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by

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ABSTRACT

This paper considers the impact of the intellectual property (IP) system on the timing of cooperation/licensing by start-up technology entrepreneurs. If the market for technology licenses is efficient, the timing of licensing is independent of whether the patent has already been granted, and productive efficiency considerations will determine license timing (which likely will be as early as possible after invention). In contrast, the need for disclosure of unprotected knowledge on the part of the inventor, asymmetric information between the licensor and potential licensees, or search costs may retard efficient technology transfer. In these cases, reductions in uncertainty surrounding the scope and extent of IP rights may facilitate trade in the market for ideas. Employing a dataset which combines information about cooperative licensing and the timing of patent allowances (the administrative event when patent rights are clarified), we find that pre-allowance licensing is quite common, occurring in about 27% of our sample. Furthermore, the administrative resolution of uncertainty over patent rights significantly increases the hazard rate for achieving a cooperative licensing agreement, and this effect is particularly salient in the period immediately following the patent allowance date. Finally, the impact of the patent system depends on the strategic and institutional environment in which firms operate. In those environments where productive efficiency is important (e.g., where the technology lifecycle is short), or when alternative mechanisms such as copyright protection, reputation, or brokers are available, the impact of patent allowances on licensing is reduced. The findings suggest that imperfections in the market for ideas may be important, and that formal IP rights may facilitate gains from technological trade.

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1. Introduction

The commercialization of innovation often depends on transferring the knowledge and technology underlying an innovation from the original inventor to a firm able to effectively develop that innovation for the market (Teece, 1986; Arora et al., 2001). The gains from technological trade may include reductions in the costs associated with translating an idea into a commercially viable product and enhancing specialization by firms into knowledge production or commercialization (Arora and Gambardella, 1994). Imperfections in the market for technology may significantly reduce the gains from technological trade. Potential licensors may limit information disclosure in order to avoid expropriation by potential partners (Arrow, 1962; Anton and Yao, 1994), particularly when knowledge disclosure requires effort on the part of the licensor (Arora, 1995). Moreover, matching in the market for technology may depend on a costly search process, limiting technology partnerships (Hellmann, 2005).

This paper evaluates the role that *formal* intellectual property (IP) rights, most notably patents, play in facilitating technology transfer between firms in the market for ideas (Nelson and Merges, 1990; Arora, 1995; Arora, et al., 2001; Gans, et al., 2002). We focus on how the IP system impacts the *timing* of cooperation between start-up technology entrepreneurs and more established firms in the commercialization process. Building on recent studies that highlight the operation of the patent system (Cohen and Merrill, 2003; Jaffe and Lerner, 2004; Johnson and Popp, 2003), we empirically exploit a fundamental feature associated with the process of patenting: patent grant delay. While most analyses implicitly assume that once an invention is developed, IP rights are granted and enforced, both the grant of IP rights and the achievement of cooperation take place over time. When licensing occurs, it takes place in one of two institutional regimes: a pre-patent period in which the scope and timing of rights is uncertain, or a post-patent period in which uncertainty about the scope of IP rights has been narrowed. Start-up innovators pursuing a cooperative commercialization strategy face a crucial dynamic tradeoff: while an early agreement enhances productive efficiency (and reduces time-to-market), later agreements may be associated with greater bargaining power and more effective technology transfer. We contend that the timing of cooperation is, therefore, a key strategic choice, and the optimal timing of cooperation depends on the commercialization environment in which the firm operates.[1]

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[1] Only a small number of studies consider the timing of licensing behavior (Katila and Mang, 2003; Dechaneaux et al., 2003; Elfenbein, 2005), and we are not aware of prior work focusing on the role of patent grant delay in the timing of cooperative behavior between start-ups and potential licensees. While an extensive literature examines the role of uncertainty in patent licensing, and the drivers of patent licensing and patent litigation settlement (e.g., Katz and Shapiro, 1986; Gallini and Winter, 1985; Lanjouw and Lerner, 2001; Schankerman and Scotchmer, 2001), these studies do not explicitly consider the timing of licensing, focusing primarily on the impact of alternative legal rules on the division of rents between licensee and licensor.

To explore the role of the commercialization environment in shaping commercialization dynamics, we focus on the moment at which uncertainty over the rights to be granted by the USPTO are announced to the patent applicant, called the Notice of Patent Allowance (the formal patent "grant" follows 5-7 months later, on average). The identification strategy exploits the significant empirical variation in patent allowance and licensing lags across technologies, and the timing of licensing relative to patent allowance. We construct a novel dataset of 200 technologies developed by start-up innovators and ultimately commercialized through cooperation. For each technology, we link the timing of cooperative licensing with the timing of patent application and allowance, as well as other firm and market characteristics. We then examine whether the likelihood of cooperation (as measured by the cooperation hazard rate) *changes* in response to a *change* in the commercialization environment (most notably the mitigation of uncertainty over the scope of patent rights resulting from patent allowance). Moreover, we explore whether the impact of patent allowances depends on the firm's industry, location, and organization, or characteristics of the technology. By considering how the timing of cooperation is changed by the timing of patent allowance, we provide evidence for the causal influence of the IP system on the functioning of the market for ideas.

Our findings indicate that patent allowance substantially increases the hazard rate of achieving a licensing agreement (a 70-80% increase in the licensing hazard), and this effect is most pronounced in the time period immediately following the patent allowance event. Moreover, the overall rate of licensing and the salience of patent allowance on the licensing hazard rate are associated with measures of the strategic and institutional environment in which firms operate. For technologies where productive efficiency effects are important, the overall rate of licensing is more rapid. For technologies with alternative IP rights available (such as copyright) or firms in locations where information brokers and reputational mechanisms may be important (such as Silicon Valley), the impact of patent allowance on the licensing hazard rate is reduced. We are cautious in our interpretation, however, as the sample size is modest and the analysis is conditioned on a sample of firms for which licenses are observed (and so we do not model the behavior of firms choosing alternative commercialization strategies (as we do in Gans et al., 2002)). With these caveats in mind, the results provide evidence that the market for ideas is subject to significant imperfections, and formal IP rights play a role in facilitating cooperative commercialization.

The paper is organized as follows. The next two sections motivate our empirical analysis by discussing the dimensions of uncertainty associated with the patent system and introducing a framework for understanding the role of uncertainty in shaping the timing of cooperation between start-up technology entrepreneurs and more established organizations. After describing the data, Section 5 develops the empirical framework. And Section 6 presents our main empirical results. A final section concludes.

2. Probabilistic Patents[2]

Recent research on the impact of the patent system on technology entrepreneurship emphasizes the potential role of intellectual property in facilitating commercialization through the market for ideas (Kitch, 1977; Nelson and Merges, 1990; Arora et al., 2001; Gans et al., 2002). In the absence of formal intellectual property, start-up innovators seeking commercialization partners may be subject to expropriation (Arrow, 1962, Anton and Yao, 1994). At the same time, efficient commercialization often requires contracting with more established partners in control of key complementary assets (Teece, 1986). Formal intellectual property rights may enable technology transfer by reducing the potential for expropriation, thereby increasing the incentives for knowledge disclosure and technology contracting.

This perspective on the patent system implicitly (or explicitly) assumes that the operation of the patent system is itself efficient and involves an unambiguous administrative process: patents are granted in a timely manner and are associated with well-defined property rights conferring significant competitive advantage. However, recent research on the operation of the patent system and the enforcement of patents have emphasized that patents are "probabilistic" property rights (Cohen and Merrill, 2003; Lemley and Shapiro, 2005). To the extent that patent grants, patent enforcement, and the market value of patents are probabilistic, this uncertainty may have implications for technology contracting. As we discuss in Section 3, the presence of specific types of uncertainty may limit opportunities for efficient contracting and shift the timing of cooperative commercialization. It is therefore useful to distill the different types of uncertainty affecting the patenting process, including uncertainty over: (1) patent allowance, (2) patent scope, (3) patent grant delay, (4) patent enforceability, and (5) patent value.

Patent grant uncertainty. From a legal and conceptual perspective, one of the crucial sources of potential uncertainty in the patent system could be whether a patent applicant is likely to receive any patent rights. However, while the formal structure and rules of the patent system suggests a high degree of uncertainty over patent grant, recent empirical research on the US and EU patent systems suggest that most patent applications are granted in some form. Once one takes into account "continuing patent applications" (which allow applicants to revise their applications over time), the US patent grant rate may be as high as 90 percent (Quillen and Webster, 2001, 2006; Graham and Harhoff, 2006). In short, most "committed" applicants receive at least some form of protection in the US, Europe and Japan (Jensen et al., 2006). The key moment at which the uncertainty over grant is resolved is associated with a Notice of Allowance. When inventors receive a Notice of Allowance, the precise nature of the claims that will be granted are specified (i.e., "The application identified above has been examined and is allowed for issuance as a patent. Prosecution on the merits is closed. This Notice of Allowance is not a grant of patent

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[2] This title is drawn from Lemley and Shapiro's (2005) who highlight the crucial role of uncertainty in shaping the use and function of formal intellectual property rights.

rights. This application is subject to withdrawal from issue at the initiative of the office or upon petition by the applicant.").[3] While the Notice of Allowance substantially reduces uncertainty over whether a patent grant will occur, it reduces but does not eliminate more pervasive sources of uncertainty, such as the ultimate scope of the patent, or the costs and challenges of enforcing the patent through litigation.

Patent scope uncertainty. While most patent applicants are granted a patent in some form, significant uncertainty exists over the scope of the patent rights ultimately allowed and the enforceability of allowed claims through litigation.[4] Indeed, the heart of the patent examination process involves repeat negotiations and correspondence between a patent applicant and the patent examiner over the allowance or disallowance of particular patent claims, or the precise wording of those claims (Cohen and Merrill, 2003). This uncertainty surrounding the wording and scope of patents prior to allowance increases the costs of specifying a technology license (Lerner and Merges, 1998); as emphasized in our practitioner interviews, pre-allowance contracts often require complex contingent clauses (e.g., "royalty rate r applies if Claim #x is allowed, while royalty rate r' applies if Claim #x is disallowed"). As noted by Heller and Eisenberg (1998) in their discussion of biotechnology patents: "Although US patent law does not recognize enforceable rights in pending patent applications, firms and universities typically enter into license agreements before the issuance of patents, and firms raise capital on the basis of the inchoate rights preserved by patent filings…each potential patent creates a specter of rights that may be larger than the actual rights, if any, conferred by the PTO." Patent allowance not only reduces the uncertainty of patent scope, but also reduces the information asymmetry between patent applicants and potential licensees (applicants have more detailed information about interactions with the examiner and the likely scope of allowed claims). Of course, uncertainty over patent scope is not fully resolved until "the last court speaks," a process which involves significant (endogenous) investment and time (Lanjouw and Schankerman, 2001; Lemley and Shapiro, 2005).

Patent pendency uncertainty. Though most research on the patent system implicitly assumes that patent application and grant are coincident (or are, at best, an administrative matter), patent application

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[3] See: www.uspto.gov/web/offices/pac/mpep/documents/1300_1303.htm#sect1303 (underlined in the original and accessed 11/15/06). The Notice specifies issue and publication fees and deadlines, and initiates an administrative process of readying the allowed patent for formal grant and publication. In our empirical analysis, we focus on the Notice of Allowance date (rather than the more traditional patent grant date) since this is the date at which *uncertainty* over the likely nature of the patent grant. As a result, we mainly adopt the term "allowance" rather than "grant" in our exposition, except where we discuss the literature which has mainly studied the patent grant event.

[4] Individual examiners maintain significant discretion in this process (Nelson and Merges, 1990; Cockburn et al., 2003). Examiners produce "office actions" (interim decisions regarding applications) that are meant to provide applicants with information that "may be useful in aiding the applicant to judge the propriety of continuing the prosecution of his/her application…If the examiner finds that the claimed invention lacks novelty or differs only in an obvious manner from what is found in the prior art, the claims may also be rejected. It is not uncommon for some or all of the claims to be rejected on the first Office action by the examiner; relatively few applications are allowed as filed." http://www.uspto.gov/web/offices/pac/doc/general/index.html#office (accessed 11/15/06).

lags are long and variable. According to Popp et al. (2004), the average patent grant lag (inclusive of provisional applications and patent continuance) is 28 months, with a standard deviation of 20 months. Uncertainty over the length of time it takes to receive a patent grant is particularly salient for start-up innovators, since there are no patent rights until a patent is granted and, uncertainty over patent scope and the precise nature of allowed claims is reduced as the result of a grant.[5] By and large, variation in patent grant delay seems to be driven by idiosyncratic factors: even with detailed controls, only 10% of the overall variance in patent grant delay is explained by observable factors, and the most important factors seem to be broad differences across different technological fields (Popp et al., 2004).[6] Patent pendency (and the idiosyncratic variance of the process) potentially has important implications for the timing of technology licensing: while licensors may be able to reduce transactional costs and enhance the value of licenses realized after patent allowance, innovators face significant opportunity costs if they delay commercialization for several years while applications are pending.

