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

by

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ABSTRACT

This paper considers the impact of the intellectual property (IP) system on the timing of cooperation/licensing by start-up technology entrepreneurs. If the market for technology licenses is efficient, the timing of licensing is independent of the patent grant date, and productive efficiency considerations will result in licensing as early as possible after invention. In contrast, the need for disclosure of unprotected knowledge on the part of the inventor, asymmetric information between the licensor and potential licensees, or search costs may retard efficient technology transfer. In these cases, the actual grant of a patent may facilitate trade in the market for ideas by establishing the scope of IP rights. Employing a dataset which combines information about the timing of patent grants and cooperative licensing, we find that pre-grant licensing is quite common, occurring in about 40% of our sample; moreover, the hazard rate for achieving a cooperative licensing agreement increases significantly with the granting of formal IP rights. Finally, the importance of a patent grant for licensing depends on the strategic environment in which the firm operates. When productive efficiency effects are important (as when technology cycle times are short), or when alternative mechanisms such as reputation may serve to mitigate expropriation concerns or reduce search costs, patent grants are not as important. 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, Fosfuri and Gambardella, 2001). The gains from technological trade may include reductions in the costs associated with translating an idea into a commercially viable product and enhancing specialization by firms into knowledge production or commercialization (Arora and Gambardella, 1994). Imperfections in the market for technology may significantly reduce the gains from technological trade, however. Potential licensors may limit information disclosure in order to avoid expropriation by potential partners (Arrow, 1962; Anton and Yao, 1994), particularly when knowledge disclosure requires effort on the part of the licensor (Arora, 1995). Moreover, matching in the market for technology may depend on a costly search process, limiting the potential for technology partnerships (Hellmann, 2005).

This paper evaluates the role that *formal* intellectual property (IP) rights, most notably patents, play in facilitating technology transfer between firms in the market for ideas (Nelson and Merges, 1990; Arora, 1995; Arora, Fosfuri and Gambardella, 2001; Gans, Hsu and Stern, 2002). We focus on how the IP system impacts the *timing* of cooperation between start-up technology entrepreneurs and more established firms in the commercialization process. Building on recent studies that highlight the operation of the patent system (Cohen and Merrill, 2003; Jaffe and Lerner, 2004; Johnson and Popp, 2003), we exploit a fundamental feature of the process by which patent rights are received: patent grant delay. While most analyses implicitly assume that once an invention is developed, IP rights are granted and enforced, both the granting of IP rights and the achievement of cooperation take place over time. When licensing occurs, it therefore takes place in one of two institutional regimes: a pre-patent grant period in which the scope and timing of rights is uncertain, or a post-patent grant period in which uncertainty about the precise scope of rights has been narrowed. While productive efficiency favors cooperation as soon as the technology is transferable, uncertainty about the scope and extent of patent protection might delay licensing until a patent is actually granted. By considering how the timing of cooperation interacts with the timing of patent grant, we provide evidence about the role that IP rights play in facilitating trade through the market for ideas.

Consider the biotechnology industry, where start-up technology commercialization is often achieved through cooperative agreements with downstream partners. Some innovations in this industry are licensed prior to patent grant, while others are licensed only after a patent has been received. Our fieldwork suggests that entrepreneurs explicitly consider the stage and status of IP development in their licensing strategies. For example, while some firms exploit patent grant delay to enhance their bargaining power and certify their research through complementary publication outlets (such as scientific journals), others are willing to give up certain control rights and negotiate more complex arrangements in order to access and exploit downstream complementary assets.

These qualitative findings reflect a crucial dynamic tradeoff facing start-up innovators pursuing cooperative commercialization: while an early agreement reduces overall time-to-market, later agreements may be associated with greater bargaining power and more effective technology transfer. The timing of cooperation is a key managerial strategic choice, and the optimal timing of cooperation depends on the commercialization environment in which the firm operates.[1]

To explore the role of the commercialization environment in shaping commercialization dynamics,[2] we develop an identification strategy based on changing commercialization environments facing start-up innovators over time. We construct a novel dataset of 200 technologies developed by start-up innovators and ultimately commercialized through cooperation. For each of these technologies, we link the timing of cooperative licensing with the timing of patent application and grant, as well as other firm and market characteristics. We then examine whether the likelihood of cooperation (as measured by the cooperation hazard rate) *changes* in response to a *change* in the commercialization environment (specifically, the resolution of uncertainty over the scope of patent rights). Moreover, we explore whether the impact of patent grants varies with other aspects of the business environment, including the firm's industry, location, organization, and characteristics of the technology.

We establish several key findings. First, pre-grant licensing is quite common, occurring in about 40% of our sample. Second, the granting of formal IP rights increases the hazard rate for achieving a cooperative licensing agreement by 100%. Finally, shorter technology cycle times (a proxy for technological knowledge obsolescence) are associated with an increased licensing hazard. Likewise, when alternate institutional mechanisms for preventing expropriation, such as reputation within a network (Silicon Valley), are present, patent grants are less important in facilitating the market for ideas. Therefore, the role of the patent system in mediating the speed of commercialization is linked to the strategic environment in which the firm operates. We are cautious in our interpretation, however, as the

[1] Only a small number of studies consider the timing of licensing behavior at all (Katila and Mang, 2003; Dechaneaux, et al., 2003; Elfenbein, 2005), and we are not aware of any prior study which considers the impact of patent grant on the timing of cooperative behavior between technology entrepreneurs and potential downstream partners. While an extensive literature examines the determinants of patent licensing, the role of uncertainty in patent licensing, and the drivers of settlement of patent litigation (e.g., Katz and Shapiro, 1986; Gallini and Winter, 1985; Lanjouw and Lerner, 2001; Schankerman and Scotchmer, 2001), these studies do not consider the timing or hazard rate of licensing explicitly, focusing primarily on the impact of alternative court and procedural rules on the division of rents between licensee and licensor.

