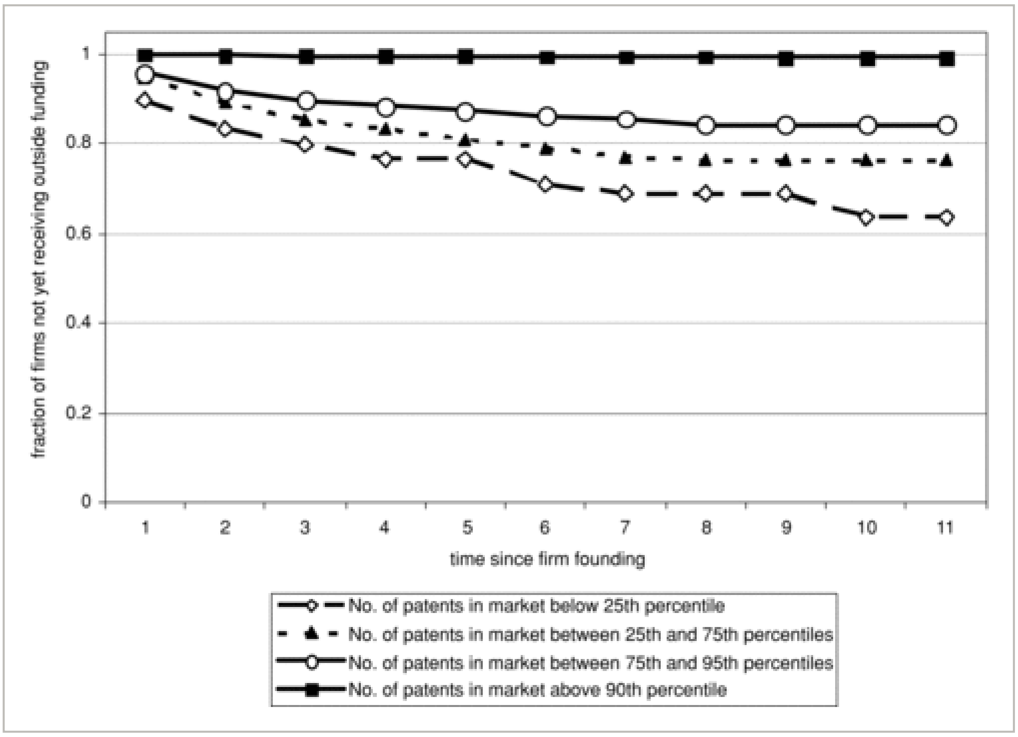

Figure 5

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SURVIVAL FUNCTIONS FOR THE HAZARD OF OBTAINING OUTSIDE FUNDING, ADJUSTED FOR THE NUMBER OF INCUMBENTS IN EACH MARKET

These results show the importance of controlling for market characteristics, and in the hazard models, our explanatory variables include year and product market fixed effects and the modal citation lag for patents in the market. Other market-level controls relating to profitability in the firm's target market include the number of incumbents in the market and the number of incumbents squared, and the growth of sales in the market. [41] Variables relating to the patent landscape include the log of the patent stock in the market and the Herfindahl over assignees of citations made by patents in the market. [42] Firm-level explanatory variables include the aforementioned dummies for firm size range, implicitly the age of the firm (because the "duration" variable is years since the birth of the firm), and the number of each firm's patents granted and pending. [43]

Table IV gives results from these regressions, reported as hazard ratios. Estimates larger than one indicating a positive effect on the hazard of receiving funding, and estimates less than one indicating a negative effect. In general the hazard of funding is nonlinearly related to the number of competitors in the market, with an initial increase—presumably reflecting an increase in expected profits due to a reduction in the market power of incumbents or a reduction of barriers to entry created by network effects—then falling as the number of incumbents increases, which could reflect the fact that large numbers of incumbents indicate more mature, more crowded, and less attractive markets. The dummies for the range of firm size (not reported, but available upon request) display a concave relationship between firm size and the hazard of initial funding. The standard errors in these regressions are somewhat sensitive to the selection of control variables, but adding or dropping control variables has little effect on the estimated coefficients on the patent variables.