Patent enforcement uncertainty. While the end of patent pendency mitigates certain uncertainties such as the variability of allowed claims, significant uncertainty remains concerning the ability to enforce those claims through the legal system. As emphasized by Lemley and Shapiro (2005), the uncertainty associated with litigation implies that patent grants are best characterized as probabilistic rights. It is useful, however, to distinguish how the nature of uncertainty *changes* after the allowance date. First, whereas the uncertainty arising during the pre-grant period involves significant information asymmetries between the applicant and potential licensees (since external parties may not have access to the complete record of “office actions” or even more informal interactions with patent examiners), the uncertainties associated with litigation are symmetric: both parties are on (roughly) equal footing in terms of evaluating the allowed claims and their likelihood to survive court scrutiny. Second, whereas the uncertainty arising in the pre-grant period is systematic (no applicant can avoid the uncertainties associated with the patent application process), the resolution of uncertainty over validity claims and the enforcement of damages is endogenous to the litigation and negotiation strategies of both patent holders and potential infringers. As Farrell and Shapiro (2007) argue, there are many cases where the incentives to litigate are low (or even negative), even in the absence of the transaction costs associated with litigation. Given that patent

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[5] The scope for pre-grant damages is *extremely* limited in the United States. Particularly during our sample period, there were few circumstances in which patent holders could receive “retrospective” damages for the period prior to the patent grant date. The American Inventors Protection Act of 2000 increased the potential for pre-grant damages slightly (by allowing for royalties after the disclosure of the patent (18 months after application), provided that four restrictive conditions are fulfilled). Interestingly, there is greater scope for pre-grant royalty-based damages in other jurisdictions (e.g., Tanaka, 2000).

[6] A recent literature debates the relationship between patent grant lags and the importance of the innovation. While Johnson and Popp (2003) suggest that more important innovations (as proxied by forward citations) are associated with more important innovation, Harhoff and Wagner (2005) find the reverse correlation using EU patent data. As well, see Popp et al. (2004) and Reitzig and Puranam (2007) for emerging evidence on the role that firm characteristics and capabilities play in the determination of patent grant delay.

litigation is quite expensive (compared to the relatively modest costs of patent application) it is not surprising that relatively few patents are litigated to a final judicial resolution: most patents never confront a full judicial review of their underlying validity or their legal scope (Lanjouw and Schankerman, 2001).

Uncertainty over market value. Finally, even if the legal uncertainty associated with patents was completely resolved, the economic and strategic value of patents is subject to a very high degree of uncertainty. Patents vary widely in their value, and much of the value associated with intellectual property depends on endogenous outcomes in technology and product markets. To take but one example, very few of the patented innovations in the biotechnology and pharmaceutical industries are ultimately commercialized, and it is very difficult to distinguish between different candidate drugs or therapies prior to the clinical trial process. As a result, the value of patent rights is probabilistic and can best be understood in terms of option value. While most patents confer very limited or negative returns to the innovator, the rights associated with a small percentage of patented innovations are associated with very high returns (Scherer and Harhoff, 2000; Arora et al., 2003; Ziedonis, forthcoming).

The importance of uncertainty in understanding the value and strategic use of formal intellectual property has only recently begun to be investigated in a systematic manner (Lemley and Shapiro, 2005). In the remainder of this paper, we focus on how the reduction in uncertainty arising from patent allowance and grant shapes the process of technology transfer, and the timing of technology licensing. In so doing, we seek to identify the impact of the operation of the patent system on the efficiency and operation of the market for ideas.

3. Patent Grant Delay and Frictions in the Markets for Ideas

When the market for technology transfer functions well, efficient trades occur and, moreover, they occur in a timely manner (Arora et al., 2001; Gans and Stern, 2003). Put simply, the “sale” of an idea allows an innovation to be commercialized more quickly generating productive efficiency gains. While the magnitude of these gains will differ from innovation to innovation and from industry to industry, there is an important sense in which delays in the timing of cooperative agreements reflect lost opportunities for maximizing the welfare gains from trade in ideas. This section briefly considers the potential drivers of delays in the licensing process, and the dynamic interplay between the timing of patent grant and the timing of cooperative agreements.[7] Our objective is not to develop a comprehensive model of the determinants of license timing (as we do in Gans et al., (2005)); instead, our objective is to simply illustrate (a) why the patent allowance date will *not* matter in the absence of market imperfections in the

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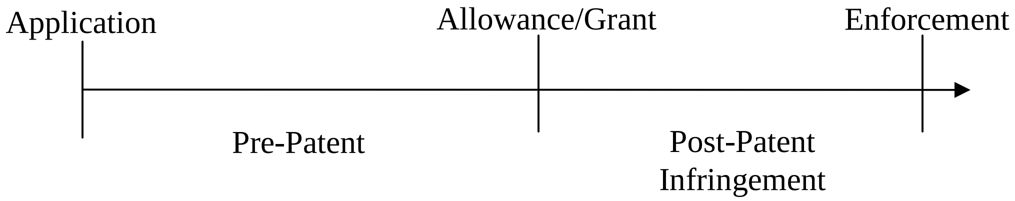
[7] In focusing on commercialization dynamics, we join a growing literature on the timing of strategic commercialization choices, including time-to-market (Hellmann and Puri, 2002; Dechaneaux et al., 2003).

market for ideas, and (b) how the presence of market imperfections implies a dependence between the patent allowance date and the timing of technology licensing.

The frictionless benchmark. Before turning to the impact of specific market imperfections, we begin by considering a "frictionless" environment in order to establish a benchmark for efficient trade in the market for ideas. Consider a stylized representation of the innovation commercialization process depicted in Figure A. There are three distinct phases. After an initial invention or prototype is developed, the technology entrepreneur files a patent application. Following a patent application there is a waiting stage during which there is uncertainty over patent scope and indeed whether it will be granted at all. Patent allowance (taken here as synonymous with the grant date[8]) reduces this uncertainty but does not resolve it because infringement may still occur, and defending against it may be costly and itself uncertain.

Figure A: Uncertainty and the Patenting Process



Consider the interactions between a single potential user of an invention (*C*) to whom the inventor (*R*) might license.[9] Both parties are risk neutral.[10] The potential commercial value of the invention to *C* is *v*. For a frictionless market, we assume that: (1) there is symmetric information between *C* and *R* regarding *v* and any other aspect of the patenting process; (2) *C* and *R* know of each other's existence from the outset (that is, *R* faces no search costs) and (3) but for the knowledge contained in the patent application, *C* has the necessary knowledge and resources to realize the value of the innovation. This last assumption implies that expropriation concerns are limited to knowledge which is potentially patentable, and that there is no specific human capital or tacit knowledge (in the sense of Arora, 1995) that must be drawn upon or otherwise disclosed for *C* to make full use of the invention. Below, we relax each of these assumptions to demonstrate the impact of frictions and market imperfections on the market for ideas.

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[8] As we demonstrate below, the lag between allowance and grant varies and is subject itself to some uncertainty. This could be incorporated in this model, however, the main result would involve additional notation without any change in our main result and hypothesis derivation.

[9] *C* stands for customer unit and *R* for research unit (as in Aghion and Tirole, 1994).

[10] Introducing risk aversion will create incentives to share risk among firms, which reinforces the incentives for early cooperation. We do not pursue this extension here, as we do not address this issue in our empirical work.

A lengthy patent process implies that it will take, say, T periods from the time of application until the time a patent is allowed.[11] In addition, there is uncertainty as to the scope of the potential patent, which will impact a pre-patent agreement. With probability p, a patent is granted with broad scope (and with probability 1-p with narrow scope). For concreteness, we define a patent with broad scope as one which is very difficult to "invent around", while a narrow patent is essentially unenforceable (either C or other firms will be able to invent around the formal intellectual property). Narrow patent scope not only reduces R's returns on the innovation, but can also impact C's returns as well (under narrow scope, the value of the innovation to C will be $\underline{v} < v$). Note that both v and $\underline{v}$ are properly interpreted as expected returns conditional on broad versus narrow patent scope. This is because, in each case, there may be residual uncertainty associated with both commercial opportunities as well as the robustness of the patent claims in any subsequent litigation that might arise. Note that patent scope is distinct from patent validity, as patent grants do not establish validity (they instead grant the right to litigate). A patent is not valid until the "last court" speaks – and so patent awards reduce but do not eliminate patent scope and validity uncertainty (Lemley and Shapiro, 2005).[12]

As the firms are risk neutral, we consider licensing agreements whereby R assigns any patent rights to C for a flat fee.[13] License agreements may be negotiated at either time 0 or T. If an agreement is signed at time 0 (for a fee, t_0), it is binding throughout the pre- and post-patent phases. If no agreement is signed, another opportunity to come to an agreement occurs at time T. Let $E[v] \equiv pv + (1-p)\underline{v}$. By signing an agreement at time 0, C gets $(1-\delta^T)v + \delta^T E[v]$ while R gets paid immediately.[14] If no agreement is signed, then a license agreement is negotiated at T (for a fee, t_T) following the reduction in patent scope uncertainty. If patent scope is narrow, C can realize the commercial value of the innovation in the absence of an agreement, and so $t_T = 0$.

We assume that the negotiators are able to achieve a cooperative outcome, so that firms "maximize" and then split the surplus.[15] At T, if patent scope is wide, $t_T = \frac{1}{2}v$, while if patent scope is

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[11] As noted in the previous section, the length of time between patent application and grant is itself uncertain. For expositional purposes, we treat it as known in this model. Adding that source of uncertainty would only strengthen the results here.

[12] We thank the reviewers and the associate editor for clarifying this point. For a discussion of how patent validity interacts with license terms, see Farrell and Shapiro (2007).

[13] C might make payment to R contingent upon realized patent scope, a contingent fee. For the results that follow, allowing for contingent fees or royalty payments would make little difference. See Gans et al. (2005).

[14] We assume that, until T, only R and C can utilize the innovation and so sustain higher returns of v for that period. Allowing others to exploit the innovation prior to patent grant would reduce pre-patent returns but would not change our results or comparative static conclusions.

[15] This is the Nash bargaining outcome assuming that parties have equal bargaining power. Gans and Stern (2000) develop non-cooperative foundations for this bargaining assumption in the context of a licensing game where the timing of agreement is endogenous (although that model implicitly assumes that a patent has already been granted).

narrow, $t_T = 0$. If we suppose that commercialization is not feasible until a licensing agreement is signed, then, if the firms wait, the expected licensing fee at time 0 is $p\tfrac{1}{2}v$ with *R*'s expected return being $\delta^T p\tfrac{1}{2}v$ and *C*'s being $\delta^T(p\tfrac{1}{2}v+(1-p)\underline{v})$.

Based on these expected returns, at time 0, there is always a joint gain for *C* and *R* to sign an earlier agreement. Put simply, the joint expected returns from an agreement at time *T* are $\delta^T E[v]$ while an agreement at time 0 will jointly yield $(1-\delta^T)v+\delta^T E[v]$, a gain of $(1-\delta^T)v$. It is mutually beneficial for the parties to agree earlier regardless of the degree of uncertainty over patent scope. Of course, the 'price' agreed to at that time will reflect the differing impacts of patent scope uncertainty on *R* and *C*. Under our assumption that firms split the surplus evenly:

$$\begin{aligned}&\underbrace{t_0-\delta^T p\tfrac{1}{2}v}_{\substack{R\text{'s surplus from an earlier}\\ \text{rather than later agreement}}} = \underbrace{(1-\delta^T)v+\delta^T E[v]-t_0-\delta^T(p\tfrac{1}{2}v+(1-p)\underline{v})}_{\substack{C\text{'s surplus from an earlier}\\ \text{rather than later agreement}}}\\ &\Rightarrow t_0=\tfrac{1}{2}\left(1-\delta^T(1-p)\right)v\end{aligned} \qquad (1)$$

In this case, *C*'s expected return is $\tfrac{1}{2}(1-\delta^T(1-p))v+\delta^T(1-p)\underline{v}$. It is useful to observe that *R*'s return through licensing is increasing in *p,* since this enhances the expected value of the innovation. Put simply, just because there is unprotected knowledge does not change the timing of licensing. In a frictionless environment, license timing is driven solely by productive efficiency. To be sure, uncertainty over IP rights impacts the distribution of returns between the parties: as the likelihood of stronger patent protection increases, *R* earns relatively more than *C. However, in the absence of frictions in the market for ideas, the patent grant allowance does not impact the timing of technology licensing.*

Patent grant delay in the presence of frictions in the market for ideas. While delay and uncertainty over the patent approval process has no impact on the timing of technological trade in the baseline model, barriers to exchange in the market for ideas can induce a dependency between the patent allowance date and the timing of cooperative agreements. We are interested in frictions which not only reduce the ability to achieve (early) productively efficient trade but for which the reduction of uncertainty over the scope of patent rights will serve to spur technological trade. There are at least three types of frictions: (a) asymmetric information regarding the value of patent rights, (b) search costs, and (c) the ability of potential licensors to expropriate knowledge which is disclosed but unprotected by IP rights.

