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The Impact of Uncertain Intellectual Property Rights on the Market for Ideas: Evidence from Patent Grant Delays

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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 IP has already been granted. In contrast, the need to disclose complementary (yet unprotected) knowledge, asymmetric information 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. We employ a data set combining information about cooperative licensing and the timing of patent allowances (the administrative event when patent rights are clarified). Although preallowance licensing does occur, the hazard rate for achieving a cooperative licensing agreement significantly increases after patent allowance. Moreover, the impact of the patent system depends on the strategic and institutional environment in which firms operate. Patent allowance plays a particularly important role for technologies with longer technology life cycles or that lack alternative appropriation mechanisms such as copyright, reputation, or brokers. 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 et al. 2001). Imperfections in the market for technology may significantly reduce the gains from technological trade. Potential licensors may limit information disclosure 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 2007).

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 (Kitch 1977, 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 established firms during commercialization. Building on studies of the operation of the patent system (Cohen and Merrill 2003, Jaffe and Lerner 2004), we empirically exploit a fundamental feature of the patent system: patent grant delay. Although 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 prepatent period in which the scope and timing of rights are 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 trade-off: whereas 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]

To explore how the business environment shapes commercialization dynamics, we focus on the moment at which the rights to be granted by the U.S. Patent and Trademark Office (USPTO) are announced to the patent applicant, the Notice of Patent Allowance event ("patent grant" follows several months later). 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. Using a novel data set of technologies developed by start-up innovators and ultimately commercialized through cooperation, we link the timing of cooperative licensing with the timing of patent allowance. We examine whether the hazard rate for cooperation *changes* in response to a *change* in the commercialization environment (the mitigation of uncertainty resulting from patent allowance), and how the impact of patent allowance depends on firm, technology, and industry characteristics. By studying how the timing of cooperation is influenced by the timing of patent allowance, we provide evidence of the causal influence of the IP system on the market for ideas.

Our findings indicate that patent allowance substantially increases (by 70%–80%) the hazard rate of achieving a licensing agreement, and this effect is most pronounced in the time period immediately following the patent allowance event. The overall rate of licensing and the salience of patent allowance on the licensing hazard rate also have significant interactions with measures of the strategic and institutional environment in which firms operate. For example, when alternative IP rights are available, such as copyright protection in the software industry, patent notification matters less for licensing. In environments in which expropriation threats can be mitigated through alternate channels, such as reputation preservation in Silicon Valley, the impact of patent allowance on the licensing hazard rate is also reduced. We are cautious in our interpretation, however, because the sample size is modest and the analysis is conditioned on a sample of firms for which licenses are observed.

[1] Only a few studies consider licensing timing (Katila and Mang 2003, Dechenaux et al. 2008, Elfenbein 2007), and these do not focus on the role of patent grant delay in start-up commercialization.

2. Probabilistic Patents

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 (e.g., Nelson and Merges 1990, Anand and Khanna 2000, 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 assumes that the operation of the patent system is 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 patent enforcement has emphasized that patents are "probabilistic" property rights (Lemley and Shapiro 2005). To the extent that IP rights are probabilistic, uncertainty may have implications for technology contracting. As discussed in §3, specific types of uncertainty may limit opportunities for efficient contracting and shift the timing of cooperative commercialization. It is, therefore, useful to distill the distinct types of uncertainty over patent rights: patent allowance, patent scope, patent grant delay, patent enforceability, and patent value.

2.1. Patent Grant Uncertainty

A crucial source of potential uncertainty in the patent system could be whether a patent applicant is likely to receive *any* patent rights. Although the formal structure of the patent system suggests a high degree of uncertainty over patent grant, recent empirical research on the U.S. and European (EU) patent systems suggest that most patent applications are granted in some form. Accounting for "continuing patent applications" (which allow applicants to revise their applications over time), the U.S. grant rate may be as high as 90% (Quillen and Webster 2001, Graham and Harhoff 2006). The key moment at which the uncertainty over grant is resolved is the notice of Allowance. When inventors receive this notice, the claims that will be granted are specified.[2] Although the Notice of Allowance mitigates uncertainty over allowed claims, it reduces but does not eliminate more pervasive sources of uncertainty, such as the ultimate patent scope, or the costs and probability of enforcement.

2.2. Patent Scope Uncertainty

Although 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.[3] The heart of the patent examination process involves repeat negotiations and correspondence between a patent applicant and the patent examiner over the allowance of particular patent claims, or the wording of those claims (Cohen and Merrill 2003). This uncertainty of patent scope prior to allowance increases the costs of specifying a technology license (Lerner and Merges 1998). Moreover, preallowance contracts often require complex contingent clauses (one of our practitioner interviews said: "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, p. 699),

> Although U.S. 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... conferred by the PTO.

Patent allowance not only reduces patent scope uncertainty, but also reduces information asymmetry between applicants and potential licensees (applicants have detailed information about interactions with the examiner and likely patent scope). Of course, uncertainty over patent scope is not fully resolved until "the last court speaks," requiring significant (endogenous) investment and time (Lanjouw and Schankerman 2001, Lemley and Shapiro 2005).

2.3. Patent Pendency Uncertainty

Although most research on the patent system implicitly assumes that patent application and grant are coincident (or are, at best, an administrative matter), patent application 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. 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 technological fields (Popp et al. 2004).[4] Patent pendency (and idiosyncratic variance in the process) has important implications for the timing of technology licensing: whereas 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 while applications are pending.

2.4. Patent Enforcement Uncertainty

Although 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 (because 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 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

[2] See http://www.uspto.gov/web/offices/pac/mpep/documents/1300_1303.htm#sect1303: "The application identified above has been examined and is allowed for issuance as a patent. *Prosecution on the merits is closed*." (Underlined in the original and accessed November 15, 2006.) The notice specifies issue and publication fees, deadlines, and the process of readying the patent for formal grant. We focus on the Notice of Allowance date (rather than the traditional patent grant date) because this is when *uncertainty* over allowed claims is resolved. We adopt the term "allowance" rather than "grant," except where we discuss studies or phenomena focusing on the patent grant event per se.

[3] Examiners produce "office actions" (interim decisions regarding applications) providing information that "may be useful in aiding the applicant to judge the propriety of continuing the prosecution of his/her application... few applications are allowed as filed." (http://www.uspto.gov/web/offices/pac/doc/general/index.html#office.)

[4] A recent literature debates the relationship between patent grant lags and the importance of the innovation. Although 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. See Popp et al. (2004).

negotiation strategies of patent holders and potential infringers. As Farrell and Shapiro (2008) 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 litigation is 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).

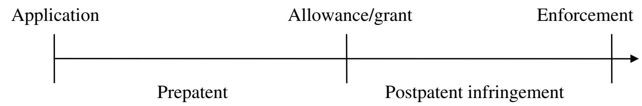
2.5. Uncertainty Over Market Value

Finally, even if the legal uncertainty associated with patents was completely resolved, the economic and strategic value of patents is subject to a high degree of uncertainty. Patents vary widely in their value, which depends on endogenous outcomes in technology and product markets (Scherer and Harhoff 2000, Arora et al. 2008, Giuri et al. 2007). For example, very few of the patented innovations in the biopharmaceutical industries are ultimately commercialized, and it is difficult to distinguish between different candidate drugs prior to the clinical trial process. Moreover, there is likely to be significant disagreement among licensors and licensees about the value of patent rights and the commercialization opportunities from new technologies, and uncertainty and disagreement about patent value is likely to persist even after patent grant. On the one hand, technology entrepreneurs may tend to be overlyoptimistic about the market value of a nascent technology (Giuri et al. 2007). On the other hand, potential licensors may in many cases be more informed about the market value of a new technology as a result of possessing specialized complementary assets, and based on their product market experience (Beggs 1992). More generally, the multiple sources of uncertainty surrounding patents highlight the probabilistic value of patent rights, and that the commercialization of technology depends on whether (and when) the market for ideas can operate in the face of such uncertainties.