Table IV.

Hazard model of initial funding episode

Dummies for Year, Market and Employment Size Range Category Included. Standard Errors Clustered by Firm						
Patent Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Full Sample		**Post-Regime Change**			**Discrete-Time**
Ln (Patents in Market)	0.748	0.767	0.209	0.155	0.201	0.935
	(0.274)	(0.268)	(0.160)**	(0.120)**	(0.161)**	(0.350)
Firm's patents granted	0.963					
	(0.050)					
Firm's patents pending	1.161	1.154	1.149	1.149	1.148	1.243
	(0.050)***	(0.047)***	(0.049)***	(0.049)***	(0.049)***	(0.080)***
D(Regime Change)		3.024				4.069
		(2.657)				(4.065)
D(Regime Change) × ln (Patents in Market)		0.776				0.749
		(0.095)**				(0.105)**
Herfindahl of citations in market				0.998		
				(0.001)*		

Coefficients expressed as hazard ratios.

* significant at 10%; ** significant at 5%; *** significant at 1%.

The “patent landscape” variables display a pattern consistent with several of our hypotheses. In all of the regressions, increases in the total number of patents in the market are associated with a substantial reduction in the hazard of receiving funding (or, equivalently, longer delays in receiving funding). Conversely, we find a positive and significant effect on the hazard of receiving funding for software ventures that have their own patents. Consistent with the idea that investors are forward-looking (and with anecdotal evidence about interaction of start-ups with venture capitalists) a much larger and statistically significant effect is found for the number of patents pending than for the number of patents granted. [44] This finding is consistent with the results of Haussler, Harhoff, and Muller (2009), who also find that patent applications matter for the financing of start-up firms while patent grants do not.

In column (2), the differences-in-differences specification shows that the negative effect of patent thickets is larger in markets where patent rights were strengthened relative to those where it was not. A one standard deviation increase in the number of patents in the market is associated with a reduction in the hazard of being funded of about one percentage point. This effect is much larger after the regime changes, with for a one standard deviation increase in the patent stock in the market associated with a 0.04 reduction in the hazard of funding. Given that the mean probability of obtaining funding in a given year is 0.086 overall and 0.101 after the regime changes, this effect appears to be of considerable importance. The significance of these results is robust to clustering at the market level. The "average treatment effect" implied by the interaction term is of similar magnitude, estimated from a logit discrete-time version of the Cox continuous-time model.

Comparing estimates using the full sample of data to those obtained for the subsample of observations after the regime change shows that the impact of patent thickets was much larger during this latter period. Consistent with the quite large negative interaction term effect in column (2), the hazard of receiving funding is substantially lower for this subsample than for the full sample. The marginal effect of the number of patents in force is almost four times larger after 1996 than for the full sample.

Column (4) of Table IV reports results from including the Herfindahl index of citations across assignees, a measure of the concentration of ownership of patent rights which is our proxy for bargaining costs. (We report results only for the post-regime subsample. Coefficients were insignificant but of the same sign and similar magnitude when the same specification was used on the full sample.) In contrast to the hypotheses about bargaining costs and the concentration of patent ownership discussed above, we find a negative and borderline significant (with a p-value of 0.051) effect on the hazard of receiving initial funding. In other words, an initial round of funding by external investors is *less* likely to be obtained by software ventures operating in markets where IP ownership is more concentrated. Our alternative measure of bargaining costs, a quadratic in the number of cited assignees, was not significant. This finding contrasts with other papers in the literature, such as Ziedonis (2004) and Noel and Schankerman (2007). It is more consistent with an alternative story laid out in Galasso and Schankerman (2008), in which increases in fragmentation of ownership of IP reduce the amount at stake in licensing negotiations and thus reduce the probability of litigation.