[2] In focusing on commercialization dynamics for start-up innovators, we join a growing literature on the timing of strategic commercialization choices, including the role of time-to-market (as in Hellmann and Puri, 2002 and Dechaneaux, et al., 2003).

sample size is relatively small and the analysis is conditioned on a sample of firms for which licenses are observed (and so we do not model the behavior of firms choosing alternative commercialization strategies (as we do in Gans, Hsu, and Stern, 2002)). With these caveats in mind, the results provide evidence that the market for ideas is subject to significant imperfections, and formal IP rights play a role in facilitating cooperative commercialization.

The remainder of the paper is organized as follows. In the next section, we motivate our analysis by describing fieldwork that assesses how technology entrepreneurs actively involved in licensing technology perceive the impact of patent grant timing on the ability to cooperate with other firms. We then build on this qualitative evidence in Section 3 to discuss theoretical explanations shaping the timing of cooperation between start-up technology entrepreneurs and more established organizations. After reviewing our sample of licensing data, Section 5 develops the empirical framework. Section 6 presents our main empirical results, and a final section concludes.

2. Does Uncertainty Over the Scope of Patent Rights Impact the Timing of Agreements? Evidence from the Field

To get a better understanding of the phenomenon of technology licensing in the face of uncertain IP rights, we conducted a series of interviews with senior executive officers at a number of start-ups in the fall of 2002. We did so with the aim of better understanding drivers of their cooperation timing decisions before launching a more formal modeling and empirical data collection effort. We confined ourselves to investigating biotechnology companies and the role of uncertain IP rights in the process of licensing their technology to more established pharmaceutical firms. This section conveys some insights learned from that interview process.

BioFirm's experience. The first biotechnology company, which we will refer to as BioFirm, engaged in licensing with an established firm, which we will refer to as Pharmaco, after patents – the most important of which was the composition of matter patent – had already been issued. BioFirm's CEO believed that the substantial uncertainty regarding the efficacy of the drug candidate made potential pharmaceutical company purchasers of the technology wary of a licensing deal before the scope of the patent rights were known. BioFirm's CEO opined that pharmaceutical firms did not mind paying a premium to in-license technology that had less uncertain IP scope because established pharmaceutical companies were averse to devoting organizational resources to very early stage drug discovery efforts.

Furthermore, in BioFirm's case, developing the compound in-house initially was attractive because the scientists felt that they could get an assessment of the efficacy profile relatively quickly, and at reasonable cost. As well, because the compound was a first-in-class drug candidate, BioFirm thought the economic rewards would be large enough to justify devoting large internal efforts to its development. In general, BioFirm likes to do proof of concept experiments and to get clinical evidence from human patients before partnering, if it can be done in a certain budget.

External validation through a lead article published in the *New England Journal of Medicine* helped BioFirm establish scientific credibility in the area. The publication was also important in the search for and negotiation with their eventual pharmaceutical partner, Pharmaco. In April 2002, BioFirm signed an agreement with Pharmaco for the exclusive world-wide development and commercialization of the drug candidate for two indications that are in US Federal Drug Administration (FDA) phase III clinical trials. Pharmaco was selected as a partner because of its extensive sales and marketing infrastructure. Significant support in the form of championing by the head of Pharmaco's research and development division was also important in selecting Pharmaco as a partner. The two companies agreed to co-develop and co-promote the drug and share development for a number of other acute and chronic indications for out-patient settings. Under the terms of the agreement, Pharmaco paid BioFirm a signing fee of $50M and clinical and regulatory milestone payments of up to $220M depending on development progress of the various indications. Expenses for development and promotion, as well as resulting revenues would be shared (though not evenly). Pharmaco would be primarily responsible for developing chronic indications, and BioFirm would be chiefly in charge of hospital indications development.

The timing of BioFirm's deal with Pharmaco was a key managerial decision, and was in part driven by BioFirm's need to scale up the clinical trials efforts into human patients. As well, BioFirm felt that partnering with a large pharmaceutical company would give credibility to eventual drug purchasing by drug formularies. As for the process of bargaining with Pharmaco, outside of the pricing, BioFirm was concerned with the following control points: to be involved in manufacturing the product, as well as to be involved in promoting the product. In pricing the deal, BioFirm knew that recent late stage deals that were comparable had involved the range of $25-100M, and so the boundaries for bargaining were implicitly set. From there, it was a question of negotiating more upfront payments versus a higher royalty rate. Pharmaco's main concern seemed to be worldwide exclusive rights, and the company was willing to share the development expenses with BioFirm.

BioCo's experience. A second biotechnology company, which we will refer to as BioCo, engaged in licensing with an established firm before its patents had been issued. BioCo's CEO offered the opinion that there are two times at which it is optimal to out-license (from the perspective of maximizing value and minimizing risk): very early (before human testing but after there is good molecular support and efficacy in animals) or after FDA phase II clinicals (shown safe and effective in a modest sample of human subjects). At the early stage, patents are typically not issued (often only the application will have been filed). BioCo's CEO went on to state that the choice between early and late licensing is mostly demand-driven. In this case, the complementarities in BioCo and its partner's capabilities and resources were compelling, and so an early agreement was the logical choice.