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). Put simply, the "sale" of an idea allows an innovation to be commercialized more quickly, yielding gains in productive efficiency, and so delays in the timing of cooperative agreements reflect a lost opportunity for maximizing the welfare gains from ideas trading. This section considers the potential drivers of delays in the licensing process and the dynamic interplay between patent grant timing and the timing of cooperative agreements. Our objective is neither to develop a comprehensive model of the determinants of license timing nor the mechanisms used to achieve efficient licensing contracts (see, for example, Scotchmer 2004, for a useful introduction to this literature); instead, our objective is to concisely illustrate (a) why the patent allowance date will *not* matter in the absence of market imperfections in the 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. In so doing, we seek to identify the impact of the operation of the patent system on the efficiency of the market for ideas.

Figure 1 Uncertainty and the Patenting Process



3.1. The Frictionless Benchmark

Before turning to the impact of specific market imperfections, we begin by considering a "frictionless" environment to establish a benchmark for efficient trade in the market for ideas. Consider a stylized representation of the innovation commercialization process depicted in Figure 1. 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)[5] reduces this uncertainty, but does not resolve it because infringement may still occur, and defending against it may be costly and uncertain.

Consider the interactions between a single potential "customer" for an invention (C) to whom the research firm (R) might license (as in Aghion and Tirole 1994). Both parties are risk neutral.[6] 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

[5] The lag between allowance and grant varies and is subject to some uncertainty. Although this could be incorporated with additional notation, it would not change the main result or our hypotheses.

[6] Introducing risk aversion will create incentives to share risk among firms, which reinforces the incentives for early cooperation. See Scotchmer (2004) for a discussion.

innovation. This last assumption implies that expropriation concerns are limited to knowledge that 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.

A lengthy patent process implies that it will take, say, T periods from the time of application until the time a patent is allowed.[7] In addition, there is uncertainty as to the scope of the potential patent, which will impact a prepatent 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 that is very difficult to "invent around," whereas 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 expected returns conditional on broad versus narrow patent scope. This is due to the possibility of residual uncertainty from both commercial opportunities and the robustness of the patent claims in any subsequent litigation that might arise. Note that patent scope is distinct from patent validity, because 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).[8]

Because the firms are risk neutral, we consider licensing agreements whereby R assigns any patent rights to C for a flat fee.[9] 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 postpatent 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 $(1-\delta^T)v + \delta^T E[v]$ whereas R gets paid immediately. 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.[10] If scope is narrow, C can realize the commercial value of the innovation without an agreement ($t_T = 0$). We assume that the negotiators are able to achieve a cooperative outcome (i.e., firms "maximize" and split the surplus evenly).[11] At T, if patent scope is wide, $t_T = \frac{1}{2}v$, whereas if patent scope is narrow, $t_T = 0$. If we suppose that commercialization is not feasible until a licensing agreement is signed, if the firms wait, the expected licensing fee at time 0 is $p\frac{1}{2}v$ with R's expected return being $\delta^T p\frac{1}{2}v$ and C's being $\delta^T(p\frac{1}{2}v + (1-p)\underline{v})$. Based on these expected returns, there is always a joint gain for C and R to sign an agreement at time 0. The joint expected returns from an agreement at time T are $\delta^T E[v]$, whereas 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 beneficial for the parties to agree earlier regardless of the uncertainty over scope. The "price" agreed to at that time will reflect the differing impacts of patent scope uncertainty on R and C. Because firms split the surplus evenly:

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

In this case, C's expected return is $\frac{1}{2}(1-\delta^T(1-p))v + \delta^T(1-p)\underline{v}$. It is useful to observe that R's return through licensing is increasing in p, because this enhances the expected value of the innovation. 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*.

3.2. The Case of Frictions

Although delay and uncertainty have 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 focus on frictions that not only reduce

[7] Patent grant delay is itself uncertain. Adding this additional uncertainty would only strengthen our results.

[8] We thank the editorial reviewers for bring up this point. See Farrell and Shapiro (2008) for further discussion.

[9] 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, even in the market friction case.

[10] We assume that until T, only R and C can utilize the innovation and so sustain higher returns of v for that period. Allowing additional pre-grant imitators would reduce prepatent returns but does not change the comparative statics.

[11] This is the Nash bargaining outcome assuming that parties have equal bargaining power. Gans and Stern (2000) develop noncooperative 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).

the ability to achieve efficient trade, but for which the reduction of uncertainty over patent scope serves to spur technological trade, including asymmetric information, search costs, and the ability of potential licensors to expropriate knowledge that 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. Asymmetric information (from whatever source) leads to the potential failure 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.[12] If the source of asymmetric information or bargaining disagreement is unrelated to the information resolved by patent grant, the mere allowance of a patent will not alleviate this breakdown in technological trade. For example, if a technology entrepreneur is overoptimistic about the value of their technology (and the licensee cannot credibly offer a binding royalty contract), patent allowance per se may have little impact on the timing and effectiveness of commercialization. Similarly, if licensors are more accurately informed about potential commercialization opportunities or the long-term value of a patent, the ability to overcome persistent information asymmetries may be unrelated to the granting of the patent. On the other hand, 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 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 are likely to receive broad protection (relative to the expectations of potential licensees) are able to earn a licensing premium. When the patent allowance 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 of patent scope is mitigated.

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, the incentives to search may only be sufficient after a patent (with broad scope) has already been allowed (Hellmann 2007). 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 $\frac{1}{2}(1-\delta^T(1-p))\Delta$. 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 $\frac{1}{2}(1-\delta^T(1-p))\Delta < f \leq \frac{1}{2}\Delta$, 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, whereas the returns from a time T agreement will be increased to $\delta^T p(\frac{1}{2}(v+\Delta)-f)$. Therefore, if $\frac{1}{2}(\Delta-((1-\delta^T)/p\delta^T)v) \geq f$, then R will prefer to delay search. Because the returns to search are higher when patent scope is known to be broad, search costs may induce delay until uncertainty over patent scope is resolved.

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). As emphasized in the baseline model, the mere presence of unprotected knowledge has no impact on the timing of cooperative licensing (although it will have a significant impact on the division of rents). However, establishing patent rights scope can have a significant impact on the risk of expropriation and the willingness of licensors to disclose unprotected information. While it may be difficult to predict the impact of unpatentable knowledge disclosure 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, nondisclosure 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.

[12] There is some analysis of this in the literature on patent licensing (e.g., 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 (Ausubel et al. 2002).

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 (Arora 1995).[13] Suppose we reinterpret Δ in the search model above as the additional value that comes through knowledge transfer, and f as R's effort in facilitating that transfer. 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.[14] 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 $\frac{1}{2}(1-\delta^T(1-p))\Delta < f \leq \frac{1}{2}\Delta$, 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 $(1-\delta^T)v$. Therefore, if $\Delta - ((1-\delta^T)/p\delta^T)v > f$, delay will occur.[15]

Intuitively, whereas 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. 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, because 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. When the value arising from broad patent rights is sufficiently high and the "boost" from complementary knowledge disclosure is sufficiently steep, both licensors and licensees may delay licensing negotiations until patent allowance to maximize the innovator's incentives to transfer tacit knowledge.