3.2.2 Exits

Table V presents results of a model of the probability that a new venture ultimately "exits" from the entrepreneurial phase by going public or being acquired by another firm, as opposed to continuing to operate as an independent privately held firm (or being liquidated.) Most of the information on the dates of IPO or M&A comes from VentureXpert. For a subset of firms that are listed on CorpTech as having gone public or been acquired by 2002, we performed lexis-nexis and web searches to obtain the dates of these events. Firms that were founded after 1990 and are listed as private on CorpTech as of 2002 for which there is no date of IPO on VentureXpert are assumed not to have gone public in the interim. [45] Although not all of the firms contained in the time-to-first funding sample analyzed in Table IV are included in the dataset analyzed in Table V, the number of observations in Table V is larger than in Table IV because firms exit the time-to-first funding sample once they receive their first round of funding. The market-level variables are as described above. [46]

Table V.

Duration Model of IPO/Acquisition

Dummies for Year, Market, and Employment Size Range Included. Standard Errors Clustered by Firm.					
Patent Variables	(1)	(2)	(3)	(4)	(5)
	Cox Proportional-Hazards Model			Competing Risks Model	
	All Firms		Firms Without Patents	All Firms	
				IPO	M&A
Ln(Patents in the market)	0.323	0.329	0.998	[illegible]	[illegible]
	(0.268)	(0.268)	(0.664)	(0.215)	(0.562)
Firm's patents pending	1.092	1.094		1.291	0.832
	(0.046)**	(0.046)**		(0.074)***	(0.158)
Firm's patents granted	1.019	1.111		0.940	1.148
	(0.033)	(0.124)		(0.072)	(0.059)***
D(Regime change)		5.201	13.572		
		(7.970)	(23.851)		
D(Regime change) × Ln(Market's patents)		0.709	0.596		
		(0.156)	(0.154)**		
D(Regime change) × Firm's		0.915			

Robust standard errors in parentheses.

* significant at 10%; ** significant at 5%; *** significant at 1%.

The unit of observation for this analysis is a calendar year, and in columns (1), (2), and (3) we use a Cox proportional hazard model. As in Table IV, coefficients presented in the table are hazard ratios.

The last two columns of Table V give results from estimating a competing risks discrete time hazard model in which we use a multinomial logit for the probability in each period of "exit" versus IPO, "exit" via acquisition. The dependent variable is equal to 0 in each year prior to exit via IPO or acquisition, 1 in the year that the firm goes public, and 2 when the firm exits via acquisition. Firms that are censored or liquidated take on a value of zero in all periods. (Competing risks can be estimated using this type of multinomial logit model provided the competing risks are independent, see Allison (1982).

Consistent with the market-level results on IPOs, we find that the hazard of going public or being acquired is generally lower in markets with more patents, though the coefficient is not significant. We also find that the hazard of exiting from the sample in these ways is increasing in the number of pending patents owned by the venture (a strongly significant effect) and is substantially higher for VC-backed and corporate investor-backed firms.

In the differences-in-differences specification in column (2) we find a negative and insignificant effect of the number of patents in the market on the probability of exiting via IPO or acquisition, an insignificant positive effect of the regime shift dummy, [47] and a negative but insignificant interaction effect of the legal regime change with the number of patents in the market. As with the model for hazard of initial funding the firm's own patents pending have a strongly significant positive effect on the probability if getting outside investment, but not patents granted. Note also that the regime shift has an insignificant interaction with the firm's own patents.

The impact of patent thickets is apparent when we estimate the model on the subset of firms that did not obtain any patents of their own (column (3).) Here the estimated “treatment effect” of the regime shift is substantially more negative, and statistically significant. This finding is striking in light of the fact that only a minority of the firms in our sample hold patents by the time of exit (approximately 20% have patents granted by the time of IPO/acquisition). An important question for future research is why, given the apparent differences in success rates between patent-holding and firms that do not hold patents, relatively few firms in these markets filed patents during this time period.