Furthermore, the contracting elements associated with pre-patent grant licensing deal were important for BioCo. In the agreement, BioCo received a modest upfront payment together with ongoing research support, milestone payments, and relatively large royalties. BioCo was willing to negotiate a lower upfront payment in order to get a higher royalty rate, which BioCo's CEO notes is in contrast to many biotech firms which want to "eat today rather than tomorrow." This was facilitated by the cash position that the firm has accumulated through two offerings to the public markets (as well as five rounds of venture capital totaling approximately $50M).

As for other contracting terms, BioCo's CEO was sanguine about agreeing to an exclusive license. Furthermore, in this individual's experience, if a deal involves patents that have not yet been granted, contracts can be written contingent on the granting of intellectual property that is broad enough to cover the purported innovation. For example, royalty rate X will apply if IP rights for the innovation is broad enough to cover the innovation and royalty rate Y will apply if not. Overall, using fairly sophisticated contracting terms, BioCo was able to achieve a higher level of productive efficiency by establishing a technology license early in the development process.

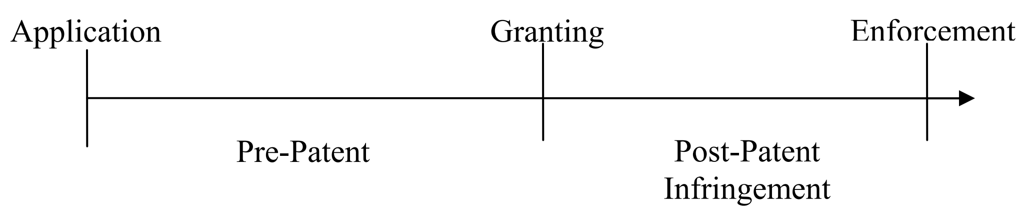
Summary. These case studies focused on one technology-based industrial sector in which cooperative commercialization is common. We observed significant heterogeneity in the timing of cooperation. While we observed both pre-grant and post-grant licensing, the strategic rationale underlying the cooperation decision differed depending on when the agreement was realized. While BioFirm used the time associated with patent grant delay to enhance its bargaining power and certify the research underlying its IP, BioCo chose to focus on productive efficiency, partially mitigating contractual hazards through a more complex licensing agreement.

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, Fosfuri, and Gambardella, 2001; Gans and Stern, 2003). Put simply, the "sale" of an idea allows an innovation to be commercialized more quickly generating productive efficiency gains. While the magnitude of these gains will differ from innovation to innovation and from industry to industry, there is an important sense in which delays in the timing of cooperative agreements reflect lost opportunities for maximizing the welfare gains from trade in ideas. This section briefly considers the potential drivers of delays in the licensing process, and the interplay between the timing of patent grant and the timing of cooperative agreements. Our objective is not to develop a comprehensive model of the determinants of license timing (as we do in Gans, Hsu, and Stern (2005)); instead, our objective is to simply illustrate (a) why the patent grant 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 grant date and the timing of technology licensing.

The frictionless benchmark. Before turning to the impact of specific market imperfections, we begin by considering a "frictionless" environment in order to establish a benchmark for efficient trade in the market for ideas. Consider a stylized representation of the innovation commercialization process depicted in Figure A. There are three distinct phases. After an initial invention or prototype is developed, the technology entrepreneur files a patent application. Following a patent application there is a waiting stage during which there is uncertainty over patent scope and indeed whether it will be granted at all. The granting of the patent reduces this uncertainty. However, infringement may still occur, if defending against infringements is too costly.

Figure A: Uncertainty and the Patenting Process



Consider the interactions between a single potential user of an invention (*C*) to whom the inventor (*R*) might license.[3] Both parties are risk neutral.[4] The potential commercial value of the invention to *C* is *v*. For a frictionless market, we assume that: (1) there is symmetric information between *C* and *R* regarding *v* and any other aspect of the patenting process; (2) *C* and *R* know of each other's existence from the outset (that is, *R* faces no search costs) and (3) but for the knowledge contained in the patent application, *C* has the necessary knowledge and resources to realize the value of the innovation. This last assumption implies that expropriation concerns are limited to knowledge which is potentially patentable, and that there is no specific human capital or tacit knowledge (in the sense of Arora, 1995) that must be drawn upon or otherwise disclosed for *C* to make full use of the invention. Below, we relax each of these assumptions to demonstrate the impact of frictions and market imperfections on the market for ideas.

A lengthy patent process implies that it will take, say, *T* periods from the time of application until the time a patent is granted. In addition, there is uncertainty as to the scope of the potential patent, which

[3] *C* stands for customer unit and *R* for research unit (as in Aghion and Tirole, 1994).
[4] Introducing risk aversion will create incentives to share risk among firms, which reinforces the incentives for early cooperation. We do not pursue this extension here, as we do not address this issue in our empirical work.

will impact a pre-patent agreement. With probability *p*, a patent is granted with broad scope (and with probability 1-*p* with narrow scope). For concreteness, we define broad scope to be defined as an ironclad patent while a narrow patent is essentially unenforceable (either *C* or other firms will be able to invent around the formal intellectual property). Narrow patent scope not only reduces *R*'s returns on the innovation, but can also impact *C*'s returns as well (under narrow scope, the value of the innovation to *C* will be $\underline{v} < v$).