3.3. Empirical Implications

Market frictions—barriers to efficient technological trade—can induce a systematic relationship between the patent grant process and the timing of technology licensing. Although information asymmetries, search costs, and expropriation risks may limit technological trade prior to the receipt of a patent, the reduction of uncertainty resulting from patent grant can trigger trade in the market for ideas. Conversely, without frictions, there should be no systematic relationship between patent allowance and the timing of cooperative agreements. This insight holds several testable 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 innovations. Moreover, one might expect that this variation will be narrower within a given industry than across industries. For example, most software products are associated with relatively short product life cycles, and so the benefits from productive efficiency are likely to be 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 (Hall and MacGarvie 2006 and references therein). Conversely, studies of the "patent thicket" in the semiconductor industry (Shapiro 2001) suggest significant barriers to efficient technological trade (and the ability of enforceable IP rights in reducing those barriers) in those sectors. *Therefore, both preallowance and postallowance licensing agreements will be observed in equilibrium, and the propensity for pre-grant and post-grant licensing will vary by industry and other observable characteristics of the technology and innovator*. Second, if barriers to technological exchange limit early licensing, clarification of patent rights reduces 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*. Relative to a baseline pattern of the timing of cooperation, patent allowances are predicted to be associated with a "boost" in licensing.

Third, the theoretical framework suggests that after the scope of IP rights is clarified, productive efficiency considerations provide incentives for firms to achieve a licensing agreement as soon as possible. Thus, for firms seeking a licensing partner as part of the commercialization process, *licensing will tend to take place*

[13] As Arora et al. (2001, p. 117) state: "Technology licensing involves more than just the transfer of blueprints, drawings, and specifications. In many cases, the information required for successful utilization includes heuristics, rules of thumb, and other tricks of the trade."

[14] This framing is consistent with Lowe's (2004) formulation of licensing when a great deal of knowledge is tacit.

[15] There is a key difference between the search and knowledge transfer models. In the search model, delay is driven by R's own incentives, while in the knowledge transfer model, if trade delay results in losses, 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 relative to the search model.

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 impact of patent allowance 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). The impact of patent allowance will thus be relatively unimportant in environments where productive efficiency is particularly important, such as industrial sectors with short product life cycles (e.g., software). The impact of patent allowance will also be muted in environments where the impact of frictions is modest. This can take place in locations in which alternative institutional arrangements provide a substitute for formal IP rights, such as in Silicon Valley, where reputational governance is facilitated by the highly networked environment (e.g., Saxenian 1994).

4. Data

Our data are drawn from a sample of more than 200 technology licensing deals announced between 1990 and 1999 and appearing in the Security Data Corporation (SDC) database. Our sample allows us to focus on the timing of licensing relative to changes in the IP environment for a sample of technologies that seek and receive patent protection and for which a licensing outcome is realized. For each deal, we gathered the license date announcement, the deal industry sector, and firm location and age information. For each patent-license pair, we then collected detailed patent information from the USPTO and the NBER patent data file (Hall et al. 2001), and venture capital (VC) financing information from the Venture Economics database. After trimming the data set to focus on an unambiguous set of patent-license pairs between start-up innovators and downstream firms, the final data set consists of 198 observations across four industry sectors (more details of the sampling scheme are contained in Online Appendix A, which is provided in the e-companion).[16]

4.1. Variable Definitions and Summary Statistics

Table 1 reports variable definitions and summary statistics for each of the timing measures, and patent and firm characteristics. Each of the timing measures is calculated relative to the patent application date. *Patent application date* is the date of the first patent application for a given technology, inclusive of continuances, divisions, and provisional applications.[17] 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" (see Footnote 2). From the perspective of our theoretical framework, the patent allowance date is a key event, because the Notice of Patent Allowance provides an unambiguous and finalized statement of claims allowed by the patent office (claims that may be revised by the judicial system (Lemley and Shapiro 2005)).[18] We define the *patent allowance lag* as simply the *patent allowance date* less the *patent application date*, measured in months; and the *postallowance administrative lag* as the *patent grant date* less the *patent allowance date*, also in months. Whereas 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 *postallowance administrative lag* is more than 6 months, and ranges from 1 to 19 months (with 60% experiencing a 5–7 month administrative lag).

The central focus of our empirical analysis is the relative timing of technology licensing and patent allowance. Our remaining timing measures therefore depend on the licensing date. For each technology, the licensing date is the first publicly reported instance of licensing, as indicated by the SDC database. We define the *licensing lag* to be equal to the time (in months) between patent application date and the licensing date (mean = 44.54). As well, we construct a dummy variable, *postpatent allowance*, equal to one for those licenses recorded after the patent allowance date (mean = 0.73), and a separate dummy variable, *postpatent grant*, equal to one for those licenses recorded after the *patent grant date* (mean = 0.58). Figure 2 plots the distribution of the *difference* between *patent allowance lag* and *licensing lag*: data to the left of zero are associated with licensing deals reached prior to patent allowance, whereas data to the right of zero indicate postallowance licensing. There seems to be a marked increase in the level of licensing for about a year from the patent allowance date. In other words,

[16] An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.

[17] Our results are also robust to use of the "final" application date.

[18] It is possible that communications prior to the Notice of Patent Allowance reduce uncertainty over claims *prior* to the *patent allowance date*. We investigate this by checking for an uptick in licensing prior to the *patent allowance date*. We also investigate whether the *patent grant date* has an additional impact beyond the *patent allowance date*.

Table 1a Variable Definitions, Means, and Standard Deviations

Variable	Definition	Mean	Std. dev.
Timing measures			
Patent application date	Date of patent application	1,991.16	3.96
Patent allowance date	Date of USPTO notice of patent allowance	1,993.88	3.94
Patent grant date	Date of USPTO notice of patent grant	1,994.40	3.89
Licensing date	Date of patent licensing	1,994.95	3.47
Licensing lag	*Licensing date* − *patent application date* (in months)	44.54	26.46
Postpatent allowance	Dummy = 1 if *licensing date* > *patent allowance date*	0.73	0.45
Postpatent 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
Postallowance administrative lag	Months between patent allowance and patent grant	6.79	2.81
Patent characteristics*			
Patent claims	No. of claims made in the patent	20.84	19.70
Patent citations made	No. of patent citations referenced in the patent	11.17	11.48
Patent classes	No. of 3-digit classes to which the patent is assigned	1.90	1.07
Patent backward citation lag	No. 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	No. of nonpatent references made in the patent to the scientific literature	7.56	16.75
Nonscience references	No. of nonpatent 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 et al. (2001).