The competing risks model results are presented in columns (5) and (6). We cannot reject the hypothesis that the effect of number of patents in the market is the same for IPO and acquisition. Interestingly, while granted patents do not matter for IPOs, they are positively and significantly associated with the probability of being acquired.

4. Summary and Conclusions

The impact of stronger intellectual property rights in the software industry is controversial. One often underemphasized means by which patents can affect technical change, industry dynamics, and ultimately welfare, is through their role in stimulating or stifling entry by new ventures. The mechanisms through which patents can impact this process are, as ever, complex. Patents can block entry, or raise entrants' costs in variety of ways, while at the same time they may stimulate entry by improving the bargaining position of entrants vis-à-vis incumbents, and supporting a “market for technology,” which enables new ventures to license their way into the market, or realize value through other forms of trade in their intangible assets. Some of the impact of patent thickets may therefore be felt in the interaction of new ventures with the capital markets, and here we find evidence that the extraordinary growth in patenting of software has had a variety of effects on the financing of software companies.

Our analysis of an unique dataset that contains information on software ventures that do not obtain outside funding as well as those that do attract VC and corporate investments provides evidence that patents significantly affect the likelihood of obtaining funding for early-stage firms. Firms in “thicketed” markets with large numbers of patents are less likely to receive funding from outside investors at both early and late stages in the entrepreneurial process compared to those in markets with fewer patents. In aggregate, start-up software companies operating in markets characterized by larger patent thickets see their initial round of VC or corporate funding delayed relative to firms in markets less affected by patents. In firm-level analyses that control for additional characteristics of start-up firms, we find similar results. We also find that changes in the legal regime that strengthened patent rights made the association between patents in a market and the probability of receiving initial outside funding significantly more negative. Our results suggest that there is less entry into markets where patents on average have a higher ratio of claims made to the amount of prior cited, which we interpret as a proxy for uncertainty about the quality of patents in a market. However, these results were not found in the firm-level models of timing of funding from outside investors or liquidity events.

One of the most statistically robust (and provocative) findings of this paper is the importance of new ventures obtaining their own patents. Firms that have higher numbers of their own patents are more likely to receive funding from outside investors, and more likely to subsequently “exit” from the entrepreneurial phase through IPO or acquisition. Interestingly, the number of a firm's patents *pending* is positively and significantly related to the probability of obtaining external funding, while the number of patents already granted is not—holding constant the number of patents granted, outside investors appear to be more focused on these firms' “pipeline” of IP assets under development. The estimated effect is quite large: each additional patent pending increases the hazard of funding by around 15%.

One interpretation of these results is simply that patents reflect the value of the firm's technology: firms with higher quality innovations obtain more patents and are also more attractive to outside investors. However, patents may also convey other information. For example these findings may in part reflect the value to outside investors of the ability to obtain patents as signal of the quality of a new venture's management. Hsu and Ziedonis (2007) show that larger numbers of patent applications are associated with higher valuations of early-stage semiconductor companies, and attribute this in part to factors other than the information about a firm's technology that is provided by patents. Beyond this “capabilities” argument, we suggest that when faced with a patent thicket, patents also confer significant competitive advantages on entrant firms in minimizing transactions costs associated with incumbents' patent holdings.

Unfortunately, it is hard to disentangle these effects in these data without independent information about the value of nonpatented innovations. Nonetheless, we find it striking that only 20% of the firms in our funding regression sample (and only 33% of the firms that ultimately got funding) ever filed for a patent during our sample period. If the benefits from holding patents are as substantial as our results suggest, it is puzzling why more of the firms that were active in these markets during this period did not obtain them. One explanation may be that causality between funding and patent applications runs in the opposite direction: it may be that investors require early-stage firms to file patent applications as a condition of receiving funds, or that applications are observed disproportionately by firms that get funding and are more able to support the substantial costs of patent prosecution. In these data we only observe applications that are subsequently granted, so this may be a significant source of bias if large numbers of unobserved applications are abandoned by firms who are not funded.