As the firms are risk neutral, we consider licensing agreements whereby *R* assigns any patent rights to *C* for a flat fee.[5] License agreements may be negotiated at either time 0 or *T*. If an agreement is signed at time 0 (for a fee, t_0), it is binding throughout the pre- and post-patent phases. If no agreement is signed, another opportunity to come to an agreement occurs at time *T*. Let $E[v] \equiv pv + (1-p)\underline{v}$. By signing an agreement at time 0, *C* gets $(1-\delta^T)v + \delta^T E[v]$ while *R* gets paid immediately.[6] If no agreement is signed, then a license agreement is negotiated at *T* (for a fee, t_T) following the resolution of patent scope uncertainty. If patent scope is narrow, *C* can realize the commercial value of the innovation in the absence of an agreement, and so $t_T = 0$.

We assume that the negotiators are able to achieve a cooperative outcome, so that firms "maximize" and then split the surplus.[7] At *T*, if patent scope is wide, $t_T = \frac{1}{2}v$, while if patent scope is narrow, $t_T = 0$. If we suppose that commercialization is not feasible until a licensing agreement is signed, then, if the firms wait, the expected licensing fee at time 0 is $p\frac{1}{2}v$ 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, at time 0, there is always a joint gain for *C* and *R* to sign an earlier agreement. Put simply, the joint expected returns from an agreement at time *T* are $\delta^T E[v]$ while an agreement at time 0 will jointly yield $(1-\delta^T)v + \delta^T E[v]$, a gain of $(1-\delta^T)v$. It is mutually beneficial for the parties to agree earlier regardless of the degree of uncertainty over patent scope. Of course, the 'price' agreed to at that time will reflect the differing impacts of patent scope uncertainty on *R* and *C*. Under our assumption that firms split the surplus evenly:

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

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

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

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

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,* since this enhances the expected value of the innovation. Put simply, just because there is unprotected knowledge does not change the timing of licensing. In the frictionless environment, license timing is driven solely by productive efficiency. Uncertainty over IP rights in the frictionless case impacts the distribution of returns between the parties: as the likelihood of stronger patent protection increases, *R* earns relatively more than *C*. *Therefore, in the absence of frictions in the market for ideas, the patent grant date does not impact the timing of technology licensing.*

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

Consider the role of information asymmetries. The licensor may possess a number of different types of advantaged information, from information about the overall value of the license (and in which contingencies the innovation might be valuable) or the timing and/or scope of the rights to be granted. A direct consequence of asymmetric information (from whatever source) is the potential failure to be able to achieve a productively efficient agreement. Even when productively efficient technology exchanges would be jointly efficient, if potential licensors cannot credibly signal the value of their innovation (relative to the distribution of types), the market for ideas can break down.[8] Of course, if the source of asymmetric information is unrelated to the information resolved by patent grant, the mere granting of a patent will not alleviate this breakdown in technological trade. However, if the asymmetric information between the licensor and potential licensees relates, in part, to the probability that a patent will receive narrow (rather than broad) scope (i.e., differences in the value of *p*), or the precise nature of the claims that are likely to be allowed, then the clarification of those rights may spur market exchange. By waiting

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

until IP rights are clarified, those who believe they are likely to receive broad protection (relative to the expectations of potential licensees) will be able to earn a premium on the rights to their innovation. In other words, when patent grant itself reduces the degree of asymmetric information (or, equivalently, allows for more efficient sorting of technologies), at least some potential licensors will delay cooperative commercialization until the uncertainty surrounding patent scope is resolved.

A second mechanism resulting in a dependency between patent grant and the timing of cooperation arises from the presence of search costs. If the innovator has to engage in costly search to locate the most suitable commercialization partner, then incentives to do so may only be sufficient after a patent (with broad scope) has already been granted (Hellmann, 2005). Suppose that the cost of finding a partner is a fixed cost, *f*, in which *R* can locate a customer, *C*, who would value the innovation Δ greater than the baseline of *v* or $\underline{v}$, and that once *f* is sunk, an agreement with this high-valuation partner is immediately feasible. On the one hand, locating a partner at time 0 increases *R*'s returns by $\frac{1}{2}\left(1-\delta^T(1-p)\right)\Delta$. However, if *R* waits until the patent is granted at *T*, the search will only be undertaken if the patent scope is broad, and its returns from search would be $\frac{1}{2}\Delta$. If $\frac{1}{2}\left(1-\delta^T(1-p)\right)\Delta < f \leq \frac{1}{2}\Delta$, then *R* will be willing to search at *T* but unwilling to search at time 0. Moreover, the returns from time 0 agreement stay constant, while the returns from a time *T* agreement will be increased to $\delta^T p\left(\frac{1}{2}(v+\Delta)-f\right)$. Therefore, if $\frac{1}{2}\left(\Delta - v(\frac{1-\delta^T}{p\delta^T})\right) \geq f$, then *R* will prefer to delay and search rather than sign a low-value agreement at time 0. In other words, since the returns from search may be higher when patent scope is known to be broad, the presence of search costs may induce delay until the uncertainty over patent grant 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). Of course, as emphasized in the baseline model, the mere presence of unprotected knowledge has no impact on the timing of cooperative licensing (though it will have a significant impact on the division of rents and the overall incentives to proceed with commercialization). However, the establishment of the scope of patent rights can have a significant impact on the risk of expropriation and the willingness of licensors to disclose unprotected information. First, the resolution of patent scope may clarify the extent of unprotected knowledge which can be disclosed without fear of expropriation. While it may be difficult to predict the impact of the disclosure of unpatentable knowledge during the pre-grant period, start-up innovators may be able to tailor their disclosures to avoid expropriation in the event of bargaining breakdown once the exact scope of rights is clarified. For example, prior to patent grants, non-disclosure agreements with potential partners may be difficult (if not impossible) to write with any degree of precision or potential for enforcement; after a patent is granted, the costs and complexity of such contracts may decrease significantly. To the extent that the clarification of formal property rights reduces the risks of expropriation over unprotected knowledge, patent grant itself may spur participation in the market for ideas.