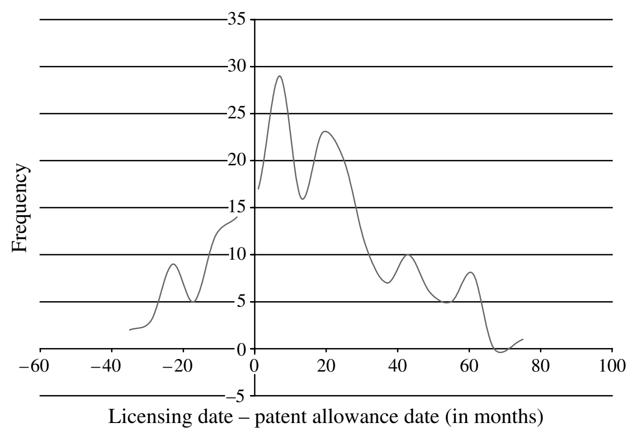
Table 1b Means of Timing Measures by Industry Sector

	Biotechnology	*Electronics*	*Software*	*Scientific instruments*
No. of 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)
Postpatent allowance	0.70 (0.46)	0.80 (0.41)	0.66 (0.48)	0.78 (0.42)

despite wide variation in both the patent allowance and licensing lag, there seems to be a striking linkage between the timing of patent allowance and licensing agreements.

As described in Table 1 and in more detail in Online Appendix A, our data set also includes firm and patent characteristics. These measures allow us to evaluate the impact of observable measures of the business environment on licensing behavior. In terms of firm characteristics, we define dummies for locations that may provide access to different types of technology-licensing networks (*Silicon Valley*, *Route 128*, and *Canada*), and proxies for firm experience and resources, including *firm age* and *VC funded*. We also construct four industry dummy variables: *biotechnology*, *electronics*, *software*, and *scientific instruments* sectors. Not only might the underlying timing of licensing differ significantly across industry sectors (and so we stratify the baseline hazard rate by industry), but the importance of patent allowance may also vary across industries. For example, patent allowance may be relatively unimportant in the software industry, where product cycle time is short and patents are either weak or copyright protection may serve as a substitute (Graham and Mowery 2003, Lerner and Zhu 2007), but more salient in biotechnology, where the product lifecycle is less rapid and where achieving effective tacit knowledge transfer may be particularly important. Finally, we include several patent characteristics in the analysis. From the NBER patent data file (Hall et al. 2001), we include

Figure 2 Distribution of Difference Between Patent Allowance and Licensing Dates



patent claims, *patent classes*, *patent citations made*, *patent backward citation lag*, and *patent originality*. We also include the number of nonpatent references to the scientific literature, *science references*, and the number of nonpatent, nonscientific references, *nonscience references*. These patent characteristics may be informative about the incentives for preallowance versus postallowance 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. As we discuss in Online Appendix A, these individual measures can proxy for different effects, and so we are cautious in our interpretation.

Table 1b provides a tabulation of the *patent allowance lag* and *licensing lag* by industry. Whereas *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). Whereas the licensing lag is also longest in *biotechnology*, *software* is associated with the shortest licensing lag (40 months). Whereas 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: although postallowance licensing occurs more than 80% of the time in *electronics*, less than two-thirds of *software* industry licenses occur prior to the *patent allowance date*. Patents seem to play different roles in different sectors; evaluating this claim systematically requires an analysis of how *patent allowance date* shifts the licensing hazard rate. More detail on timing lag distributions is contained in Online Appendix B, provided in the e-companion.

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 divide the data into monthly observations from the *patent application date*, and define $License_{it}$ to be equal to zero until the month in which the first license occurs, at which point $License_{it}$ is set equal to one (i.e., there is a unique absorbing event). We also define a time-varying regressor, $PostPatent_{it}$, equal to zero for months after the *patent application date* but prior to the *patent allowance date*, and equal to one after the *patent allowance date*. Because we observe a prepatent and postpatent period for each innovation (and it is possible that licensing occurs prior to the postpatent 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).

Our analysis employs a Cox proportional hazard-rate model with time-varying regressors. The Cox model is specified as a continuous-time hazard-rate function, incorporating a nonparametric baseline hazard rate and a multiplicative term allowing regressors to have a proportional impact relative to the baseline (Lancaster 1990). Letting $h_{license}$ equal the hazard rate of *license* changing from zero to one (i.e., the instantaneous probability of failure at t, conditional on survival until t), allowing for stratification by industry, and including controls for observable factors yields

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

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 *post patent* on the *licensing* hazard rate. We exploit two features of the data in estimating and interpreting $\beta_{\text{POST PATENT}}$ as a treatment effect. First, we take advantage of variation in the *patent allowance lag*: if all technologies had an identical patent allowance lag, we could not separately identify the impact of patent allowance from the (nonparametric) baseline hazard rate. Second, we directly account for the bias that might arise from a correlation between the *patent allowance lag* and unobserved heterogeneity in the hazard rate (i.e., a technology-specific factor, ν_i, which raises or lowers the baseline hazard rate but is unobservable to the econometrician). For example, technologies with long *patent allowance lags* may tend to have a low underlying hazard rate, resulting in a spurious correlation between the patent allowance lag and the licensing lag. To disentangle the impact of a "treatment effect" (in this case, patent allowance) from unobserved heterogeneity, it is useful to recognize that although the value of ν_i impacts the hazard rate in all periods, POST PATENT only impacts the hazard rate after patent allowance (Abbring and van den Berg 2003). Because we observe the *patent allowance lag* for all technologies, even those licensing prior to patent allowance, we include the *patent allowance lag* as a regressor in the hazard function, controlling directly for spurious correlation between *patent allowance lag* and ν_i, yielding:[19]

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

As long as *post patent* is *conditionally* independent of ν_i (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 of *licensing* (Abbring and van den Berg 2003).

This framework provides a parametric test for our first hypothesis, and can be adapted to evaluate our supplementary hypotheses (see Online Appendix C, provided in the e-companion). First, we can define a set of time-varying measures that 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, because information is being revealed *prior* to the *patent allowance date*, followed by an enhanced *licensing* hazard rate, attenuating over time. Second, we can introduce several interaction terms between *postpatent allowance* and measures of the strategic and technological environment. We de-mean each element of our control vector Z_i (i.e., calculate $\bar{Z}$) to formulate a specification which allows us to estimate how the overall impact of *patent allowance date* on *licensing* changes with changes in the underlying economic, strategic, and technical environment. Third, we can distinguish whether the *licensing* hazard rate results from the *patent allowance date* or from the subsequent formal *patent grant date*.

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), because 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 postallowance 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 a more than 200% increase in the underlying hazard rate.[20] The second 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 *postpatent allowance* estimate is identified from within-industry variation of patent "cohorts." By controlling directly for the spurious correlation between patent allowance lags and licensing lags (due to potential unobserved features of the technology), and controlling for unobserved heterogeneity through stratification and application year fixed effects, we expect the absolute size of the *postpatent 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%). Also, the coefficient on *patent allowance lag* is negative and highly significant, suggesting that longer patent allowance times are correlated with longer licensing lags. Together, these results suggest that although 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.[21] In the final specification in Table 2, we add one additional regressor, *postpatent 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 *postpatent allowance* coefficient remains large and significant. Hence, the probability of licensing is significantly enhanced when uncertainty surrounding formal IP rights is reduced.

Table 3 examines whether this core finding is robust to the inclusion of different controls. Each specification continues to include a complete set of patent

[19] Including *patent lag* as a linear term is arbitrary; experiments with a "control function" approach or a shared frailty parameter do not change the qualitative results (see Online Appendix D, provided in the e-companion). More generally, this approach builds on a subtle, recent literature on the identification of treatment effects in duration models (van den Berg 2001).

[20] All findings are robust to either the *patent allowance date* or *patent grant date* as the key timing measure.

[21] Online Appendix D includes additional specifications exploring this baseline result, including the use of a control function approach, a shared frailty parameter, and a parametric distribution for the baseline hazard rate. The estimated coefficient on *postpatent allowance* is larger in these specifications and remains statistically significant.