This paper documents a number of mechanisms through which patents confer private benefits to software companies. Patent thickets appear to offer significant protection to incumbent firms, and their presence also appears to have given entrant firms a powerful incentive to acquire their own patents. These effects are reflected in the extraordinary surge in patenting in this industry. However, these incentives to obtain patents may ultimately become collectively self-destructive. Our differences-in-differences estimates of the relative impact of strengthening patent rights show a general intensification of the negative association with entry and financing in the most heavily thicketed markets. Continued accumulation of patents therefore could potentially result in the "stifling" effects identified here substantially offsetting the "stimulating" effect on innovation.

Footnotes

1 U.S. House of Representatives Oversight Hearing on the Patent System, February 15, 2007. See Jaffe and Lerner (2004) and Bessen and Meurer (2008).
2 Exactly how many software patents have been issued is a controversial issue, because many software inventions may be embedded in other technology. See Graham and Mowery (2003), Bessen and Hunt (2007).
3 Shapiro (2001), p.2.
4 Pignalberi (2004), Lessig (2002).
5 See Robbins (2008). Public auctions of IP such as those conducted by Ocean Tomo in recent years are provocative, but cover only very small and highly selective samples of patents.
6 In a related paper (Cockburn and MacGarvie, 2007), we looked at the impact of thickets on rates of entry of new firms, and find that there are fewer entrants into software markets in which there are more patents, after controlling for characteristics of the firm such as age or own patent holdings, and characteristics of the market such as the average importance of patents and the stage of the product lifecycle.
7 Infringing valid patents can present the entrant with very substantial ex post penalties, such as damages judgments (tripled in the case of "willful infringement") or the loss in value of assets stranded in the wake of an injunction obtained by the patent holder.
8 Brian Kahin (2004) cites the hearings in 2002 on *Competition and Intellectual Property Law and Policy in the Knowledge-Based Economy*, held by the U.S. Federal Trade Commission and the Department of Justice at which Frederick J. Telecky of Texas Instruments stated that: "TI has something like 8000 patents in the United States that are active patents, and for us to know what's in that portfolio, we think, is just a mind-boggling, budget-busting exercise to try to figure that out with any degree of accuracy at all." Kahin notes that, "If a company with TI's resources cannot assess what they have in-house, it is difficult to expect a small company entering a market to evaluate what claims they may be facing."
9 Arrow (1968), Bernanke (1983), Dixit and Pindyck (1994), among others.
10 These "exits" are also important mechanism for industry consolidation and restructuring, which is a topic beyond this scope of this paper.
11 Allison et al. (2007) describes the patent filing behavior of several large players in the industry, showing that IBM was an early patenter while firms like Adobe, Autodesk, Computer Associates and Oracle came late to the software patent game (in terms of applications filed). While a detailed examination of the various motivations for patenting by the firms in our sample is indeed an interesting subject for future research, we focus here on the observed patterns of patenting and entry and investment rather than on documenting the organizational processes at work.
12 According to the USPTO website, "The length of this delay is determined by many factors, including PTO workload, budget and manpower levels, and patent printing schedules…[for example,] The 1986 patent grant data are lower than would have normally been expected due to a lack of printing funds."
13 In Cockburn and MacGarvie (2007) we used an instrumental variables approach to address the potential endogeneity of patenting by incumbents, and obtained coefficients essentially identical to those estimated by OLS.
14 Of course, if these changes in the legal regime result in increased incentives to obtain patents, the thicket we evolve endogenously over time, leading to more complicated dynamics that are beyond the scope of this paper. Note though that the given the pendency period at the USTPO, these effects are manifested in granted patents only very slowly. The differences-in-differences approach used here thus identifies only the "prompt" impact of the regime shift.
15 We define software companies as the firms listed in CorpTech as having at least one product classification beginning with "SOF," which is CorpTech's code for software. Note that the CorpTech data reports biennially rather than annually, so that we see 12 sample years of data rather than 24 calendar years.
16 We are grateful to Bronwyn Hall for code that comprises the core of our name-matching program.
17 The founding dates on CorpTech and SDC are within 3 years of each other 83% of the time. For firms with more than 3 years disagreement between founding dates in the two samples, we used web searches to obtain the correct founding year.
18 Clearly there is some potential for selection bias to influence our results, however, we believe that the criteria used to choose these markets are independent of entry and exit dynamics and the sample of 27 SOFs does not appear to be markedly different from the other 262 in terms of firm characteristics and entry and exit rates (see