The role of the strategic disclosure of unprotected complementary knowledge will be particularly important when such disclosures require effort on the part of the licensor. As Arora (1995, p.42) emphasizes, "[t]echnology licensing involves more than just the permission to use the knowledge covered by patents: In many cases, the information required for successful utilization extends even beyond blueprints, drawings, and specifications and includes heuristics, rules of thumb, and other 'tricks of the trade.'" Though the value derived from cooperative commercialization may depend on the transfer of complementary tacit knowledge, the ability to contract on such transfers may be quite limited. Even if the outcome of such transfer is observable to both parties, it may be unverifiable to a third party (such as a judge) and so any agreement may not be enforceable. While the incentives to disclose tacit knowledge after a licensing agreement has been signed are limited (the licensee will simply expropriate the value of any such disclosures), there may be significant incentives to disclose complementary tacit knowledge prior to the realization of a cooperative agreement.[9] Specifically, if disclosing such knowledge raises the value of the patentable portion of the innovation to potential licensors (while maintaining the relative bargaining position of licensee and licensor), then the willingness-to-pay by *C* will be increasing in the effort devoted to disclosure by *R*. Moreover, since the additional value created by knowledge disclosure depends on the value of the patentable knowledge, the total incentives and equilibrium level of disclosure will depend on whether patent scope is known to be broad or whether patent rights remain uncertain.[10] When the value arising from broad patent rights are sufficiently high and the "boost" from complementary knowledge disclosure is sufficiently steep, both licensors and licensees may delay licensing negotiations until patent grant in order to maximize the innovator's incentives to transfer tacit knowledge.

Empirical implications. Taken together, these arguments suggest that the presence of frictions – barriers to efficient technological trade – can induce a systematic relationship between the receipt of formal intellectual property rights and the timing of technology licensing. While information

[9] This difference in incentives remains even if the licensing agreement itself is based on a royalty agreement rather than a fixed fee. For a complete derivation of a model of commercialization timing based on these incentives see Gans, Hsu and Stern (2005).
[10] Analytically, this is similar to our analysis of search costs – where search cost incentives may be insufficient prior to patent grant but are triggered by broad patent scope. From a modeling perspective, f can be interpreted as the costs associated with the transfer of knowledge and Δ as the potential "boost" to the value of the innovation.

asymmetries, search costs, and expropriation risks may limit technological trade prior to the receipt of formal IP rights, the resolution of uncertainty resulting from patent grant can trigger trade in the market for ideas. Conversely, in the absence of frictions, there should be no systematic relationship between patent grant and the timing of cooperative agreements. This theoretical insight holds several testable empirical implications.

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

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

Third, the theoretical framework suggests that after the scope of IP rights are established, productive efficiency considerations provide incentives for firms to achieve a licensing agreement as soon as possible after the uncertainty is resolved. Thus, for firms seeking a licensing partner as part of the commercialization process, *licensing will be "clustered" around the patent grant date.* From an empirical standpoint, capturing this clustering effect is subtle, since the date at which the firm receives sufficient information to provide credible information to partners is likely several months prior to the observed patent grant date (as embodied in the official publication of that grant in the *USPTO Patent Gazette*). Taking this observational bias into account, the framework implies that the licensing hazard rate will increase some months prior to the observed patent grant date, and that a "flurry" of licensing will occur just prior to and just after the observed patent grant date. Clustering around the patent grant date provides evidence for both the existence of frictions in the market for ideas and for the value of formal IP rights in facilitating cooperative technology transfer.

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

4. Data

The remainder of this paper focuses on the development and implementation of an empirical strategy to test the predictions of the theoretical framework. Before describing the results in detail, we proceed by first describing the data we employ in our empirical work, and then briefly outlining our empirical methodology and the assumptions underlying our identification strategy.

Our data are drawn from a sample of technology licensing deals announced between 1990 and 1999, and appearing in the Security Data Corporation (SDC)/Thomson Financial Platinum joint ventures and alliances database.[11] We began by selecting all recorded deals in four sectors that are closely associated with cooperative commercialization between start-up innovators and more established industry players: biotechnology, electronics, software, and scientific instruments. While the overall analysis of

[11] Beginning in November 2000, in accordance with the American Inventors Protection Act of 1999 (Public Law 106-113), patent applications are disclosed 18 months after filing (as opposed to at the time of patent grant, as was the case in the prior legal regime). See Johnson and Popp (2003) for an analysis of some likely effects of this rule change. For this study, we therefore stop our observation window prior to the implementation of AIPA to impose uniformity on this dimension.