Consider the role of information asymmetries. The licensor may possess a number of different types of advantaged information, from information about the overall value of the license (and in which contingencies the innovation might be valuable) or the timing and/or scope of the rights to be allowed. A direct consequence of asymmetric information (from whatever source) is the potential failure to be able to achieve a productively efficient agreement. Even when productively efficient technology exchanges would be jointly efficient, if potential licensors cannot credibly signal the value of their innovation (relative to the distribution of quality types), the market for ideas can break down.[16] Of course, if the source of asymmetric information is unrelated to the information resolved by patent grant, the mere allowance of a patent will not alleviate this breakdown in technological trade. However, if the asymmetric information between the licensor and potential licensees relates, in part, to the probability that a patent will receive narrow (rather than broad) scope (i.e., differences in the value of p), or the precise nature of the claims that are likely to be allowed, then the clarification of those rights may spur market exchange. By waiting until IP rights are clarified, those who believe they are likely to receive broad protection (relative to the expectations of potential licensees) will be able to earn a premium on the rights to their innovation. In other words, when the patent allowance itself reduces the degree of asymmetric information (or, equivalently, allows for more efficient sorting of technologies), at least some potential licensors will delay cooperative commercialization until the uncertainty surrounding patent scope is resolved.

A second mechanism resulting in a dependency between patent grant and the timing of cooperation arises from the presence of search costs. If the innovator has to engage in costly search to locate the most suitable commercialization partner, then incentives to do so may only be sufficient after a patent (with broad scope) has already been allowed (Hellmann, 2005). Suppose that the cost of finding a partner is a fixed cost, f, in which R can locate a customer, C, who would value the innovation Δ greater than the baseline of v or $\underline{v}$, and that once f is sunk, an agreement with this high-valuation partner is immediately feasible. On the one hand, locating a partner at time 0 increases R's returns by $\frac{1}{2}\left(1-\delta^T(1-p)\right)\Delta$. However, if R waits until the patent is granted at T, the search will only be undertaken if the patent scope is broad, and its returns from search would be $\frac{1}{2}\Delta$. If $\frac{1}{2}\left(1-\delta^T(1-p)\right)\Delta < f \leq \frac{1}{2}\Delta$, then R will be willing to search at T but unwilling to search at time 0. Moreover, the returns from time 0 agreement stay constant, while the returns from a time T agreement will be increased to $\delta^T p\left(\frac{1}{2}(v+\Delta)-f\right)$. Therefore, if $\frac{1}{2}\left(\Delta-\frac{1-\delta^T}{p\delta^T}v\right)\geq f$, then R will prefer to delay and search rather than sign a low-value agreement at time 0. In other words, since the returns from search may be higher when patent scope is known to be broad, the presence of search costs may induce delay until the uncertainty over patent scope is resolved.

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[16] There is some analysis of this in the literature on patent licensing (Kamien, 1992; Anton and Yao, 1994) but it focuses on achieving agreements in the face of information asymmetry rather than timing per se. A related literature on bargaining under asymmetric information provides a motivation for inefficient delay. See the survey by Ausubel et al. (2002).

A third mechanism – and perhaps the most important – arises from the ability of licensees to expropriate knowledge that is disclosed by the licensor but unprotected by intellectual property. The potential for expropriation can significantly limit information disclosure by licensors (Arrow, 1962; Anton and Yao, 1994), particularly when knowledge disclosure requires effort on the part of the licensor (Arora, 1995). Of course, as emphasized in the baseline model, the mere presence of unprotected knowledge has no impact on the timing of cooperative licensing (though it will have a significant impact on the division of rents and the overall incentives to proceed with commercialization). However, the establishment of the scope of patent rights can have a significant impact on the risk of expropriation and the willingness of licensors to disclose unprotected information. First, the clarification of patent scope may elucidate the extent of unprotected knowledge which can be disclosed without fear of expropriation. While it may be difficult to predict the impact of the disclosure of unpatentable knowledge during the pre-grant period, start-up innovators may be able to tailor their disclosures to avoid expropriation in the event of bargaining breakdown once the scope of rights is clarified. For example, prior to patent grant, non-disclosure agreements with potential partners may be difficult (if not impossible) to write with any degree of precision or potential for enforcement; after a patent is granted, the costs and complexity of such contracts may decrease significantly. To the extent that the clarification of formal property rights reduces the risk of knowledge leakage, patent allowances may spur participation in the market for ideas.

The role of the strategic disclosure of unprotected complementary knowledge will be particularly important when such disclosures require effort on the part of the licensor. As Arora (1995, p.42) emphasizes, “[t]echnology licensing involves more than just the permission to use the knowledge covered by patents: In many cases, the information required for successful utilization extends even beyond blueprints, drawings, and specifications and includes heuristics, rules of thumb, and other ‘tricks of the trade.’”[17] Formally, suppose we reinterpret Δ in the search model above as the additional value that comes through knowledge transfer and f is R’s effort in facilitating that transfer. The key issue is that it may be difficult to contract on the supply of effort. Even if the outcome and costs of such transfer (Δ, f) are observable to both parties, it may be unverifiable to a third party (such as a judge) and so any agreement may not be enforceable. In this case, whether knowledge is transferred will depend upon R’s incentives to do so. This framing is also consistent with Lowe’s (2004) formulation of licensing when a great deal of knowledge is tacit.

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[17] Incentives to disclose and transfer complementary knowledge in the pre-patent allowance regime may be muted, given firms’ ex ante investments. Consequently, innovators may undertake external validation of their technology (e.g., by scientific publication) to signal quality to outsiders – thereby delaying collaborative commercialization strategies. While this is an interesting empirical issue, expansion of our dataset to incorporate the details of scientific publication is beyond the scope of this paper. Such an analysis requires a systematic exploration of patent- and paper-level knowledge and the firm’s overall technology strategy (as in, for example, Gittelman and Kogut, 2003 and Murray, 2002).

As in the search model, the primary issue is whether the reduction in uncertainty afforded by the patent allowance increases the gains from trade from cooperative commercialization evaluated at that point as compared to a prior time period. Using a similar analysis to the search model, if $\frac{1}{2}\left(1-\delta^T(1-p)\right)\Delta < f \leq \frac{1}{2}\Delta$, then *R* will be willing to transfer knowledge at *T* but will be unwilling to do so at time 0. Thus, by waiting, the gains from trade rise by $p\delta^T(\Delta - f)$. However, the opportunity cost of that delay is $(1-\delta^T)v$. So if $\Delta - \frac{1-\delta^T}{p\delta^T}v > f$, delay will occur.[18]

Intuitively, while the incentives to disclose tacit knowledge after a licensing agreement has been signed are limited (the licensee will simply expropriate the value of any such disclosures), there may be significant incentives to disclose complementary tacit knowledge prior to the realization of a cooperative agreement.[19] Specifically, if disclosing such knowledge raises the value of the patentable portion of the innovation to potential licensors (while maintaining the relative bargaining position of licensee and licensor), then the willingness-to-pay by *C* will be increasing in the effort devoted to disclosure by *R*. Moreover, since the additional value created by knowledge disclosure depends on the value of the patentable knowledge, the total incentives and equilibrium level of disclosure will depend on whether patent scope is known to be broad or whether patent rights remain uncertain.[20] When the value arising from broad patent rights are sufficiently high and the "boost" from complementary knowledge disclosure is sufficiently steep, both licensors and licensees may delay licensing negotiations until patent allowance in order to maximize the innovator's incentives to transfer tacit knowledge.

Empirical implications. Taken together, these arguments suggest that the presence of frictions – barriers to efficient technological trade – can induce a systematic relationship between the receipt of formal intellectual property rights and the timing of technology licensing. While information asymmetries, search costs, and expropriation risks may limit technological trade prior to the receipt of formal IP rights, the reduction of uncertainty resulting from patent grant can trigger trade in the market for ideas. Conversely, in the absence of frictions, there should be no systematic relationship between

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[18] Note that there is a difference between the search and knowledge transfer models. In the search model, delay is driven by *R*'s own incentives to maximize its return. In the knowledge transfer model, if the gains from trade from delay were negative, *C* would have the ability to compensate *R* for any loss in its bargaining position that comes from delay. Hence, delay is more likely (given the same parameter values) in the knowledge transfer model compared with the search model.

[19] This difference in incentives remains even if the licensing agreement itself is based on a royalty agreement rather than a fixed fee. For a complete derivation of a model of commercialization timing based on these incentives see Gans et al. (2005).

[20] Analytically, this is similar to our analysis of search costs – where search cost incentives may be insufficient prior to patent grant but are triggered by broad patent scope. From a modeling perspective, f can be interpreted as the costs associated with the transfer of knowledge and Δ as the potential "boost" to the value of the innovation.

patent allowance and the timing of cooperative agreements. This theoretical insight holds several testable empirical implications.

First, the relative importance of productive efficiency and barriers to technological exchange will differ across technologies. As such, the incentives for early licensing and the benefits from delay until patent rights are clarified will vary across different innovations. Moreover, one might expect that this variation will be narrower within a given industry relative to the variation across industries. For example, most software products are associated with relatively short product lifecycles, and so the benefits from productive efficiency are likely quite high in this sector. In addition, software patents are thought by some to be susceptible to being "low quality" and held invalid if challenged (see the references contained in Hall and MacGarvie, 2006 for research on this issue). Conversely, as suggested by several studies of the "patent thicket" in the semiconductor industry (Hall and Ziedonis, 2001; Ziedonis, 2004), the barriers to efficient technological trade (and the ability of enforceable IP rights in reducing those barriers) may be higher in the semiconductor and electronics sector. As a result of this variation, *both pre-allowance and post-allowance licensing agreements will be observed in equilibrium, and the propensity for pre-grant and post-grant licensing will likely vary by industry and other observable characteristics of the technology and innovator.*

Second, if barriers to technological exchange limit early licensing, the clarification of patent rights can reduce the frictions in the market for ideas and so raise the incentives to achieve a cooperative agreement. *As a result of these enhanced incentives, the equilibrium impact of patent allowance will be to raise the hazard rate of achieving a licensing agreement.* Therefore, relative to a baseline pattern of the timing of cooperative agreements, patent allowances are predicted to be associated with a "boost" in the underlying rate of licensing. To test this implication, we must disentangle the impact of patent allowance from the baseline hazard rate. We do so by taking advantage of the substantial variation in the patent allowance lag – the time between patent application and patent allowance. As described in more detail in Section 5, by observing different technologies with different patent allowance lags, we are able to estimate the direct impact of patent allowance, controlling for the underlying time profile for technology licensing agreements.

Third, the theoretical framework suggests that after the scope of IP rights are clarified, productive efficiency considerations provide incentives for firms to achieve a licensing agreement as soon as possible after the uncertainty is mitigated. Thus, for firms seeking a licensing partner as part of the commercialization process, *licensing will tend to take place immediately after the patent allowance date.* A higher hazard of licensing immediately following the patent allowance date provides evidence for both the existence of frictions in the market for ideas and for the value of formal IP rights in facilitating cooperative technology transfer.

Finally, the degree to which the patent allowance matters depends upon the strategic environment in which the firm operates. The clustering of licensing after the patent allowance date results from the strategic choice by firms to wait for the clarification of uncertainty (and is balanced against a desire for productive efficiency in the commercialization process). The impact of patent allowance will therefore be relatively unimportant in environments where productive efficiency is particularly important, such as industrial sectors with short product life cycles (such as the software industry). As well, the impact of patent allowance will be muted in environments where the impact of frictions is modest. For example, in locations or industries in which alternative institutional arrangements may provide a substitute for formal IP rights, the impact of patent allowance on the hazard rate of licensing will be reduced. As such, the framework predicts that the impact of patent allowance will be lower for firms with access to rich informal "knowledge broker" networks, such as those located in Silicon Valley or those who are affiliated with networked venture capitalists (e.g., Saxenian, 1994).

4. Data

Our data are drawn from a sample of technology licensing deals announced between 1990 and 1999, and appearing in the Security Data Corporation (SDC)/Thomson Financial Platinum joint ventures and alliances database.[21] We began by selecting all recorded deals in four sectors that are closely associated with cooperative commercialization between start-up innovators and more established industry players: biotechnology, electronics, software, and scientific instruments. While the overall analysis of deal structure across different types of players is extremely informative (Lerner and Merges, 1998; Anand and Khanna, 2000; Arora et al., 2001; Dechenaux et al., 2003; Elfenbein, 2004), we focus our data sample in order to construct a clear test of our theoretical framework. Our sample is composed of licensing deals between start-up innovators and more established firms that are focused on specific technologies (rather than more general agreements involving long-term alliances or that are primarily focused on cross-licensing arrangements). From our initial database, we eliminate deals with the following characteristics: an established firm licensing to another established firm, an established firm licensing to a start-up, a non-profit entity as a licensor or licensee, renewal of a prior technology transfer agreement, and transactions involving strictly technology cross-licenses between or among parties.