the appendix of Cockburn and MacGarvie [2007]). One area in which our sample differs, however, is in terms of the average number of patents held by firms active in the market. The average firm active in one of the sample markets has 29 patents, while the average firm in a market omitted by the sample has only 18 patents, and this difference is statistically significant. Note though that this difference arises by construction: it is difficult, if not impossible to identify patents related to many of the more vaguely defined markets. In our judgment, therefore, this subset of markets is reasonably representative of software products in general.

19 Firms are treated as *de novo* entrants if the firms are younger than 10 years old and specialize in only one of CorpTech's main software product classes, e.g. AI: artificial intelligence.

20 For firm *i* active in in market *j* as well as *n*-1 other markets, we compute average sales per market in market *j* as $SALES_i/n$ (the total sales of the firm divided by the number of markets in which it is active). We then add up the average sales per market for all firms active in the market. CorpTech contains a numerical sales variable as well as a categorical variable that indicates the range in which the firm's revenues fall. A significant portion of observations on the former are missing, and we fill in these observations with the midpoint of the range indicated by the categorical sales variable.

21 Arora et al. (2007) use a somewhat similar approach to create a comprehensive concordance between USPTO classes and software product categories. Silverman (1999) is a notable example of the principle alternative to this approach, which is to link data on patent classes to industry classifications using on a concordance developed from "industries of use" assigned by Canadian patent examiners. We judged this approach to be unhelpful here, given the fine-grained industry definition that we use, and substantial differences over this period between the US and Canada in patentability of software.

22 Infringement of valid patents can present the entrant with very substantial *ex post* penalties, such as damages judgments (tripled in the case of "willful infringement") or the loss in value of assets stranded in the wake of an injunction obtained by the patent holder.

23 Following the literature we also computed a patent stock from annual flows of patent grants, using the perpetual inventory method and the standard "Griliches constant" 15% depreciation rate. By depreciating the stock over and above expirations of patents, this would allow for some obsolescence of patents. During the sample period, while the average market had 2371 patents in force, the depreciated stock averaged 1238. Very similar results were obtained in the regressions below using the this measure as an alternative to the undepreciated accumulated stock of patents in force.

24 In Cockburn and MacGarvie (2007) we use an alternative measure, a count of the number of cited assignees in each market.

25 "Prior art" is not confined to patents, indeed most forms of printed publication describing the claimed invention can constitute prior art, as can public knowledge, use, or sale of the technology.

26 We also experimented with using the four-firm concentration index of citations across assignees to measure the concentration of patent rights, and obtained similar results. These results are available from the authors upon request.

27 We compute the citation frequency as the ratio of the number of observed citations to the number of potential citations. That is, if Ckgd is the number of citations made to patents in market k in citing year g to patents granted in market k in cited year d, Pkg is the number of patents granted in class k in year g, and Pkd is the number of patents granted in class k in year d, the citation frequency is Ckgd/(Pkg Pkd).

28 The usefulness of this variable as an indicator of the stage of the product cycle obviously depends on the assumption that the key inventions are patented, and that the propensity to patent stays more or less constant over the lifecycle.

29 See also Bessen and Meurer (2006).

30 *In re* Alappat, 33 F.3d 1526, 1544 (Fed. Cir. 1994), quoted in Sterne and Bugaisky, p. 222.