deal structure across different types of players is extremely informative (Anand and Khanna, 2000; Arora, Fosfuri, and Gambardella, 2001), we limit our dataset along several dimensions in order to construct a clear test of our theoretical framework. Accordingly, we focus on 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). Specifically, 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
- Only technology cross-licensing between the parties

For the remaining technology transfer licensing deals, based on a reading of the deal description from the SDC database, we identified the first significant patent associated with the technology from searching the US Patent and Trademark Office (USPTO) website. This was done by searching patent titles and abstracts for key words taken from the SDC technology licensing activity description. The deal was excluded if there was ambiguity over the match between the licensed technology and the patent associated with that technology or if the licensing date was earlier than the patent application date (the latter cause for exclusion may be related to the former). This process yielded 219 patent-license pairs. For each deal, the license date announcement, the deal industry sector, and firm location and age information was collected from the SDC database. For each patent-license pair, we then collected detailed patent information from the USPTO website and the NBER patent data file (Hall, Jaffe, and Trajtenberg (2001)), and detailed information about venture capital financing from the Venture Economics database. Taken together, our dataset consists of 200 observations for which we observe both an unambiguous licensing date and an unambiguous patent grant date.

Variable definitions and summary statistics. Table 1 reports variable definitions and summary statistics. Our dataset consists of three different types of measures: timing measures, patent characteristics and firm characteristics. Each of the timing measures is calculated relative to the *patent application date*. *Patent application date* is the date associated with the first patent application for a given technology, inclusive of continuances, divisions, and provisional applications.[12] *Patent grant date* is the date in which

[12] While the use of the "first" patent application date is in line with our objective of examining the timing of licensing relative to the date of initial invention, all of our qualitative results are robust to the use of the "final" application date (i.e., the date associated with the application that is ultimately issued); while the results are a bit noisier, all of the key findings remain quantitatively and statistically significant. In order to be eligible to receive a patent for a technology, the inventor must file a provisional application within a year after the first public disclosure of the invention (and must file in advance of public disclosure to be eligible for a patent in Europe and elsewhere); because of the relationship between disclosure and eligibility, the initial patent application date is a reasonable

the patent is published in the USPTO *Official Gazette*, which is the official date on which a patent is issued. While the uncertainty over the scope of granted claims (the key force in our theoretical model) is unambiguously resolved by the publication date in the *Gazette*, this uncertainty is often significantly reduced prior to the actual date of publication, for several reasons. First, there is a modest lag (between 6-8 weeks) between the date on which patent applicants receive a final correspondence from the USPTO about the scope of their claims and the date in which the patent is published in the *Gazette*.[13] Second, the final grant of a patent results from a process of detailed negotiation with the patent examiner – according to interviews with patent lawyers in the industries we study, a tentative correspondence from the patent examiner revealing the key claims to be allowed is often available several months prior to the date of the final patent grant. As such, while the key date that we examine will relate to the *patent grant date*, our empirical analysis exploits these institutional features by examining whether there is a "flurry" of licensing in and around the patent grant date, looking at dates both just prior to and just after the official *patent grant date*. *Patent lag* is simply the *patent grant date – patent application date*, measured in months. While the mean of *patent application date* is in the early portion of 1991, the average *patent grant date* occurs in the middle of 1994 (the average *patent lag* is equal to 39.25 months).

The central focus of our empirical analysis is the relative timing of technology licensing and the patent grant date. Accordingly, our remaining timing measures depend on the *licensing date*. For each technology, *licensing date* is the first publicly reported instance of licensing, as reported by the SDC Platinum joint ventures and alliances database. A principal focus of our analysis is the determinants of the *licensing lag*, which is simply equal to the time (in months) between *patent application date* and the *licensing date* (mean = 44.08). As well, we construct a dummy variable, *post patent grant license*, which is equal to one for those licenses recorded after the *patent grant date* (mean = 0.58).

Figures 1 and 2 present histograms of the key timing variables: *patent grant lag*, *licensing lag* and the difference of these measures. While only a very small number of technologies receive a patent grant in the first twelve months after the application date, the majority of the technologies in our sample receive a patent in the third, fourth, and fifth year after the initial application.[14] As well, the *patent grant lag* has a large right tail, with a small number of technologies with patent grant lags in excess of 9 years.[15] In

(though obviously not perfect) proxy for the initial date of invention for invention which ultimately receive patent protection.

[13] In particular, applicants receive a notice from the USPTO and then must pay a fee to have the patent issued and printed in the Gazette (see http://www.uspto.gov/web/patents/pubs/pgfaq.html for details.)

[14] An emerging literature has focused on the determinants of patent grant lag itself, including Popp, Juhl and Johnson (2003), Regibieu and Rocket (2003), and Harhoff and Wagner (2005). While there is some evidence in these studies that longer grant lags may be associated with more highly cited patents, each of these studies suggests that there is a very high level of unexplained variation in the patent grant lag.

[15] It is possible that extreme patent grant 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

contrast to the *patent grant lag* distribution, *licensing lag* is more evenly distributed. Figure 2 combines these histograms in reporting the distribution of *licensing lag date – patent grant lag date*. Data plotted to the left of the value zero are associated with licensing deals reached prior to patent grant, while data plotted to the right of zero indicate post-grant licensing. The histogram suggests a striking relationship between licensing and patent grant – overall, there is a significant increase and decrease in the licensing rate, and the rate of licensing peaks at just about the time that a patent is granted (within a month or so prior of the *patent grant date*). Moreover, there is a second "flurry" of licensing activity in the 12-16 months after the patent grant. Though there is wide variation in both the length of time that passes until patents are granted, and the length of time that passes until licensing occurs, there seems to be a linkage between the patent grant lag and the underlying rate of reaching a licensing agreement.