For the remaining technology transfer licensing deals, based on a reading of the deal description from the SDC database, we identified the first significant patent associated with the technology from

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[21] Beginning in November 2000, in accordance with the American Inventors Protection Act of 1999, patent applications are disclosed 18 months after filing (as opposed to at the time of patent grant, as was the case in the prior legal regime). See Johnson and Popp (2003) for an analysis of some likely effects of this rule change. To impose uniformity in the timing of disclosure and limit right-censoring, we limit our observation window to the period prior to the implementation of AIPA.

searching the US Patent and Trademark Office (USPTO) website. This was done by searching patent titles and abstracts for key words taken from the SDC technology licensing activity description. The deal was excluded if there was ambiguity over the match between the licensed technology and the patent associated with that technology or if the licensing date was earlier than the patent application date (the latter cause for exclusion may be related to the former). This process yielded 219 patent-license pairs. By construction, our dataset excludes licenses for technologies in which no patent was ever issued, as well as technologies which are patented but never licensed. Instead, our sampling scheme allows us to focus on the timing of licensing relative to changes in the intellectual property environment for a sample of technologies which seek and receive patent protection and for which a licensing outcome is realized.[22]

For each deal, the license date announcement, the deal industry sector, and firm location and age information was collected from the SDC database. For each patent-license pair, we then collected detailed patent information from the USPTO website and the NBER patent data file (Hall et al., 2001), and venture capital financing information from the Venture Economics database. The final dataset consists of 198 observations for which we observe both an unambiguous licensing date and an unambiguous patent allowance date.

Variable definitions and summary statistics. Table 1 reports variable definitions and summary statistics. Our dataset consists of three different types of measures: timing measures, patent characteristics and firm characteristics. Each of the timing measures is calculated relative to the patent application date. *Patent application date* is the date associated with the first patent application for a given technology, inclusive of continuances, divisions, and provisional applications.[23] We investigate two timing measures linked to the reduction in uncertainty resulting from administrative actions on the part of the patent office. *Patent allowance date* is the date on which the USPTO sends a Notice of Patent Allowance to the patent applicant, at which point the "prosecution on the merits is closed."[24] From the perspective of our theoretical framework, the patent allowance date is a key event, since the Notice of Patent Allowance provides an unambiguous and finalized statement of claims allowed by the patent office (claims which

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[22] As emphasized by, among others, Quillen and Webster (2001, 2006) and Graham and Harhoff (2006), motivated patent applicants are nearly always successful in receiving a patent, and so it is likely that the main source of selection is whether inventors ever applies for a patent (rather than whether than their application is denied). We discuss the impact of the sampling scheme on the interpretation of estimates more carefully in Section 5.

[23] While the use of the "first" patent application date is consistent with examining the timing of licensing relative to initial invention, our results are robust to the use of the "final" application date (i.e., the date associated with the application that is ultimately issued). While the results are noisier, the key findings remain quantitatively and statistically significant. In order to be eligible to receive a patent, the inventor must file a provisional application within a year after the first public disclosure of the invention (and must file in advance of disclosure for eligibility in Europe and elsewhere). Because of the relationship between disclosure and eligibility, the initial patent application date is a reasonable (though obviously not perfect) proxy for the initial date of invention.

[24] See www.uspto.gov/web/offices/pac/mpep/documents/1300_1303.htm#sect1303 (accessed 11/15/06). The Notice of Patent Allowance dates were gathered through the USPTO PAIR system, which allows access to electronic administrative transaction histories for recent US patents.

may of course be revised by the judicial system (Lemley and Shapiro, 2005)).[25] There is a subsequent administrative lag between the patent allowance date and the patent grant date. Between these two dates, the patent applicant must pay patent issue and publication fees, and the finalized patent grant is prepared for issuance, including the mailing of an Issue Notification to the assignee and publication in the US Patent Gazette (from which we draw the patent grant date). While our model (and discussions with attorneys and practitioners) suggests that the Notice of Patent Allowance is the critical moment at which uncertainty is reduced, we investigate both the impact of the patent allowance date and the patent grant date on licensing behavior.[26] We define the *patent allowance lag* as simply the *patent allowance date* less the *patent application date*, measured in months, and the *post-allowance administrative lag* as the *patent grant date* less the *patent allowance date*, also measured in months. While the mean of *patent application date* is in the early portion of 1991, the average *patent grant date* occurs at the end of 1993 (the average patent allowance lag is more than 32 months). Interestingly, the average *post-allowance administrative lag* is more than 6 months, and ranges from 1 to 19 months (more than 60% of the sample experiences a 5-7 month administrative lag).

The central focus of our empirical analysis is the relative timing of technology licensing and patent allowance. Accordingly, our remaining timing measures depend on the licensing date. For each technology, the licensing date is the first publicly reported instance of licensing, as reported by the SDC Platinum joint ventures and alliances database. A principal focus of our analysis is the determinants of the *licensing lag*, which is simply equal to the time (in months) between patent application date and the licensing date (mean = 44.54). As well, we construct a dummy variable, *post patent allowance*, which is equal to one for those licenses recorded after the patent allowance date (mean = 0.73), and a separate dummy variable, *post patent grant*, which is equal to one for those licenses recorded after the *patent grant date* (mean = 0.58).

Figures 1 and 2 present three key histograms: *patent allowance lag*, *licensing lag* and the difference of these measures. While only a very small number of technologies receive a patent allowance within a year of the application date, the majority of the technologies in our sample receive a patent allowance in the second, third, and fourth year after application.[27] As well, the patent allowance lag has a

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[25] It is possible that communications and correspondence prior to the Notice of Patent Allowance might reduce uncertainty over claims *prior* to the *patent allowance date*. In our empirical analysis, we investigate this possibility by checking for an uptick in licensing prior to the *patent allowance date*.

[26] In an earlier version of this paper, we focused exclusively on the *patent grant date* (rather than the *patent allowance date*), where we observed a significant rise in licensing activity in the four months prior to the *patent grant date*. We thank an anonymous referee for suggesting a more detailed investigation into the timing of allowances and grants. In line with the predictions of our theoretical model, we primarily focus on the administrative action associated with the greatest uncertainty reduction, *patent allowance date*.

[27] An emerging literature has focused on the determinants of patent grant lag (we believe this is the first study to focus specifically on patent allowance lag), including Popp et al. (2004), Johnson and Popp (2003), King (2003),

large right tail, with a small number of technologies with patent allowance lags in excess of nine years.[28] In contrast to the *patent allowance lag* distribution, *licensing lag* is more evenly distributed. Figure 2 combines these histograms in reporting the distribution of *licensing lag* less *patent allowance lag*. Data plotted to the left of the value zero are associated with licensing deals reached prior to patent allowance, while data plotted to the right of zero indicate post-allowance licensing. The histogram suggests a striking relationship between licensing and patent allowance – there is a marked increase in the level of licensing for about a year from the patent allowance date. Though there is wide variation in both the length of time that passes until patents are allowed, and the length of time that passes until licensing occurs, there seems to be a linkage between patent allowance and the timing of licensing agreements.[29]

Our dataset also includes detailed patent and firm characteristics, allowing us to evaluate the impact of observable measures of the business environment on licensing behavior. We are particularly concerned about the possibility of latent differences across inventions affecting both the licensing lag and the patent allowance lag (and so resulting in a spurious correlation between these two).[30] These controls allow us to identify the impact of patent allowance on licensing, controlling for observable technology and licensor characteristics. Finally, we are interested in evaluating the interaction between patent allowance and observable features of the environment, which will allow us to assess whether the impact of patent allowance on licensing is enhanced (or muted) depending on the economic environment and nature of the underlying innovation.

First, we define dummy variables indicating locations that may provide access to different types of technology licensing networks: *Silicon Valley*, *Route 128*, and *Canada*. As key high-technology regions, firms located in Silicon Valley and Route 128 may experience a higher overall rate of technology licensing. As well, firms located in these regions may have access to informal network-based mechanisms that overcome the delays associated with the patent system; as such, licensing may be less sensitive to patent grant in these regions. Our sampling scheme also yielded a relatively high number of Canadian

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Regibieu and Rocket (2003), Harhoff and Wagner (2005), and Reitzig and Puranam (2007). While Johnson and Popp (2003) suggest that longer lags may be associated with highly cited patents, all studies note the high level of unexplained variation in the patent grant lag.

[28] It is possible that extreme lags may be associated with technologies in which productive efficiency considerations may not be crucial; accordingly, we have experimented extensively with imposing a maximum patent allowance lag (e.g., 60 months). None of our key qualitative findings are affected.

[29] If we plot the histogram of *licensing date* less *patent grant date* (rather than *patent allowance date*), there is a pronounced increase in the rate of licensing in the four to six months prior to the *patent grant date*, which peaks in the first few months after the *patent grant date*. This is consistent with the fact that managers respond to the event associated with uncertainty reduction (the patent allowance date) rather than the date at which formal rights commence and the patent grant is published.

[30] Section 5 discusses the potential for endogeneity in more detail, including how we address this in our empirical framework.

licensing deals (mean = 0.18), and so we include a location control for these firms in case their underlying hazard rate or sensitivity to patent grant is significantly different than the US firms in the sample.

We also incorporate several measures of firm resources, experiences and capabilities. *Firm age* (mean = 6.03) is measured as of the patent application date, and a venture capital funding dummy, *VC funded* (mean = 0.48), only equals one for firms receiving venture funding prior to the patent application date. On the one hand, access to a VC network, as well as increased maturity and reputation, might enhance the ability of a firm to engage in cooperative commercialization even in the absence of formal patent rights (Hsu, 2006). At the same time, firms with fewer financial or organizational resources may be unable to delay licensing until patent allowance, and so may forego an enhanced bargaining position in order to achieve an earlier licensing agreement (Lerner et al., 2003). Less mature firms may be less sophisticated in their approach to licensing, or may be willing to sacrifice bargaining power in order to quickly establish a cooperative commercialization agreement with an established industry player. While the overall effect of *firm age* or *VC funded* on the timing of commercialization may, therefore, be ambiguous, inclusion of these measures in our empirical analysis allows us to control for the possibility that differences in experience or resources may be correlated with *both* the *licensing lag* and the *patent allowance lag*.

We additionally construct four industry dummy variables. *Biotechnology* is a dummy indicating whether a licensing deal took place in the *biotechnology* industry (mean = 0.41); similar measures are constructed for *electronics* (mean = 0.22), *software* (mean = 0.18), and *scientific instruments* (mean = 0.18).[31] These industry controls aim to account for two distinct effects. First, it is possible that the underlying timing of licensing differs significantly according to industry sector. Consequently, in our main regressions, we stratify our results by industry. Second, it is likely that the impact of patent allowance differs significantly according to industry sector. For example, while patents may be relatively unimportant in the software industry (where productive efficiency is quite important and copyright protection may serve as a substitute for patent protection (Lerner and Zhu, forthcoming; Graham and Mowery, 2003; Graham and Somaya, 2006), patents are likely more salient in areas such as biotechnology (where the product lifecycle is less rapid and where achieving effective tacit knowledge transfer may be particularly important). We, therefore, investigate whether the sensitivity of the licensing hazard rate to patent allowance differs significantly across different industry settings.

We also incorporate several patent characteristics in the analysis. Most of these measures are simply the standard measures from the Hall, et al. (HJT, 2001) NBER data file: patent claims, patent

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[31] The industry coverage is distinct from the geography dummies. Each of the industries is represented in each of the geographic regions (Silicon Valley, Route 128, Canada, and other), and the only significant pairwise correlation between the industry and geography measures is a positive correlation between *Route 128* and *software* ($\rho = 0.20$).

classes, patent citations made, backward citation lag, and originality.[32] *Patent claims* is simply the number of claims allowed by the examiner (mean = 20.84), while *patent classes* is the number of distinct primary three digit patent classes to which the patent is assigned (this measure ranges from 0-9; mean = 1.90). An additional three HJT patent characteristics exploit the citations made in each patent to the prior patent record. *Patent citations made* is equal to the number of "backward" citations to prior patents (mean = 11.17). *Patent backward citation lag* is the number of years between the *patent grant date* and the average grant year of those cited patents (mean = 7.56), and *patent originality* measures the diversity of cited references, based on the degree to which prior references are drawn from different patent classes. Similar to a traditional Herfindahl index (where originality = 1 if all cited patents are drawn from a single category, and originality goes to zero as the share from all patent classes goes to zero), the mean of originality = 0.43. As well, we include the number of non-patent references to the scientific literature (*science references*, mean = 7.56) and the number of non-patent, non-scientific references (*non-science references*, mean = 2.40).