Table 2 Baseline Cox Hazards (*Dependent Variable* = *LICENSE*)

	(2-1)		(2-2)		(2-3)	
Independent variable	Hazard ratio	Coefficient	Hazard ratio	Coefficient	Hazard ratio	Coefficient
Postpatent 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)
Postpatent grant					0.793 (0.198)	−0.231 (0.250)
Patent application year fixed effects			Yes		Yes	
Biotechnology *Electrical equipment* *Software*			Hazard rate stratified by industry		Hazard rate stratified by industry	
Log likelihood	−834.170		−537.620		−537.698	

Notes. ** and *** indicate statistical significance at the 5% or 1% level, respectively. Robust standard errors are clustered by firm; $N = 8{,}045$.

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 effects are different in technologically "networked" locales such as Silicon Valley and Route 128; see 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). Although none of these control variables is individually significant (or even estimated to have a large impact), the underlying size and significance of the *postpatent allowance* coefficient persists. We then include the complete set

Table 3 Baseline Industry-Stratified Cox Hazards with Controls (*Dependent Variable* = *LICENSE*)

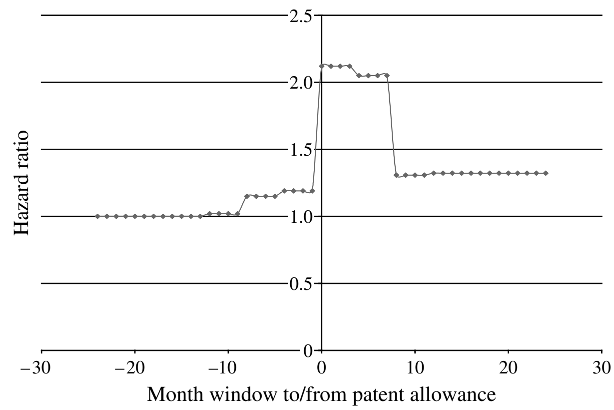
	(3-1)		(3-2)		(3-3)		(3-4)	
Independent variable	Hazard ratio	Coefficient	Hazard ratio	Coefficient	Hazard ratio	Coefficient	Hazard ratio	Coefficient
Postpatent allowance	1.690** (0.451)	0.524** (0.267)	1.695** (0.453)	0.528** (0.267)	1.757** (0.492)	0.564** (0.280)	1.757** (0.494)	0.563** (0.281)
Patent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

Notes. ** and *** indicates statistical significance at the 5% and 1% levels, respectively. Robust standard errors are clustered by firm; $N = 8{,}045$.

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 *postpatent allowance* is remarkably stable, both in economic and statistical significance. In addition, two of the patent characteristic variables are significantly related to changes in the licensing hazard rate. A one standard deviation increase in *patent backward citation lag* is associated with a more than 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. Productive efficiency considerations may not be as important in such settings, resulting in a lower hazard. The coefficient on *science references* is also significant and positive (although the estimated magnitude is relatively small), and is consistent with Fleming and Sorenson's (2004) suggestion that science-intensive patents have a higher degree of technological transparency (and would thus involve a less complex licensing process). These patterns hold across a wide range of control structures and robustness checks.[22]

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 *postpatent allowance* dummy variable, we estimate eight mutually exclusive time window dummies.[23] 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. 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 a treatment is whether the hazard rate increases significantly in the period immediately after the treatment (but not before). Figure 3 accords precisely with the intuition, suggesting a causal influence of patent allowance on the hazard rate of licensing.

Figure 3 **Licensing Hazard Ratio, Prepatent vs. Postpatent Allowance**



6.1. Does the Impact of Patent Allowance Depend on the Firm's Strategic Environment?

Finally, we examine interaction effects between *postpatent allowance* and patent and firm characteristics. Although the interaction effects with industry dummies are modeled directly (i.e., $PostPatent\ Allowance_i^t \cdot Industry_i$), the remainder of the interaction effects are defined as an interaction between *postpatent allowance* and deviations from the sample means for each measure (i.e., $PostPatent\ Allowance_i^t \cdot (Z_i - \overline{Z})$). The coefficient on *postpatent allowance* (or *postpatent allowance* ∗ *industry*) can thus be interpreted as the effect when each of the interaction measures equals their sample means. The first column of Table 4 examines the complete set of *postpatent allowance* ∗ *industry* interactions. Although *postpatent allowance* is positive for all industries, the effect is statistically significant in the electronics and biotechnology industries, insignificant in scientific instruments, and negligible and noisy in software. This pattern is consistent with key differences between these industries. In biotechnol-

[22] We experimented with measures of technology "importance," including the *forward citations* to each patent. Because this measure may be endogenous (early licensing may induce higher number of forward citations), we do not include it in Table 3 (the results are similar, and *forward citations* is insignificant). The results are also robust to various subsamples: young firms (below the median sample age), "early" cohorts (applications before 1996), "late" cohorts (applications after 1990), using a time window to account for a "preannouncement" effect (allowing the treatment three months prior to the actual allowance date), and excluding six patents that have undergone litigation.

[23] The windows are as follows: greater than 12 months prior to patent allowance (normalized to 1.0), 12 to 8 months prior to allowance, 7 to 4 months prior to allowance, 3 months to allowance, 1 to 4 months after allowance, 5 to 8 months after allowance, 9 to 12 months after allowance, and greater than 12 months after allowance. Because these time-window dummies are exhaustive and mutually exclusive, we cannot separately estimate the impact of *postpatent allowance*. We instead focus on the changes during the periods up to and after the allowance date.

Table 4 Industry-Stratified Cox Hazards: Industry, Location, and Firm Interaction Effects (*Dependent Variable = LICENSE*)

	(4-1)				(4-2)				(4-3)				(4-4)			
Independent variable	Hazard ratio		Coefficient		Hazard ratio		Coefficient		Hazard ratio		Coefficient		Hazard ratio		Coefficient	
Postpatent 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 ∗ postpatent allowance	1.78*	(0.61)	0.57*	(0.35)									1.54	(0.70)	0.43	(0.45)
Software ∗ postpatent allowance	1.05	(0.50)	0.05	(0.48)									1.29	(0.82)	0.26	(0.63)
Electr. equip ∗ postpatent allowance	2.47**	(1.13)	0.91**	(0.46)									4.19***	(2.22)	1.43***	(0.53)
Sci. instrum. ∗ postpatent 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 ∗ postpatent allowance					0.39**	(0.18)	−0.94**	(0.46)					0.41*	(0.20)	−0.90*	(0.48)
Route 128 ∗ postpatent allowance					0.44*	(0.22)	−0.81*	(0.48)					0.75	(0.46)	−0.28	(0.61)
Canada ∗ postpatent allowance					0.66	(0.32)	−0.41	(0.48)					0.91	(0.43)	−0.09	(0.47)
VC funded ∗ postpatent allowance					0.76	(0.27)	−0.28	(0.36)					0.92	(0.38)	−0.08	(0.42)
Firm age ∗ postpatent 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)
Science references									1.01*	(0.01)	0.01*	(0.01)	1.01	(0.01)	0.01	(0.01)
Nonscience references									1.00	(0.02)	0.00	(0.02)	1.00	(0.02)	−0.00	(0.02)
Patent claims ∗ postpatent allowance									1.00	(0.01)	0.00	(0.01)	1.00	(0.01)	0.00	(0.01)
Patent classes ∗ postpatent allowance									0.69**	(0.12)	−0.37**	(0.17)	0.64***	(0.11)	−0.44***	(0.01)
Patent cit. made ∗ postpatent allowance									1.00	(0.02)	0.00	(0.02)	1.00	(0.02)	0.00	(0.02)
Patent bkwd. cit. lag ∗ postpatent allowance									1.11	(0.08)	0.10	(0.07)	1.12	(0.08)	0.12	(0.07)
Patent orig. ∗ postpatent allowance									2.88	(2.36)	1.06	(0.82)	1.00	(0.01)	1.18	(0.87)
Science ref. ∗ postpatent allowance									1.00	(0.01)	0.00	(0.01)	1.01	(0.00)	0.00	(0.01)
Nonscience ref. ∗ postpatent allowance									0.99	(0.02)	−0.01	(0.029)	0.99	(0.03)	−0.01	(0.03)
Patent allowance lag ∗ postpatent allowance									1.00	(0.01)	0.00	(0.01)	1.00	(0.01)	0.00	(0.01)
Patent application year fixed effects	Yes				Yes				Yes				Yes			
Log likelihood	−537.379				−534.559				−522.555				−518.699			