To investigate this relationship more carefully, we have also gathered detailed patent characteristics and firm characteristics. These controls allow us to identify the impact of patent grant on licensing, controlling for observables about the underlying technology and the licensor. As well, we will evaluate the *interaction* between patent grant and observable features of the business environment. In so doing, we can evaluate whether the impact of patent grant on licensing is enhanced (or muted) depending on the economic environment and nature of the underlying invention.

The patent characteristics are standardized measures drawn from the Hall, Jaffe, and Trajtenberg (HJT, 2001) NBER data file: *patent claims*, *patent classes*, *patent citations made*, *backward citation lag*, and *originality*.[16] *Patent claims* is simply the number of claims allowed by the examiner (mean = 20.8), 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 = 1.91). The final three patent characteristics exploit the citations made in each patent to the prior patent record. *Patent citations made* is equal to the number of "backward" citations to prior patents (mean = 11.19) while *backward citation lag* is the number of years between the patent grant year and the average grant year of those cited patents (mean = 7.56). Finally, *originality* measures the diversity of cited references, based on the degree to which prior references are drawn from different patent classes. Similar to a traditional Herfindahl index (where *originality* = 1 if all cited patents are drawn from a single category, and *originality* goes to zero as the share from all patent classes goes to zero), the mean of *originality* = 0.42.

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grant lag (e.g., 60 months, or 80 months). None of our key qualitative findings are affected by this choice, and so we present results for the full sample.

[16] For a small set of observations towards the end of the sample period, the JHT characteristics data are not available. In particular, while the JHT data ends in 1999, our dataset covers patents granted beyond 1999 (since the end of 1999 is the cut-off date for the license to be announced). We have constructed the JHT measures by hand for each of these observations, and experimented with whether our results are sensitive to their inclusion or exclusion. All of the qualitative results remain the same. For comparability, we report results in which we code any "missing" data as a constant, and include a dummy variable denoting that the JHT measures are missing for that observation.

We exploit the patent characteristics in two ways. First, technologies associated with a greater number of more complex patent claims may be associated with a longer patent grant lag and a longer licensing lag; accordingly, it is important for us to control for each of these five measures in our analysis. We expect that the rate of licensing may be lower for patents with a higher number of claims or classes, or that draw on a larger, newer, or more diverse level of prior research. Second, it is possible that patent characteristics will also mediate the salience of patent grant itself. For example, similar to Narin (1994) and Markewicz (2005), we interpret smaller values of *backward citation lag* to be consistent with business environments characterized by short technological cycle times, which in turn should be related to the importance of productive efficiency gains to technology trade. As such, we expect that licensing will become more sensitive to *patent grant* as the value of *backward citation lag* increases (i.e., as productive efficiency becomes less important).

We have also gathered a number of firm characteristics. We have two measures of the resources, experiences and capabilities a firm is likely to possess. *Firm age* (mean = 5.97) is measured as of the patent application date while our dummy for venture capital funding, *VC funded* (mean = 0.48), only equals one for those firms that received venture capital funding prior to the patent application date. In terms of their impact on licensing rates, more experienced firms and firms with more financial resources may be more patient in their search for a commercialization partner (leading to a reduction in the licensing rate). At the same time, increased maturity and access to a VC network might enhance the rate of cooperative commercialization (Hsu, 2006). While their overall effect may be ambiguous, it is important that we control for these factors in evaluating the impact of patent grant on the incidence of licensing.

We define three dummy variables to indicate locations that may provide access to different types of technology licensing networks: *Silicon Valley*, *Route 128*, and *Canada*. As key high-technology regions, firms located in *Silicon Valley* and *Route 128* may experience a higher overall rate of technology licensing. As well, firms located in these regions may have access to informal network-based mechanisms that overcome the delays associated with the patent system; as such, the licensing rate may be less sensitive to patent grant in regions such as Silicon Valley or Route 128. In addition, as our data sampling scheme yielded a relatively high number of Canadian licensing deals (mean = 0.18), we include a location control for these firms in case their underlying hazard rate or sensitivity to patent grant is significantly different than the US firms in the sample.

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

Table 1B provides a tabulation of the patent grant lag and licensing lag by industry. While *electronics* and *scientific instruments* are associated with a relatively short patent grant lag (33 months), average patent grant lag is much longer in the *biotechnology* industry (45 months). Interestingly, while the licensing lag is also longest in *biotechnology*, *software* is associated with the shortest licensing lag (38 months). Whereas the patent grant delay is shortest in the electronics industry, this industry is associated with the second longest licensing lag. This variation in both patent grant delay and licensing lag leads to significant cross-industry variation in *post patent grant license*. While *post patent grant licensing* occurs more than two-thirds of the time in electronics, more than half of all licensing deals in the software industry occur prior to the patent grant date. This preliminary evidence suggests that the role of intellectual property may differ across different industrial sectors. Evaluating these claims systematically requires shifting from an analysis of the overall probability of a post-grant license to how the patent grant (or its expectation) shifts the licensing hazard rate, which we turn to in the next sections.