These patent characteristics may be informative about the incentives for pre-allowance versus post-allowance licensing, such as the importance of productive efficiency, the level of tacit knowledge, or patent scope, and so may influence the baseline hazard rate of licensing, or mediate the salience of patent allowance itself. Of course, the interpretation of each measure is subtle (HJT, 2001; Lanjouw and Schankerman, 2004). *Patent citations made* may indicate a higher level of technological complexity (and therefore a higher level of tacit knowledge disclosure for effective commercialization), or alternately, a high level of this variable may be associated with significant uncertainty over the ultimate (enforceable) scope of a patent, since patent rights are more uncertain in the presence of a patent thicket (Shapiro, 2001; Ziedonis, 2004; Lemley and Shapiro, 2005). Similarly, while a higher level of *patent claims*, *patent classes*, or *patent originality* indicates a higher level of technological complexity and the likely importance of tacit knowledge, these measures may also be associated with increased patent scope (Lanjouw and Schankerman, 2001). While some authors argue that *science references* (and perhaps *non-science references*) indicate a higher degree of transparency for an invention (Fleming and Sorenson, 2004), Lowe (2004) suggests that patents including *science references* are more likely to require a high

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[32] We exclude the HJT measure of *forward citations* (i.e., the number of times a patent is cited by subsequent patents), as we are concerned that licensing itself influences the subsequence diffusion and cumulative impact of a technology (resulting in endogeneity). Our qualitative results are unaffected by the inclusion of the *forward citations* measure. Also, for a small set of observations (post-1999 patent grants), the HJT characteristics data are not available through the NBER database. We constructed the HJT measures for these observations, and checked whether our results are sensitive to their inclusion or exclusion. All qualitative results remain the same. For comparability, we code any "missing" data as a constant, and include a dummy variable denoting that the HJT measures are missing for that observation.

level of tacit knowledge transfer for effective commercialization.[33] Finally, building on the arguments of Narin (1994) and Markewicz (2005), smaller values of *patent backward citation lag* may be consistent with a business environment characterized by short technological cycle times, which in turn should be related to the importance of the productive efficiency motive for technology trade (and so increase the incentives for pre-allowance licensing). As well, extending Lowe's (2004) argument relating technological recency to tacit knowledge suggests that a longer *patent backward citation lag* may be related to smaller amounts of tacit knowledge, as less of the focal knowledge may be novel. Taken together, these patent characteristics have a complex relationship with the incentives for licensing at different points in time, and we are, accordingly, cautious in our interpretation of each of these measures, in terms of their impact on licensing behavior.

Table 1B provides a tabulation of the *patent allowance lag* and *licensing lag* by industry. While *electronics* and *scientific instruments* are associated with a relatively short *patent allowance lag* (27 months), average allowance lags are much longer in *biotechnology* (38 months). Interestingly, while the licensing lag is also longest in *biotechnology*, *software* is associated with the shortest licensing lag (40 months). Whereas the patent delay is shortest in the *electronics* industry, this industry is associated with the second longest licensing lag. This variation in both *patent allowance lag* and *licensing lag* leads to significant cross-industry variation in the share of licenses realized after patent allowance. While post allowance licensing occurs more than 80% of the time in *electronics*, less than two-third of *software* industry licenses occur prior to the *patent allowance date*. This preliminary evidence suggests that patents may indeed play different roles in different sectors; evaluating these claims systematically requires a more systematic analysis of how *patent allowance date* (or *patent grant date*) shifts the licensing hazard rate.

5. The Empirical Framework

Our objective is to identify the causal impact of *patent allowance date* (or *patent grant date*) on the timing of licensing behavior. The heart of the empirical strategy is to exploit the significant empirical variation in patent allowance and licensing lags across technologies, and the timing of licensing relative to patent allowance. For each technology, we structure the dataset into monthly observations from the *patent application date*, and define $License_{it}$ equal to 0 for the period prior to the end of the *licensing lag*, and equal to 1 for the month in which the *licensing lag* ends (resulting in a unique absorbing event resulting from the first license). We also define a time-varying regressor, $Post\text{-}Patent_{it}$, which is equal to 0 for months after the *patent application date* but prior to the *patent allowance date*, and is equal to 1 for all

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[33] At least in part, this difference in perspective may arise because Lowe's sample specifically compares different patents arising from academic research, while Fleming and Sorenson evaluate patents with origins in the private sector.

months after the *patent allowance date*. Since we observe a pre-patent and post-patent period for each technology in our sample (and it is possible that licensing occurs prior to the post-patent period), our empirical objective is analogous to the estimation of the "treatment effect" of *patent allowance date* on the timing of licensing (Abbring and van den Berg, 2003). We begin by discussing the details of our empirical specification for identifying this parameter, our approach to testing for the key hypotheses, and the impact of our sample selection criteria on the interpretation of the estimates.

Our analysis focuses on results using a Cox proportional hazard rate model with time-varying regressors. The Cox model is specified in terms of a continuous time hazard rate function, which incorporates a non-parametric baseline hazard rate, and a multiplicative term that allows regressors to have a proportional impact relative to the baseline hazard rate (Lancaster, 1990; van den Berg, 2001).[34] We allow for stratification by industry (since the overall licensing pattern differ significantly across industries), and include detailed controls for factors shifting the hazard rate function. Letting $h_{license}$ equal the hazard rate of *license* changing from 0 to 1, we specify the basic Cox model:[35]

$$h_{LICENSE}(t, \text{POST PATENT}_i^t, l_i, Z_i) = h^{l_i}(t) \cdot \exp\left\{\beta_0 + \beta_Z Z_i + \beta_{\text{POST PATENT}} \text{POST PATENT}_i^t\right\} \qquad (2)$$

where *l* subscripts each industrial sector, and *Z* includes firm, location, and patent characteristics. Under the assumption that (2) is the true model, $\beta_{\text{POST PATENT}}$ can be interpreted as the impact of *patent allowance date* on the *licensing* hazard rate. The identification of this parameter relies on variation in the *patent allowance lag* - if all technologies experienced the *same* patent allowance lag, we would not be able to disentangle the impact of *patent allowance date* from the baseline hazard rate. However, the potential for unobserved heterogeneity poses a challenge to identifying $\beta_{\text{POST PATENT}}$:[36]

$$h_{LICENSE}(t, \text{POST PATENT}_i^t, l, Z_i) = h^{l}(t) \cdot \exp\left\{\beta_0 + \beta_Z Z_i + \beta_{\text{POST PATENT}} \text{POST PATENT}_i^t + \nu_i\right\} \qquad (3)$$

where ν_i is drawn from a distribution, *f(ν)*, but is unobservable to the econometrician.

The presence of unobserved heterogeneity can result in bias if ν_i is correlated with the observables, in particular POST PATENT. For example, technologies with long *patent allowance lags* may tend to have low realizations of ν_i. In other words, rather than a *causal* impact of *patent allowance date* on the *licensing* hazard rate, there may simply be a spurious correlation between the length of the patent allowance lag and the length of the licensing lag. However, as emphasized by Abbring and van den Berg (2003, 2004), the presence of unobserved heterogeneity does not necessarily undermine the

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[34] Duration analysis is a vast topic; we focus only on the distinctive issues arising in this empirical setting. For a general introduction, see Lancaster (1990), van den Berg (2001), and Wooldridge (2003).

[35] More precisely the hazard rate is the instantaneous probability of the failure event at *t*, conditional on survival until that point: $h_{LICENSE,t} = \lim_{\Delta \to 0} \frac{1}{\Delta} \Pr(t \leq Licensing\ Lag_i \leq t+\Delta) \mid Licensing\ Lag_i \geq t)$

[36] The treatment of unobserved heterogeneity in duration models is a well-studied and still active area in econometrics and labor economics. See, among many others, Heckman and Singer (1984), Han and Hausman (1988), Lancaster (1990), Heckman and Taber (1994), and van den Berg (2001).

identification of the impact of a "treatment effect" (in this case, $\beta_{\text{POST PATENT}}$). Whereas the value of ν_i impacts the hazard rate in all periods, POST PATENT only impacts the hazard rate after the *patent allowance date*.[37] To exploit this insight, we take advantage of a relatively unique feature of our dataset – namely, that we observe *patent allowance lag* for all technologies, even those who "fail" (i.e., license) prior to the *patent allowance date*. As such, we can simply include *patent allowance lag* as a regressor in the hazard function (i.e., as an element of *Z*). In other words, we directly control for the overall correlation between *patent allowance lag* and *licensing lag*, and focus on whether there is a *change* in the hazard rate after the *patent allowance date*:[38]

$$h_{LICENSE}(t, \text{POST PATENT}_i^t, l, Z_i) = h^l(t) \cdot \exp\left\{\beta_0 + \beta_Z Z_i + \beta_{\text{PATENTLAG}} \text{PATENT LAG}_\text{i} + \beta_{\text{POST PATENT}} \text{POST PATENT}_i^t + \nu_i\right\} \qquad (3)$$

As long as *post patent* is *conditionally* independent of ν_i (i.e., conditional on stratification by industry, *Z*, and *patent allowance lag*), the Cox regression coefficient on $\beta_{\text{POST PATENT}}$ can be interpreted as the impact of *patent allowance date* on the hazard rate of *licensing*.[39] In addition to providing a test for our first hypothesis, this framework can be adapted to evaluate our supplementary hypotheses as well.

First, to evaluate whether licensing is "clustered" immediately after the patent allowance date, we define a set of "window" variables (*pre patent allowance* (*k,l*) and *post patent allowance* (*k,l*)), equal to 1 from *k* to *l* months prior to (or after) the *patent allowance date*, and 0 otherwise:

$$h_{LICENSE}(t, \text{POST PATENT}_i^t, l, Z_i) = h^l(t) \cdot \exp\left\{\begin{array}{l} \beta_0 + \beta_Z Z_i + \beta_{\text{PATENTLAG}} \text{PATENT LAG}_\text{i} + \sum_{k,l} \psi_{PRE\_k,l} \text{PRE PATENT}(k,l)_i^t \\ + \sum_{k,l} \psi_{POST\_k,l} \text{POST PATENT}\,(k,l)_i^t + \nu_i \end{array}\right\} \qquad (4)$$

In other words, we define a set of time-varying measures which will allow us to estimate coefficients to evaluate how the hazard rate is changing during time intervals as the *patent allowance date* approaches and during time intervals after patent allowance has occurred. According to the theory, there should be no effect (or, at most, a modest effect as information is being revealed) *prior* to the *patent allowance date*, followed by an enhanced *licensing* hazard rate, attenuating over time.

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[37] Whereas the overall treatment of unobserved heterogeneity in duration analysis is relatively mature, the identification of treatment effects using time-varying regressors in duration models is more recent. Parametric models include Card and Sullivan (1988) and Lillard and Panis (1996), and recent examples emphasizing nonparametric identification include Abbring and van den Berg (2003, 2004).

[38] The inclusion of *patent lag* as a linear term is arbitrary; in Appendix A, in the spirit of a control function approach, we experiment with nonlinear specifications of *patent allowance lag* in the hazard rate function (van den Berg, 2004). As well, since the "time to treatment" is usually unobserved for those who experience an exit event prior to treatment, the use of shared frailty models has become a popular approach to account for unobserved heterogeneity in a straightforward fashion. Appendix A presents a model including a shared frailty parameter, where technologies are grouped into 12 *patent allowance lag* categories. The qualitative results are unchanged.

[39] This assumption is similar to the strict exogeneity assumption discussed in Wooldridge (2003). Abbring and van den Berg (2003) provide general identification conditions, and emphasize the importance of conditional independence through their discussion and assumption of "no anticipation of treatment."

Second, we introduce several interaction terms between *post patent allowance* and measures of the strategic and technological environment. To do so, we de-mean each element of our control vector Z_i (i.e., calculate $\bar{Z}$) to formulate the following hazard model:

$$h_{LICENSE}(t,\text{POST PATENT}_i^t,l,Z_i)=h^l(t)\cdot\exp\left\{\begin{matrix}\beta_0+\beta_Z Z_i+\beta_{\text{PATENTLAG}}\text{PATENT LAG}_\text{i}+\beta_{\text{POST PATENT}}\text{POST PATENT}_i^t\\+\beta_{PATGRANT,Z}\text{POST PATENT}_i^t\cdot(Z_i-\bar{Z})+\nu_i\end{matrix}\right\}$$

This specification allows us to estimate the overall impact of *patent grant date* on *licensing* and how this changes with changes in the underlying economic, strategic, and technical environment.

Third, it is possible to incorporate multiple time-varying regressors and to distinguish whether the key “shock” to the *licensing* hazard rate results from the *patent allowance date* or from the subsequent formal *patent grant date*, as follows:

$$h_{LICENSE}(t,\text{POST PATENT}_i^t,l,Z_i)=h^l(t)\cdot\exp\left\{\begin{matrix}\beta_0+\beta_Z Z_i+\beta_{\text{PATENTLAG}}\text{PATENT LAG}_\text{i}+\beta_{\substack{\text{POST PATENT}\\\text{ALLOWANCE}}}\text{POST PATENT ALLOWANCE}_i^t\\+\beta_{\substack{\text{POST PATENT}\\\text{GRANT}}}\text{POST PATENT GRANT}_i^t+\nu_i\end{matrix}\right\}$$

Finally, it is important to recall that the analysis is conditioned on the sample selection criteria of focusing on a set of technologies which receive patents and are ultimately licensed. While our specification provides an estimate of the impact of the patent system on this sample, it is likely that our estimates overstate the overall impact of the patent system on the market for ideas. Specifically, to the extent that some innovators never seek licenses for their technology (either before or after the patent allowance), the “population” impact of patent allowance will be equal to $\beta_{\text{POST PATENT}}$ multiplied by the share of innovators seeking to license their technology. In the conclusion, we discuss the counterfactual estimate of the population impact of patent grant on the market for ideas in more detail.