Notes. *, **, and *** indicates statistical significance at the 10%, 5%, and 1% levels, respectively. Robust standard errors are clustered by firm; $N = 8{,}045$.

ogy, patent protection and long regulatory lags make productive efficiency concerns less important. Conversely, in software, product life cycles are rapid, and copyright protection offers an effective substitute for protecting IP in the context of licensing negotiations (indeed, software patents may be of uncertain 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. Although 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). Although there may be several explanations for this finding (e.g., the types of technologies developed in these locations may be different), these results are consistent with the hypothesis that the impact of *formal* intellectual property may be reduced in highly networked environments. In a highly networked environment, brokers actively seek to facilitate the licensing process, and licensees may seek to protect their reputation in the market for ideas (Lamoreaux and Sokoloff 1996, Arora et al. 2001, Hsu 2006). In (4-3), we examine interactions between patent characteristics and *postpatent allowance*. We find one effect in addition to the significant effects of *patent backward citation lag* and *science references* (as in Table 3). Whereas the direct effect of *patent classes* is positive, the interaction between *patent classes* and *postpatent allowance* is negative. Although we are cautious in our interpretation (several of the patent characteristic measures are correlated with each other), the direct *patent classes* effect 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, but that the *enforceability* of patents with coverage across a wider number of classes is more uncertain. The coefficient on *patent allowance lag ∗ postpatent allowance* is 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. Although several 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.[24]

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. Among our 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, and this effect is most pronounced in the time period immediately following the patent allowance event. The impact of the patent systems depends on the strategic and institutional environment in which firms operate. In particular, the impact of patent grant is reduced in environments where alternative institutional mechanisms are available, such as in the software industry (copyright) and Silicon Valley (where brokers and reputation-based substitutes are available).

Our findings provide evidence for frictions in the market for ideas.[25] 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 and that the dynamics of commercialization strategy are influenced by the operation of the patent system. Patent allowance reduces the uncertainty of patent scope, reducing (but not eliminating) imperfections in the market for ideas. The analysis highlights the value of grappling with the operational details of the patent system, and how institutional and strategic factors influence the level of uncertainty and information asymmetry about the value of patent rights. In particular, 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, either through alternative institutional mechanisms or through sophisticated contracting approaches (as in Thursby et al. 2007).

Our analysis also highlights the strategic trade-off innovators face between the protection of their ideas and the pursuit of an effective commercialization strategy. Although commercialization would often be enhanced by prompt and pervasive disclosure (perhaps including scientific journal publication, participation in standards-setting bodies, etc.), establishing protection against expropriation often requires delay and some level of secrecy. Because 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 regarding if and when to publish in the scientific literature, when to patent or not, and when to protect knowledge through tacit means or outright secrecy (e.g., Arora et al. 2001, Gittleman and Kogut 2003). Although this work begins to unpack some of the trade-offs 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.

8. Electronic Companion

An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.

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References

Abbring, J. H., G. J. van den Berg. 2003. The nonparametric identification of treatment effects in duration models. *Econometrica* **71** 1491–1518.

[24] We also examined whether the impact of patent allowance is changing over time by interacting *postpatent allowance* with *application year*. The coefficient is small and not significant. We also explored whether the impact of patent allowance is changing over time differentially across industries. We did not identify any significant trends. Finally, we tested 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). We only observe 29 licenses with patent application dates after 1995, and so the results are noisy (the sign and magnitude vary depending on specification).

[25] For an estimate of the overall empirical importance of these findings, consider the parametric failure time model in Online Appendix (D-4). These estimates imply that for firms using the patent system to achieve a licensing agreement, patent allowance delay results in an 18-month average delay in licensing. However, our sample is conditioned on innovations receiving patents that are ultimately licensed, yielding an upper bound on the population impact of the patent system on the market for ideas. Because some innovators never seek to license their technology, the population impact of patent allowance is equal to $\beta_{\text{POST PATENT}}$ multiplied by the share of innovators seeking licensing. Hsu (2006), using a broadly similar approach for identifying start-up innovators finds that 42% of start-up innovators receive at least one patent, and 15% of those firms commercialize through cooperation. Therefore, although the *marginal impact* of patent allowance is significant, the overall start-up licensing rate is modest.

Aghion, P., J. Tirole. 1994. The management of innovation. *Quart. J. Econom.* **109** 1185–1210.

Anand, B., T. Khanna. 2000. The structure of licensing contracts. *J. Indust. Econom.* **48** 103–135.

Anton, J. J., D. A. Yao. 1994. Expropriation and inventions: Appropriable rents in the absence of property rights. *Amer. Econom. Rev.* **84** 190–209.

Arora, A. 1995. Licensing tacit knowledge: Intellectual property rights and the market for know-how. *Econom. Innovation New Tech.* **4** 41–49.

Arora, A., M. Ceccagnoli, W. M. Cohen. 2008. R&D and the patent premium. *Internat. J. Indust. Organ.* Forthcoming.

Arora, A., A. Fosfuri, A. Gambardella. 2001. *Markets for Technology: The Economics of Innovation and Corporate Strategy*. MIT Press, Cambridge, MA.

Arrow, K. J. 1962. Economic welfare and the allocation of resources for inventions. R. Nelson, ed. *The Rate and Direction of Inventive Activity: Economic and Social Factors*. Princeton University Press, Princeton, NJ, 609–625.

Ausubel, L., P. Cramton, R. J. Deneckere. 2002. Bargaining with incomplete information. R. Aumann, S. Hart, eds. *Handbook of Game Theory*, Vol. 3, Chap. 50. North-Holland, Amsterdam.

Beggs, A. W. 1992. The licensing of patents under asymmetric information. *Internat. J. Indust. Organ*. **10** 171–191.

Cohen, W. M., S. A. Merrill, eds. 2003. *Patents in the Knowledge-Based Economy*. National Academies Press, Washington, D.C.

Dechenaux, E., B. Goldfarb, S. Shane, M. Thursby. 2008. Appropriability and commercialization: Evidence from MIT inventions. *Management Sci.* **54** 893–906.

Elfenbein, D. 2007. Publications, patents and the market for university inventions. *J. Econom. Behav. Organ.* **63** 688–715.

Farrell, J., C. Shapiro. 2008. How strong are weak patents? *Amer. Econom. Rev.* Forthcoming.

Fleming, L., O. Sorenson. 2004. Science as a map in technological research. *Strategic Management J.* **25** 909–928.