31 Sterne and Bugaisky, p. 223.

32 As a robustness check, we have also used 1994 (the year of the Alappat decision) as the date at which software became generally patentable. Results were little changed.

33 Similar patterns are visible when patents are counted by application year rather than grant year.

34 We use dummies for the deciles of the modal citation lag to allow for a potentially nonlinear relationship between the stage of the product cycle and the rate of entry.

35 In regressions not reported here (but available upon request) we split the sample into "small" markets (with a number of incumbents below the median for that year) and "large" markets, to investigate the hypothesis that transaction costs matter more for entry into small markets while uncertainty is a more significant barrier to entry when the stakes are high. We found that the smaller markets had a larger patent elasticity (i.e. the effects of transaction costs are more substantial), and the effects of the average number of claims per citation were insignificant, while the share of non patent prior art was positive and significant. In larger markets, the number of patents in the market has a less negative but still statistically significant coefficient, while the effect of

uncertainty as measured by the claims/cite ratio is stronger and more significant. The share of non patent prior art is not significantly related to entry in large markets.

36 These effects were obtained by calculating the pre- and post-regime change difference in the partial derivative with respect to the log of patents in the market, using Stata's *predictnl* command. This command computes standard errors via the delta method. See **Ai and Norton (2003)** for more on interaction effects in nonlinear models.

37 With only 243 observations, a full set of market and year fixed effects, and limited independent variation in some of these control variables these estimates are somewhat sensitive to the set of controls that are included.

38 As in the previous two columns, in these regressions we again have a balanced sample of 27 markets, but the data end in 2002 because we construct the number of pre-IPO firms active in the market using information from CorpTech on ownership status that does not go past 2002.

39 Essentially similar results are obtained using logit Discrete-Time Hazard models.

40 These graphs were created using Stata's *sts* command, which estimates separate Cox regressions for each percentile group. Adjusting for the number of incumbents means that the number of incumbents and the number of incumbents squared were included as covariates in the Cox regression.

41 The inclusion of a proxy for the CR4 of sales in the market was rejected by a likelihood ratio test. The same is true of the log of the number of forward citations per patent in the market.

42 This is computed by taking patents associated with a given market (SOF) in application year t, and calculating the share of their backward citations received by each of a set of assignees. Assignee names were cleaned using a combination of an algorithm and manual inspection. Backward citations to patents granted no more than ten years previously are omitted.

43 We also tried including controls for characteristics of the investors in each venture (total patents held by investors, the receipt of earlier rounds of funding corporate investors as opposed to VCs, and the cumulative number of IPOs by firms in which investors had previously invested) and of the venture itself (total amount invested to date, and number of patents held.). These variables were not significant.

44 To limit the influence of a small number of outliers in the number of patents granted and pending, we winsorize these variables at the 99.9th percentile. Similar results were obtained using lower percentile cutoffs.

45 While it is conceivable that a firm could have gone public and then returned to privately held status by 2002 without showing up on VentureXpert, we feel the number of firms in our sample for which this could be true is very small.

46 The coefficient on this variable is not reported but is available upon request. We also estimated models in which an observation was a firm-round, rather than a firm-year, and obtained comparable results.

47 The main effect of the regime shift dummy is very difficult to estimate in this sample due to collinearity with market and year fixed effects, and some very small cell counts. The estimated hazard ratios of 14 or 15 reported in the table have very large standard errors and should not be taken literally.

Appendix

Table AI.

Timing of Regime Changes in Software Patentability for Markets in the Sample

Pre-1996	
ba_a	Automatic teller machine software
ma_c	Robotic software
ma_q	Quality control software
ut_h	Peripheral device drivers
After 1996	
ai_a	Voice technology software
ai_l	Natural language software

ai_n	Neural network software
cs_f	Fax software
cs_i	Internet tools
cs_l	Wide area network software
cs_w	Local area network software
dm_f	File management software
dm_mh	Hierarchical DBMS software
dm_mr	Relational DBMS software

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