6. Empirical Results

We are now ready to examine the hazard rate results. Table 2 presents our baseline Cox hazard regression results based on monthly data. In this and the following empirical tables, we present both the estimated coefficients as well as the implied hazard ratios (which should be read relative to one), since the latter makes the estimated size effects more apparent. The “failure” event in these regressions is the first instance of patent licensing. The first specification, (2-1), examines the impact of a post-allowance patent (without additional controls) on the hazard of licensing. The estimate is significant at the 1% level (all estimates are based on robust standard errors, clustered at the firm level), and implies that patent allowance is associated with more than a 200% increase in the underlying hazard rate.[40] The second

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[40] All of the central qualitative findings are robust to the use of the *patent allowance date* or the *patent grant date* as the key measure of timing. We use the *patent allowance date* as the results are more consistent (in terms of the value of the estimated coefficients) across a wider range of control structures.

column of Table 2 adds the regressor *patent allowance lag*, which controls for the underlying correlation between the pendency from patent application to allowance and licensing speed. This specification also allows each industry to have its own baseline hazard function (as an industry-stratified hazard model) and includes fixed effects for each patent application year. By allowing the industry hazard rate and the impact of patent application year to be freely estimated, our *post patent allowance* estimate is identified from within-industry variation of patent "cohorts."[41] By controlling directly for the spurious correlation between patent allowance lags and licensing lags (perhaps because of some unobserved feature of the technology), and controlling for unobserved heterogeneity through stratification and application year fixed effects, we expect the absolute size of the *post patent allowance* coefficient to decline. Indeed, the size of the coefficient is reduced relative to (2-1); however, the estimated coefficient remains large and statistically significant (the notice of allowance increases the hazard rate by just under 70%). As well, the coefficient on *patent allowance lag* is negative and highly significant, suggesting that longer patent allowance times are indeed correlated with longer licensing lags. Together, these results suggest that while unobserved factors shaping the timing of licensing and patent allowance lags are important, patent allowance itself has an independent causal impact on the market for ideas.[42] In the final specification in Table 2, we add one additional regressor, *post patent grant*. This allows us to examine whether the additional event of actually receiving the patent grant changes the hazard of licensing, above and beyond the patent allowance event. It does not. The *post patent allowance* coefficient remains large and significant, with an implied 80% boost in the licensing hazard relative to the baseline. Overall, these results suggest that, for the sample of technologies considered here, the probability of licensing is significantly enhanced when uncertainty surrounding formal IP rights is reduced; moreover, the key event is associated with the reduction in uncertainty (the patent allowance date) rather than the grant date per se.

Table 3 examines whether this core finding is robust to the inclusion of different types of control variables. Each specification continues to include a complete set of patent application year fixed effects, industry-level stratification, and a control for *patent allowance lag*. We begin with firm characteristics. In (3-1), we include the three location variables (allowing us to explore whether licensing is associated with a different rhythm in technologically "networked" locales such as Silicon Valley and Route 128

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[41] By allowing for stratification, we cannot separately identify industry-specific fixed effects.

[42] Appendix A includes a number of additional specifications exploring this baseline result in further detail. In the spirit of a control function approach, (A-1) and (A-2) include alternative functional forms for the treatment of the *patent allowance lag* (including the inverse (A-1) and the inclusion of the inverse, level and square of *patent allowance lag* (A-2)). In (A-3), we allow for "shared frailty" among technologies with similar *patent allowance lags* (we allow for 13 separate groupings based on six-month allowance lag windows and assume a gamma distribution), and in (A-4), we experiment with a specific functional form (Weibull) for the baseline hazard rate. In each of these alternative specifications, the estimated coefficient on *post patent allowance* remains large and statistically significant; indeed, the estimated impact of *post patent allowance* is actually higher for each these alternative assumptions and control structures than the coefficients reported in Table 2.

(Saxenian, 1994)). (3-2) includes both *firm age* and *VC funded* (thereby controlling for firm maturity, access to financial resources, and the potential for access to the VC network). While none of these control variables is individually significant (or even estimated to have a large impact), the underlying size and significance (at the 5% level) of the *post patent allowance* coefficient persists. We then include the complete set of measured patent characteristics in (3-3) and, finally, include all control variables in (3-4). In both of these specifications (as well as the additional robustness checks we discuss below), the coefficient on *post patent allowance* is remarkably stable, both in terms of economic and statistical significance. In addition, two of the patent characteristic control variables are associated with a change in the baseline hazard rate. A longer *patent backward citation lag* is associated with a significant increase in the expected length of the licensing lag: a one standard deviation increase in *patent backward citation lag* is associated with more than a 25% reduction in the licensing hazard rate. This finding is consistent with the interpretations of Narin (1994) and Markewicz (2005), who suggest that higher backward citation lags may be associated with longer technology cycle times. Consequently, productive efficiency considerations may not be as important and firms may invest in less intensive search, and so the hazard rate will be lower. The coefficient on *science references* is also significant and positive (though the estimated magnitude is relatively small), consistent with the perspective of Fleming and Sorenson (2004) who suggest that patents associated with *science references* have a higher degree of technological transparency (and thus would be associated with a less complex licensing process).[43] Overall, these patterns hold across a wide range of control structures and robustness checks.[44]

We now turn to our second hypothesis, and examine whether licensing behavior is "clustered" in the period immediately following patent allowance. To do so, we estimate an industry-stratified model with application-year specific fixed effects (similar to (2-3)). In place of the *post patent allowance* dummy variable, we estimate 8 mutually exclusive dummy variables covering the following time windows: greater than 12 months prior to patent allowance (normalized to 1.0), 12 to 8 months prior to patent allowance, 7 to 4 months prior to patent allowance, 3 months to patent allowance month, 1 to 4

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[43] Both of these results are in contrast to the perspective emphasized by Lowe (2004), who suggests that "recency" and "science" would be associated with a higher degree of tacit knowledge, and thus a reduction in the licensing hazard rate. As we discussed earlier, this difference may be due to the fact that Lowe's analysis focuses on technologies which are developed in a university context.

[44] Among other approaches, we experimented with measures of the "importance" of the technology, including the use of the number of *forward citations* to each patent. Since this measure may be endogenous (patents that are licensed earlier may ultimately receive a higher number of forward citations), we do not include it directly in Table 3. However, the results are essentially identical when it is included (and the *forward citations* measure itself is insignificant). As well, the results are robust to the following sub-samples of the data: start-ups that are "young" (below the median age in the sample), the "early" cohort of patent applications (before 1996), the "late" cohort of patent applications (after 1990), using a time window that takes into account a patent "pre-announcement" effect (broadening the patent allowance date to include the four months prior to the actual allowance date), and excluding the six patents in our sample that have undergone litigation (with a finding in the *Federal Register*).

months after patent allowance, 5 to 8 months after patent allowance, 9 to 12 months after patent allowance, and greater than 12 months after patent allowance.[45] Our results are presented in Figure 3. In the eight months prior to the patent allowance date (which are estimated using two four month time window dummies), there is a slight (statistically insignificant) increase in the licensing hazard rate. In contrast, during the two four month windows just after patent allowance, there is a dramatic spike in the licensing hazard (the hazard rate jumps more than 100% during these two periods). Thereafter, the hazard rate once again declines, stabilizing at a level of approximately 1.25 (relative to the baseline hazard). These effects are not simply a qualitative pattern, as they are precisely estimated. For example, it is possible to reject the null hypothesis that the coefficient in the four months just after the patent allowance date is equal to earlier window coefficients. These results offer a significant refinement on our earlier analysis: not only does patent allowance have a permanent impact on the licensing hazard, but the effect also seems to be most salient in the period just after the patent allowance itself. Abbring and van den Berg (2003) suggest that a key piece of evidence for the "causal" impact of treatment (as opposed to a spurious correlation between the timing of patent allowance (i.e., a "treatment") and "failure" (i.e., licensing)) is whether the hazard rate increases significantly in the period immediately after the treatment (but not before). The pattern in Figure 3 accords precisely with the intuition, suggesting a causal influence of patent allowance on the hazard rate of licensing.

Finally, we examine key interaction effects between *post patent allowance* and patent and firm characteristics. While the interaction effects with industry dummies are modeled as direct interaction effects (i.e., $Post\ Patent\ Allowance_i^t \cdot Industry_i$), the remainder of the interaction effects are defined as an interaction between *post patent allowance* and deviations from the sample means for each measure (i.e.,. $Post\ Patent\ Allowance_i^t \cdot (Z_i - \bar{Z})$). As such, the coefficient on *post patent allowance* (or *post patent allowance * industry*) can be interpreted as the effect when each of the interaction measures are set equal to their sample means. As before, each regression is stratified by industry, with patent application year fixed effects, and the reported standard errors are robust and clustered by firm.

The first column of Table 4 examines the complete set of *post patent allowance * industry* interaction effects together with the regressor *patent allowance lag*. While the effect of *post patent allowance* is positive in all industries, patent allowance has a significant impact in the electronics and biotechnology industries, no statistically significant impact on licensing behavior in scientific instruments and only a negligible and noisy positive coefficient in the software industry. This pattern is consistent with key differences between these industries. In biotechnology, patent protection is extremely important

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[45] Because these time window dummies are exhaustive and mutually exclusive, we cannot separately estimate the impact of *post patent allowance* per se but can only identify the changes during each of the periods leading up to and after the *patent allowance date*.

and long regulatory lags may make productive efficiency concerns less important. Conversely, in the software industry, technology cycle times are very rapid, copyright protection offers a substitute mechanism for protecting IP in the context of licensing negotiations, and software patents themselves may be of uneven quality (Hall and MacGarvie, 2006).

The second column investigates interaction effects between patent allowance and firm location, age, and funding. The only significant interactions are with the Silicon Valley and Route 128 location dummies. While the direct effect of being located in Silicon Valley is an increase in the licensing hazard rate, patent allowance itself plays a much more muted role for Silicon Valley companies (and companies in the Route 128 area). Though there may be several explanations for this finding (e.g., the types of technologies developed in these high-technology hubs may be different), these results are consistent with the hypothesis that the impact of *formal* intellectual property may be reduced in highly networked environment such as Silicon Valley. In environments where licensees may be protecting their reputation in the market for ideas (and so forego expropriation), and brokers actively seek to facilitate the licensing process, the impact of formal institutions such as patent allowance may be reduced. In (4-3), we examine interactions between patent characteristics and *post patent allowance*. In addition to the significant effects of *patent backward citation lag* and *science references* (as in Table 3), the specification including interactions includes the significant effect of *patent classes*. While the direct effect of *patent classes* is positive, the interaction between *patent classes* and *post patent allowance* is negative. Though we are cautious in our interpretation (several of the patent characteristic measures are correlated with each other), the findings regarding the *patent classes* measure is consistent with the hypothesis that technologies associated with a greater number of patent classes may be of interest to a wider range of potential licensees (accelerating the search process), but that the *enforceability* of patents with coverage across a wider number of classes is more uncertain. In other words, the impact of patent allowance may be reduced for technologies subject to higher levels of market and legal uncertainty after patent allowance. It is useful to note that the coefficient on *patent allowance lag * post patent allowance* is very small and insignificant, and so the impact of patent allowance does not seem to depend on the length of the patent allowance lag. The final specification includes all patent and firm characteristics, and a complete set of interaction effects. While several of the coefficients are noisier, the overall pattern of results remains: the impact of patent allowance is highest for the *electronic equipment* industry, and is lower for firms located in Silicon Valley and technologies that cover a wider range of patent classes.[46]

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[46] In unreported specifications, we also experimented with whether the impact of patent allowance is itself changing over time by examining *interaction* effects between *post patent allowance* and *application year*. The coefficient on the main effect of *post patent allowance* remains essentially identical, while the coefficient associated with the interaction effect is small and is never significant across any of the specifications we examined. We also explored whether the impact of patent allowance is changing over time differentially for different industries (e.g., the impact

7. Conclusions

This paper considers the impact of delays in the granting of IP on the market for ideas. To the extent that patent allowance mitigates uncertainty regarding the scope of IP protection, delays in resolving that uncertainty may delay cooperative commercialization agreements. Our findings suggest that patent allowance substantially increases the hazard rate of achieving a licensing agreement, and this effect is most pronounced in the time period immediately following the patent allowance event. Moreover, the overall rate of licensing and the importance of patent uncertainty resolution on the licensing hazard rate are associated with measures of the strategic and institutional environment in which firms operate. For technologies where productive efficiency effects are important, the overall rate of licensing is rapid. For technologies with alternative IP rights available (such as copyright), or firms in locations where information brokers and reputational mechanisms may be important (such as Silicon Valley), the impact of patent allowance on the licensing hazard rate is reduced.