Gans, J. S., S. Stern. 2000. Incumbency and R&D incentives: Licensing the gale of creative destruction. *J. Econom. Management Strategy* **9** 485–511.

Gans, J. S., D. H. Hsu, S. Stern. 2002. When does start-up innovation spur the gale of creative destruction? *RAND J. Econom.* **33** 571–586.

Gittelman, M., B. Kogut. 2003. Does good science lead to valuable knowledge? Biotechnology firms and the evolutionary logic of citation patterns. *Management Sci.* **49** 366–382.

Giuri, P., M. Mariani, S. Brusoni, G. Crespi, D. Francoz, A. Gambardella, W. Garcia-Fontes, A. Geuna, R. Gonzales, D. Harhoff, K. Hoisl, C. Lebas, A. Luzzi, L. Magazzini, L. Nesta, O. Nomaler, N. Palomeras, P. Patel, M. Romanelli, B. Verspagen. 2007. Inventors and invention processes in Europe. Results from the PatVal-EU survey. *Res. Policy* **36** 1107–1127.

Graham, S. J. H., D. Harhoff. 2006. Can post-grant reviews improve patent system design? A twin study of US and European patents. CEPR Discussion Paper 5680, Centre for Economic Policy Research, London.

Graham, S. J. H., D. Mowery. 2003. Intellectual property protection in the U.S. software industry. W. M. Cohen, S. L. Merrill, eds. *Patents in the Knowledge-Based Economy*. National Academies Press, Washington, D.C., 219–281.

Hall, B. H., M. MacGarvie. 2006. The private value of software patents. NBER Working Paper 12195, National Bureau of Economic Research, Cambridge, MA.

Hall, B. H., A. B. Jaffe, M. Trajtenberg. 2001. The NBER patent citation data file: Lessons, insights and methodological tools. NBER Working Paper 8498, National Bureau of Economic Research, Cambridge, MA.

Harhoff, D., S. Wagner. 2005. Modelling the duration of patent examination at the European patent office. Working Paper 5283, Centre for Economic Policy Research, London.

Heller, M., R. Eisenberg. 1998. Can patents deter innovation? The anti-commons in biomedical research. *Science* **280** 698–701.

Hellmann, T. 2007. The role of patents for bridging the science to market gap. *J. Econom. Behav. Organ.* **63** 624–657.

Hsu, D. 2006. Venture capitalists and cooperative start-up commercialization strategy. *Management Sci.* **52** 204–219.

Jaffe, A., J. Lerner. 2004. *Innovation and Its Discontents*. Princeton University Press, Princeton, NJ.

Johnson, D. K. N., D. Popp. 2003. Forced out of the closet: The impact of the American inventors protection act on the timing of patent disclosure. *RAND J. Econom.* **34** 96–112.

Katila, R., P. Y. Mang. 2003. Exploiting technological opportunities: The timing of collaborations. *Res. Policy* **32** 317–332.

Kitch, E. 1977. The nature and function of the patent system. *J. Law Econom.* **20** 265–290.

Lamoreaux, N. R., K. L. Sokoloff. 1996. Long-term change in the organization of inventive activity. *Proc. Natl. Acad. Sci. USA* **93** 12686–12692.

Lancaster, T. 1990. *The Econometric Analysis of Transition Data*. Cambridge University Press, Cambridge.

Lanjouw, J. O., M. Schankerman. 2001. Characteristics of patent litigation: A window on competition. *RAND J. Econom.* **32** 129–151.

Lanjouw, J. O., M. Schankerman. 2004. Patent quality and research productivity: Measuring innovation with multiple indicators. *Econom. J.* **114** 441–465.

Lemley, M. A., C. Shapiro. 2005. Probabilistic patents. *J. Econom. Perspect.* **19** 75–98.

Lerner, J., R. Merges. 1998. The control of technology alliances: An empirical analysis of the biotechnology industry. *J. Indust. Econom.* **46** 125–156.

Lerner, J., F. Zhu. 2007. What is the impact of software patent shifts? Evidence from Lotus v. Borland. *Internat. J. Indust. Organ.* **25** 511–529.

Lowe, R. A. 2004. Knowledge transfer and university entrepreneurship. Mimeo, Carnegie Mellon University, Pittsburgh.

Markewicz, K. R. 2005. University patenting and the rate of knowledge exploitation. Working paper, University of California, Berkeley.

Narin, F. 1994. Patent bibliometrics. *Scientometrics* **30** 147–155.

Nelson, R. R., R. Merges. 1990. On the complex economics of patent scope. *Columbia Law Rev.* **90** 839–916.

Popp, D., T. Juhl, D. Johnson. 2004. Time in purgatory: Determinants of the grant lag for U.S. patent applications. *Topics Econom. Anal. Policy* **4**(1), Article 29.

Quillen, C. D., Jr., O. H. Webster. 2001. Continuing patent applications and performance of the U.S. patent office. *Federal Circuit Bar J.* **11** 1–21.

Saxenian, A. 1994. *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Harvard University Press, Cambridge, MA.

Scherer, F. M., D. Harhoff. 2000. Technology policy for a world of skew-distributed outcomes. *Res. Policy* **29** 559–566.

Scotchmer, S. 2004. *Innovation and Incentives*. MIT Press, Cambridge, MA.

Shapiro, C. 2001. Navigating the patent thicket: Cross licenses, patent pools, and standard setting. A. B. Jaffe, J. Lerner, S. Stern, eds. *Innovation Policy and the Economy*, Vol. 1. MIT Press, Cambridge, MA, 119–150.

Teece, D. 1986. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Res. Policy* **15** 285–305.

Thursby, M., J. Thursby, E. Dechenaux. 2007. Shirking, sharing risk, and shelving: The role of university license contracts. NBER Working Paper 11128, National Bureau of Economic Research, Cambridge, MA.

van den Berg, G. J. 2001. Duration models: Specification, identification, and multiple durations. J. J. Heckman, E. Leamer, eds. *Handbook of Econometrics*, Vol. V. North-Holland, Amsterdam, 3381–3460.

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e-companion

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Electronic Companion—"The Impact of Uncertain Intellectual Property Rights on the Market for Ideas: Evidence from Patent Grant Delays" by Joshua S. Gans, David H. Hsu, and Scott Stern, *Management Science*, DOI 10.1287/mnsc.1070.0814.

Electronic-Companion to "The Impact of Uncertain Intellectual Property Rights on the Market for Ideas: Evidence from Patent Grant Delays"

by

Joshua S. Gans, David H. Hsu *and* Scott Stern

Online Supplement
This companion to the main paper provides addition detail associated with the data, empirical framework, and empirical results of the paper.

ONLINE APPENDIX A: Data Issues

Sample Selection Criteria. 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. Based on a reading of the deal description from the SDC database, we identified the first significant patent associated with the technology from 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. 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. Beginning in November 2000, patent applications are disclosed 18 months after filing, as opposed to the time of patent grant (see Johnson and Popp (2003) for an analysis of the impact of the American Inventors Protection Act of 1999 (AIPA)). To impose uniformity regarding disclosure, and limit right-censoring, our sample covers the period prior to the AIPA.

While the overall analysis of deal structure across different types of players is extremely informative (e.g., Lerner and Merges, 1998), 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. 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 resulted in a final sample of 198 technologies for which a patent was issued and a license was granted.