Our findings provide evidence for frictions in the market for ideas. Such frictions might arise from asymmetric information, search costs, or the challenges associated with transferring tacit knowledge from start-up innovators to potential licensees. While prior research suggested the role of formal IP in enabling the markets for ideas, the evidence presented here offers the first direct evidence that private-sector innovators are causally influenced by the receipt of IP rights. Patent allowance reduces the uncertainty surrounding the scope of patent rights, and so reduces (though does not eliminate) imperfections in the market for ideas. It is useful to consider what our estimates imply about the overall impact of the patent system on the ability of start-up innovators to access the market for ideas. The estimates imply that, among a sample of start-up innovators who ultimately reach a licensing agreement, the impact of patent allowance is associated with a 70% increase in the hazard rate of licensing.[47] Of course, many start-up innovators do not seek formal intellectual property protection, and, of those that do, many choose independent commercialization over licensing. These decisions depend on the efficiency of the patent system and the salience of frictions in the market for ideas. Hsu (2006), using a broadly similar approach for identifying start-up innovators and examining a dataset of over 1,100 technology entrepreneurs, finds that 42% of start-up innovators receive at least one patent, and 15% of those firms

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of patent allowance may be increasing in the software industry due to increased strength and use of patents in that sector). No significant trends were identified. Finally, we experimented with whether there was a change in the impact of patent allowance after the 1995 patent harmonization reforms (which dated patent terms from application rather than grant date). Unfortunately, we only observe 29 licenses with patent application dates after 1995; the coefficient on this effect is very noisy (the sign and magnitude vary depending on the specification).

[47] To put this in perspective, using the estimates from the parametric failure time model estimated in (A-4), our estimates imply that, for those firms that use the patent system to achieve a licensing agreement, patent allowance delay results in more than an 18-month average delay in achieving a licensing agreement.

commercialize through a cooperative agreement. Therefore, while the *marginal impact* of patent allowance is quite significant (resulting in a sharp increase in the licensing hazard rate for the sample of licensors) the overall start-up licensing rate is modest. In part because of the probabilistic nature of patent rights (and inefficiencies associated with allowance delays), many start-up innovators commercialize innovations independently rather than through cooperation with more established firms, though the reduction of uncertainty within the patent system provides a significant boost to the ability to achieve a cooperative commercialization outcome.

The analysis highlights the value of grappling with the operational details of the patent system. The recent availability of electronic “file wrappers” for patent applications allowed us to focus on the key date associated with the reduction in uncertainty – patent allowance. We conjecture that additional insight could be gleaned through examination of how the complete set of administrative milestones associated with patent prosecution (first notice, intermediate rejection letters, continuances, etc) impacts the growth and evolution of start-up technology entrepreneurs, from their ability to raise financial capital, attract key personnel, and in their choice of commercialization strategy. Among other issues, it would be interesting to identify the types of technologies or companies that are able to achieve cooperative commercialization outcomes in the absence of patent allowance. For example, how are some firms able to realize effective license agreements (or even alliance arrangements) when the scope and extent of intellectual property protection is still at a high level of uncertainty?

More generally, our analysis highlights the strategic tradeoff innovators face between the protection of their ideas and the pursuit of an effective commercialization strategy. While commercialization would often be enhanced by prompt and pervasive disclosure (perhaps including publications in scientific journals, participation in standards-setting bodies, etc.), establishing protection against expropriation often requires delay and some level of secrecy. Given that the market for ideas is imperfect, the disclosure strategy of the firm becomes crucial. A recent literature has begun to explore these issues, ranging from choices over when to publish or not in the scientific and technical literature, when to patent or not, and when to protect knowledge through tacit means or outright secrecy (e.g., Arora et al., 2001; Gans and Stern, 2003; Murray, 2002; Gittleman and Kogut, 2003). While this work begins to unpack some of the tradeoffs arising from disclosure and the use of an (imperfect) intellectual property and litigation system, we leave the formulation of an optimal disclosure strategy across the full range of strategic and institutional environments as an open question.

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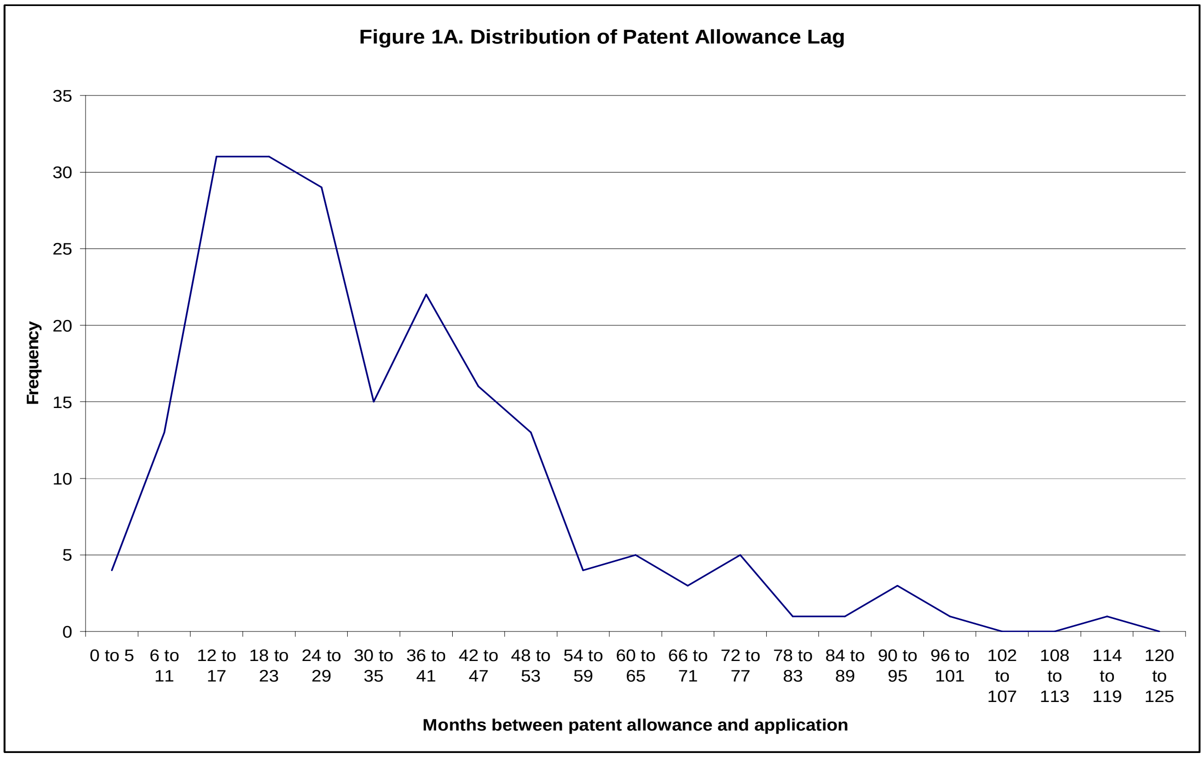
Figure 1: Timing Lag Distributions



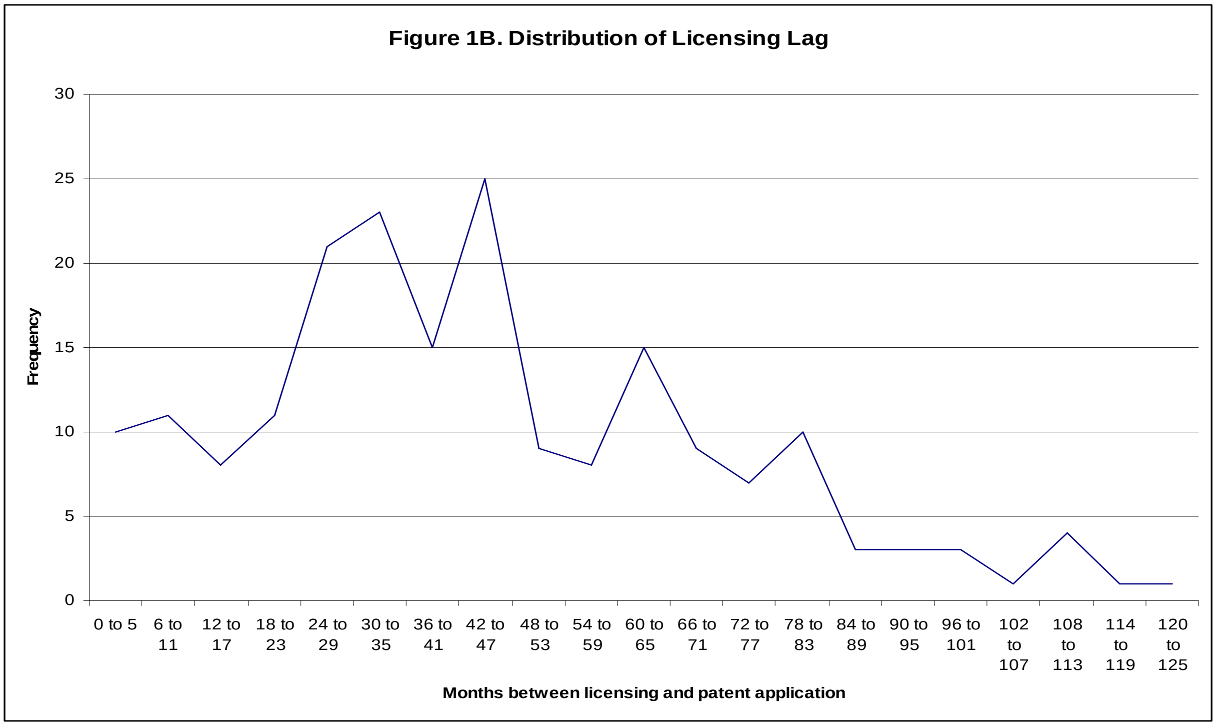


Figure 2: Distribution of Difference between Patent Allowance and Licensing Dates

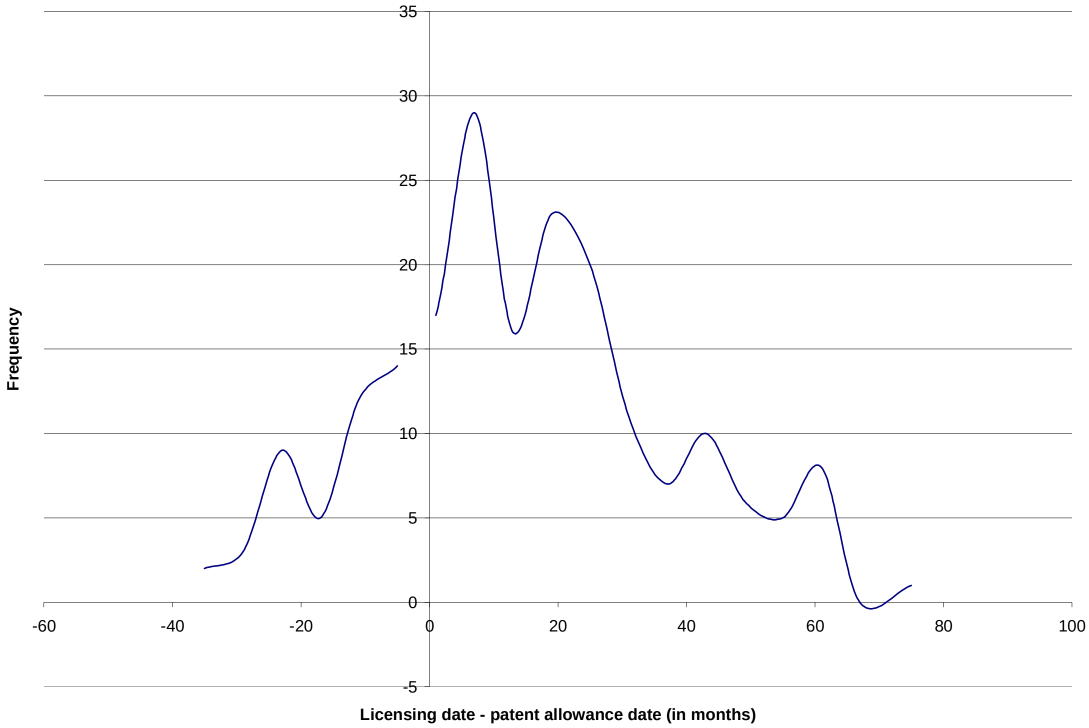


Figure 3: Licensing Hazard Ratio, Pre- vs. Post-Patent Allowance

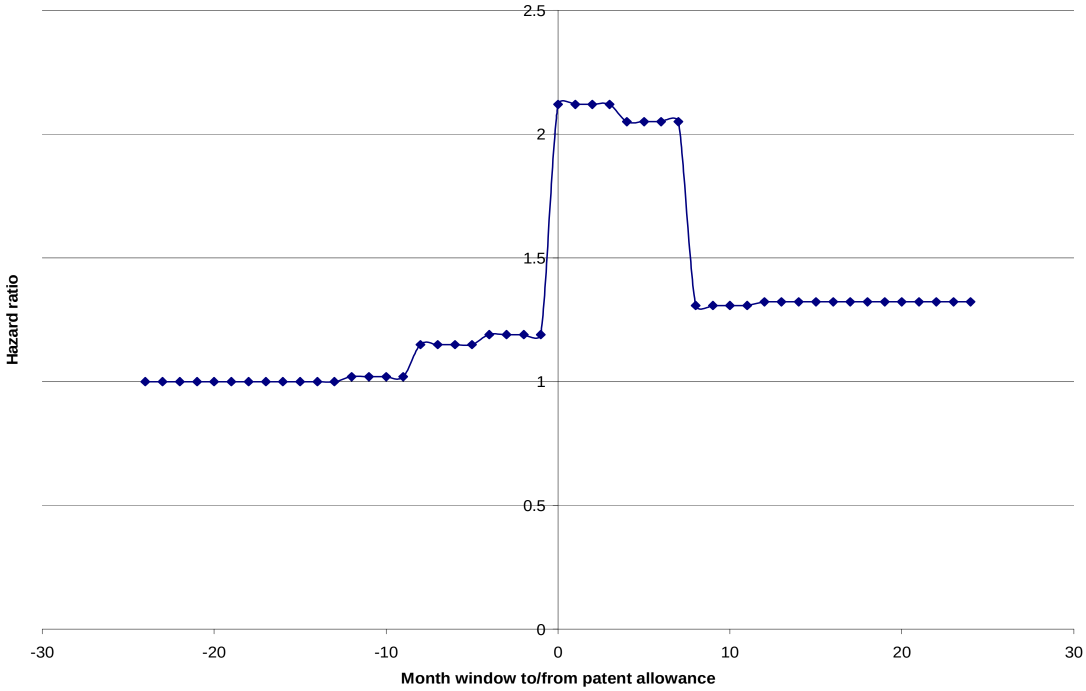


Table 1A
Variable Definitions, Means, and Standard Deviations

VARIABLE	DEFINITION	MEAN	SD
Timing Measures			
Patent application date	Date of patent application	1991.16	3.96
Patent allowance date	Date of USPTO notice of patent allowance	1993.88	3.94
Patent grant date	Date of USPTO notice of patent grant	1994.40	3.89
Licensing date	Date of patent licensing	1994.95	3.47
Licensing lag	*Licensing date – Patent application date* (in months)	44.54	26.46
Post patent allowance	Dummy = 1 if *Licensing date > Patent allowance date*	0.73	0.45
Post patent grant	Dummy = 1 if *Licensing date > Patent grant date*	0.58	0.50
Patent allowance lag	Months between patent allowance and patent application	32.58	20.18
Post-allowance administrative lag	Months between patent allowance and patent grant	6.79	2.81
Patent Characteristics[*]			
Patent claims	# of claims made in the patent	20.84	19.70
Patent citations made	# of patent citations referenced in the patent	11.17	11.48
Patent classes	# of 3-digit classes to which the patent is assigned	1.90	1.07
Patent backward citation lag	# of years between patent grant and the average grant year of backward citations	7.54	4.32
Patent originality	1 – Herfindahl of referenced patent classes (based on backward patent citations)	0.43	0.27
Science references	# of non-patent references made in the patent to the scientific literature	7.56	16.75
Non-science references	# of non-patent references made in the patent to the non-scientific literature	2.40	5.44
Firm Characteristics			
Firm age	Age of the firm in years	6.03	6.68
VC funded	Dummy = 1 if firm is funded by venture capital	0.48	0.50
Silicon Valley	Dummy = 1 if firm is located in Silicon Valley	0.21	0.41
Route 128	Dummy = 1 if firm is located in Boston region	0.12	0.33
Canada	Dummy = 1 if the firm is located in Canada	0.18	0.38

[*] These data (with the exception of the last two) are from Hall, Jaffe, and Trajtenberg (2001).

Table 1B
Means of Timing Measures by Industry Sector

	Biotechnology	*Electronics*	*Software*	*Sci. Instruments*
# observations	82	44	35	37
Patent allowance lag	38.34 (21.66)	27.32 (18.03)	31.51 (12.67)	27.05 (22.17)
Licensing lag	48.61 (28.51)	43.86 (26.33)	39.91 (19.59)	40.70 (27.16)
Post patent allowance	0.70 (0.46)	0.80 (0.41)	0.66 (0.48)	0.78 (0.42)

Table 2
Baseline Cox Hazards
Dependent Variable = LICENSE
(Robust standard errors are clustered by firm)
N = 8045

Independent Var.	**(2-1)**		**(2-2)**		**(2-3)**	
	Haz. Ratio	Coef.	Haz. Ratio	Coef.	Haz. Ratio	Coef.
Post patent allowance	3.241*** (0.626)	1.176*** (0.193)	1.695** (0.453)	0.528** (0.267)	1.815** (0.476)	0.596** (0.262)
Patent allowance lag			0.978*** (0.005)	-0.022*** (0.005)	0.976*** (0.006)	-0.025*** (0.006)
Post patent grant					0.793 (0.198)	-0.231 (0.250)
Patent App. Yr. FE			Yes		Yes	
Biotechnology			hazard rate stratified by industry		hazard rate stratified by industry	
Electrical equipment						
Software						
Log likelihood	-834.170		-537.620		-537.698	

** and *** indicate statistical significance at the 5% or 1% level, respectively.

Table 3
Baseline Industry-Stratified Cox Hazards with Controls
Dependent Variable = LICENSE
(Robust standard errors are clustered by firm)
N = 8045

Independent Var.	**(3-1)**		**(3-2)**		**(3-3)**		**(3-4)**	
	Haz. Ratio	Coef.	Haz. Ratio	Coef.	Haz. Ratio	Coef.	Haz. Ratio	Coef.
Post patent allowance	1.690**	0.524**	1.695**	0.528**	1.757**	0.564**	1.757**	0.563**
	(0.451)	(0.267)	(0.453)	(0.267)	(0.492)	(0.280)	(0.494)	(0.281)
Patent allowance lag	0.978***	-0.022***	0.978***	-0.022***	0.973***	-0.028***	0.973***	-0.028***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)
Silicon Valley	1.000	-0.000					0.992	-0.008
	(0.224)	(0.224)					(0.226)	(0.228)
Route 128	1.107	0.102					1.069	0.067
	(0.251)	(0.226)					(0.271)	(0.253)
Canada	1.056	0.055					1.028	0.028
	(0.215)	(0.204)					(0.230)	(0.224)
VC funded			1.068	0.066			1.007	0.007
			(0.176)	(0.164)			(0.190)	(0.189)
Firm age			1.001	0.001			1.000	0.000
			(0.011)	(0.011)			(0.011)	(0.011)
Patent claims					1.003	0.003	1.002	0.002
					(0.003)	(0.003)	(0.003)	(0.003)
Patent classes					1.019	0.019	1.021	0.021
					(0.107)	(0.105)	(0.109)	(0.106)
Patent citations made					1.004	0.004	1.004	0.004
					(0.008)	(0.008)	(0.008)	(0.008)
Patent backward citation lag					0.937***	-0.065***	0.937***	-0.065***
					(0.023)	(0.025)	(0.023)	(0.025)
Patent originality					1.460	0.379	1.488	0.397
					(0.527)	(0.361)	(0.562)	(0.378)
Science references					1.011***	0.011***	1.011**	0.011**
					(0.004)	(0.004)	(0.005)	(0.005)
Non-science references					0.996	-0.004	0.996	-0.004
					(0.010)	(0.010)	(0.011)	(0.011)
Patent App. Yr. FE	Yes		Yes		Yes		Yes	
Log likelihood	-537.979		-537.978		-527.916		-527.890	

** and *** indicates statistical significance at the 5% and 1% levels, respectively.

Table 4
Industry-Stratified Cox Hazards: Industry, Location & Firm Interaction Effects

Dependent Variable = LICENSE

(Robust standard errors are clustered by firm)

N = 8045

Independent Var.	**(4-1)**		**(4-2)**		**(4-3)**		**(4-4)**	
	Haz. Ratio	Coef.	Haz. Ratio	Coef.	Haz. Ratio	Coef.	Haz. Ratio	Coef.
Post patent allowance			1.64* (0.44)	0.50* (0.27)	1.72* (0.52)	0.54* (0.30)		
Patent allowance lag	0.98*** (0.01)	-0.02*** (0.01)	0.98*** (0.01)	-0.02*** (0.01)	0.97*** (0.01)	-0.03*** (0.01)	0.97*** (0.01)	-0.02*** (0.01)
*Biotech * post pat. allowance*	1.78* (0.61)	0.57* (0.35)					1.54 (0.70)	0.43 (0.45)
*Software * post patent allowance*	1.05 (0.50)	0.05 (0.48)					1.29 (0.82)	0.26 (0.63)
*Electr. equip * post pat. allowance*	2.47** (1.13)	0.91** (0.46)					4.19*** (2.22)	1.43*** (0.53)
*Sci. Instrum. * post pat. allowance*	1.68 (1.05)	0.52 (0.62)					1.28 (0.85)	0.25 (0.67)
Silicon Valley			1.89* (0.68)	0.64*(0.36)			2.04* (0.81)	0.71* (0.40)
Route 128			1.82 (0.68)	0.60 (0.37)			1.35 (0.63)	0.30 (0.47)
Canada			1.48 (0.59)	0.39 (0.40)			1.11 (0.45)	0.11 (0.41)
VC funded			1.35 (0.42)	0.30 (0.31)			1.04 (0.39)	0.04 (0.37)
Firm age			1.01 (0.02)	0.01 (0.02)			1.02 (0.02)	0.02 (0.02)
*SV * post pat. allowance*			0.39** (0.18)	-0.94** (0.46)			0.41* (0.20)	-0.90* (0.48)
*Rt. 128 * post pat. allow.*			0.44* (0.22)	-0.81* (0.48)			0.75 (0.46)	-0.28 (0.61)
*Canada * post pat. allowance*			0.66 (0.32)	-0.41 (0.48)			0.91 (0.43)	-0.09 (0.47)
*VC funded * post pat. allowance*			0.76 (0.27)	-0.28 (0.36)			0.92 (0.38)	-0.08 (0.42)
*Firm age * post patent allowance*			0.99 (0.02)	-0.01 (0.02)			0.97 (0.03)	-0.03 (0.03)
Patent claims					1.00 (0.01)	0.00 (0.01)	1.00 (0.01)	0.00 (0.01)
Patent classes					1.23** (0.12)	0.21** (0.10)	1.31*** (0.13)	0.27*** (0.10)
Patent citations made					1.00 (0.01)	0.00 (0.01)	1.00 (0.01)	0.00 (0.01)
Patent backward citation lag					0.86** (0.06)	-0.15** (0.07)	0.85** (0.06)	-0.16** (0.07)
Patent originality					0.71 (0.49)	-0.34 (0.69)	1.49 (0.56)	-0.30 (0.71)

Table 4 continues on next page

Table 4 continues from prior page

Science references			1.01* (0.01)	0.01* (0.01)	1.01 (0.01)	0.01 (0.01)
Non-science references			1.00 (0.02)	0.00 (0.02)	1.00 (0.02)	-0.00 (0.02)
Pat claims post pat. allowance*			1.00 (0.01)	0.00 (0.01)	1.00 (0.01)	0.00 (0.01)
Pat classes post pat. allowance*			0.69** (0.12)	-0.37** (0.17)	0.64*** (0.11)	-0.44*** (0.01)
Pat cit. made post pat. allowance*			1.00 (0.02)	0.00 (0.02)	1.00 (0.02)	0.00 (0.02)
Pat bkwd cit lag post pat. allow*			1.11 (0.08)	0.10 (0.07)	1.12 (0.08)	0.12 (0.07)
*Patent orig. * post pat. allowance*			2.88 (2.36)	1.06 (0.82)	1.00 (0.01)	1.18 (0.87)
Science ref post pat. allowance*			1.00 (0.01)	0.00 (0.01)	1.01 (0.00)	0.00 (0.01)
Non-sci ref post pat. allowance*			0.99 (0.02)	-0.01 (0.029)	0.99 (0.03)	-0.01 (0.03)
*Pat allow lag * post pat. allow*			1.00 (0.01)	0.00 (0.01)	1.00 (0.01)	0.00 (0.01)
Patent App. Yr. FE	Yes	Yes	Yes		Yes	
Log likelihood	-537.379	-534.559	-522.555		-518.699	

*, ** and *** indicates statistical significance at the 10%, 5%, and 1% levels, respectively.

Appendix A
Robustness to Functional Forms and Estimation Methods
Dependent Variable = LICENSE
(Robust standard errors are clustered by firm)
N = 8045

Independent Var.	**(A-1)**		**(A-2)**		**(A-3)**		**(A-4)**
	Cox proportional hazard models				*Shared gamma frailty Cox regression*		*Weibull-distributed failure time*
	Haz. Ratio	Coef.	Haz. Ratio	Coef.	Haz. Ratio	Coef.	Coef.
Post patent allowance	3.026*** (0.667)	1.107*** (0.220)	1.751** (0.474)	0.560** (0.271)	3.298*** (0.666)	1.216*** (0.202)	0.859*** (0.244)
Inverse of patent allowance lag	15.059 (31.972)	2.712 (2.123)	1.501 (4.276)	0.406 (2.849)			
Square of patent allowance lag			1.000 (0.000)	-0.000 (0.000)			
Patent allowance lag			0.994 (0.021)	-0.006 (0.022)			-0.012*** (0.004)
Patent App. Yr. FE	Yes		Yes		Yes		Yes
Log likelihood	-544.639		-537.594		-799.962		-157.177

** and *** indicates statistical significance at the 5% and 1% levels, respectively.

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01/07	Patent Opposition and the Constitution: Before or After?	*Dent*
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