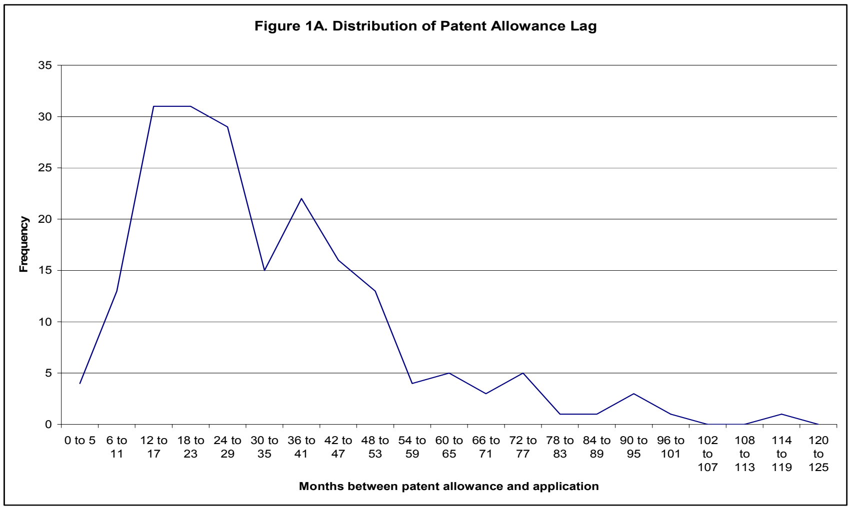
For a small set of observations (post-1999 patent grants), the HJT patent characteristics data are not available through the NBER file. We constructed the HJT measures for these observations, and checked whether our results are sensitive to their inclusion or exclusion. All qualitative results remain the same.

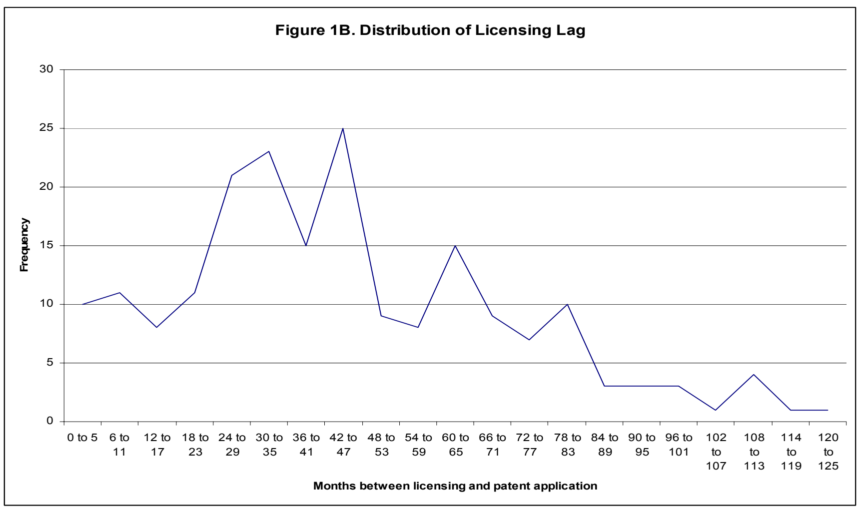
It is also useful to note that the industry coverage is distinct from the geography dummies in the dataset. Each of the industries is represented in each of the geographic regions (Silicon Valley, Route 128, Canada, and other), and the only significant pair-wise correlation between the industry and geography measures is a positive correlation between *Route 128* and *software* ($\rho = 0.20$).

Firm and patent characteristics. Our dataset also includes firm and patent characteristics, allowing us to evaluate the impact of observable measures of the business environment on licensing behavior. 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 network-based mechanisms may facilitate exchange even in the absence of IPR, and so licensing may be less sensitive to patent allowance in these regions. Our sample also includes a relatively high number of Canadian licensing deals, and so we construct a Canada dummy (mean = 0.18). We also include proxies for 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. 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 IPR (Hsu, 2006). Yet, firms with fewer organizational resources may be unable to delay licensing until patent allowance, and so may forego bargaining position to achieve an earlier licensing agreement. Younger firms may be less savvy in their approach to licensing, or may be willing to sacrifice bargaining power in order to quickly establish a cooperative commercialization agreement with an industry incumbent. 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 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* 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). *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* (mean = 0.43) measures the diversity of cited references (similar to a traditional Herfindahl index in which the measure ranges from zero to one, and is increasing in the uniformity of cited patent classes). We also 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- 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). 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 level of tacit knowledge exchange for effective transfer.

ONLINE APPENDIX B
Timing Lag Distributions





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. As well, the patent allowance lag has a large right tail, with a small number of technologies with patent allowance lags in excess of nine years. 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.

In contrast to the *patent allowance lag* distribution, *licensing lag* is more evenly distributed. Figure 2 in the text of the main paper combines these histograms in reporting the distribution of *licensing lag* less *patent allowance lag*. Finally, it is useful to note that 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 behavior of managerial response 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.

ONLINE APPENDIX C: The Empirical Framework

In our discussion of the empirical framework, we discuss but do not present the specifications for the tests of our supplementary hypotheses. 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:

$$h_{LICENSE}(t,\text{POST PATENT}_i^t,l,Z_i)=h^l(t)\cdot\exp\left\{\begin{array}{l}\beta_0+\beta_Z Z_i+\beta_{\text{PATENTLAG}}\text{PATENT LAG}_\text{i}+\sum_{k,l}\psi_{PRE\_k,l}\text{PRE PATENT}(k,l)_i^t\\+\sum_{k,l}\psi_{POST\_k,l}\text{POST PATENT}(k,l)_i^t+v_i\end{array}\right\} \quad \text{(C-1)}$$

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:

$$h_{LICENSE}(t,\text{POST PATENT}_i^t,l,Z_i)=h^l(t)\cdot\exp\left\{\begin{array}{l}\beta_0+\beta_Z Z_i+\beta_{\text{PATENTLAG}}\text{PATENT LAG}_\text{i}+\beta_{\text{POST PATENT}}\text{POST PATENT}_i^t\\+\beta_{PATGRANT,Z}\text{POST PATENT}_i^t\cdot(Z_i-\bar{Z})+v_i\end{array}\right\} \quad \text{(C-2)}$$

This 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.

Finally, 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:

$$h_{LICENSE}(t,\text{POST PATENT}_i^t,l,Z_i)=h^l(t)\cdot\exp\left\{\begin{array}{l}\beta_0+\beta_Z Z_i+\beta_{\text{PATENTLAG}}\text{PATENT LAG}_\text{i}+\beta_{\substack{\text{POST PATENT}\\\text{ALLOWANCE}}}\text{POST PATENT ALLOWANCE}_i^t\\+\beta_{\substack{\text{POST PATENT}\\\text{GRANT}}}\text{POST PATENT GRANT}_i^t+v_i\end{array}\right\} \quad \text{(C-3)}$$

ONLINE APPENDIX D

Robustness to Functional Forms and Estimation Methods

Dependent Variable = LICENSE

(Robust standard errors are clustered by firm)

N = 8045

Independent Var.	**(D-1)**		**(D-2)**		**(D-3)**		**(D-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.

This table includes a number of additional empirical specifications exploring the robustness of the baseline results in Table 2. In the spirit of a control function approach, (D-1) and (D-2) include alternative functional forms for the treatment of the *patent allowance lag* (including the inverse (D-1) and the inclusion of the inverse, level and square of *patent allowance lag* (D-2)). In (D-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 (D-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.