5. The Empirical Framework

The heart of our empirical strategy is exploiting the significant empirical variation in patent grant lags across technologies. If each of the innovations in our sample experienced roughly the same patent grant lag, we would not be able to disentangle the impact of patent grant from the baseline probability that a technology is licensed after a specific amount of time after the patent application date. Our analysis focuses on Cox proportional hazard rate models with time-varying regressors. After converting our dataset into monthly observations from the date of patent application, we define $license_{it}$ equal to 0 for months prior to the *licensing date*, and equal to 1 for the month of the *licensing date* (resulting in an the unique absorbing event of a first license). In addition to time-independent control variables, Z_i (such as patent and firm characteristics), we define a time-varying regressor, *post patent grant*$_{it}$, which is equal to 0 for all months prior to the patent grant date and equal to 1 for all months after the patent grant date.

Assuming that the baseline hazard rate is independent of the *patent grant lag* and Z, we can then define the Cox hazard rate for a given period:

$$\Pr(License_i^t \mid License_i^{t-1}{=}0,\ \text{POST PATENT GRANT}_i^t, Z_i)$$
$$\equiv H(t \mid \text{POST PATENT GRANT}_i^t, Z_i) = H(t) \cdot \exp\left\{ \beta_{\substack{\text{POST PATENT}\\ \text{GRANT}}} \text{POST PATENT GRANT}_i^t + \beta_Z Z_i \right\}$$

After accounting for the (non-parametric) baseline hazard rate and control variables *Z*, $\beta_{\substack{\text{POST PATENT}\\ \text{GRANT}}}$ measures the *change* in the hazard rate due to a change in *post patent grant*.[17]

To test our hypotheses, we amend this basic framework in two ways. First, to evaluate whether licensing is "clustered" just prior to and after the patent grant date, we define a set of "window" variables (*pre patent grant* (*k,l*) and *post patent grant* (*k,l*)), equal to 1 from *k* to *l* months prior to (or after) the patent grant date, and 0 otherwise.

$$\Pr(License_i^t \mid License_i^{t-1}{=}0,\ \text{POST PATENT GRANT}_i^t, Z_i)$$
$$= \text{H}(t) \cdot \exp\left\{ \sum_{k,l} \psi_{PRE\_k,l} \text{PRE PATENT GRANT}(k,l)_i^t + \sum_{k,l} \psi_{POST\_k,l} \text{POST PATENT GRANT}(k,l)_i^t + \beta_Z Z_i \right\}$$

In other words, we define a set of time-varying measures which will allow us to estimate coefficients to evaluate how the hazard rate is changing during time intervals as the patent grant date approaches and during time intervals after the patent grant date has occurred.

Second, we introduce several interaction terms between *post patent grant* 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 rate model:

$$\Pr(License_i^t \mid License_i^{t-1}{=}0,\ \text{POST PATENT GRANT}_i^t, Z_i) =$$
$$H(t) \cdot \exp\left\{ \beta_{\substack{\text{POST PATENT}\\ \text{GRANT}}} \text{POST PATENT GRANT}_i^t + \beta_{PATGRANT,Z} \text{POST PATENT GRANT}_i^t \cdot (Z_i - \bar{Z}) + \beta_Z Z_i \right\}$$

This specification allows us to estimate the overall impact of patent grant on licensing ($\beta_{\substack{\text{POST PATENT}\\ \text{GRANT}}}$) as well as how the overall impact changes with changes in the underlying economic, strategic, and technical environment. With these three specifications in mind, we can now turn to the detailed analysis of our empirical results.

[17] Though time-varying regressors are often employed in the context of Cox regression, it is useful to note that the use of time-varying regressors depends on a substantive assumption, *strict exogeneity*, of the time-varying regressors (Wooldridge, 2003). Specifically, we assume that the patent grant lag is independent of any technology-specific heterogeneity in the underlying hazard rate (i.e., $H_i(t)$ is independent of *patent grant lag*).

6. Empirical Results

We are now ready to examine the hazard rate results. Table 2 presents our baseline Cox hazard regression results based on monthly data. In this and the following empirical tables, we present both the estimated coefficients as well as the implied hazard ratios (which should be read relative to one), since the latter makes the estimated size effects more apparent. The "failure" event in these regressions is the first instance of patent licensing. The first specification, (2-1), examines the impact of a post-grant 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 grant is associated with more than a doubling of the underlying hazard rate. The second column of Table 2 introduces controls for *patent application year* and industry effects (via dummies for biotechnology, electrical equipment, and software). While none of the individual industry dummies are significant, there is a significant coefficient on *patent application year* which suggests that the hazard rate is significantly higher for technologies whose patent application dates are later in the sample. Finally, the *post patent grant* coefficient remains essentially the same. In the final specification in Table 2, we allow each industry to have its own baseline hazard function (as an industry-stratified hazard model) and include fixed effects for each patent application year fixed (note that, after allowing for stratification, we can no longer identify separate industry-specific dummies). By allowing both the industry hazard rate and the impact of patent application year to be freely estimated, our *post patent grant* estimate is identified from within-industry variation, controlling (non-parametrically) for the overall patent "cohort." Similar to the first two columns of Table 2, the *post patent grant* coefficient is large and significant at the 1% level. Overall, these results suggest that, for the sample of technologies considered here, the probability of licensing is significantly enhanced when formal IP rights are granted.

In Table 3, we examine whether this core finding is robust to the inclusion of each of the different types of control variables. For each Cox specification, we continue to allow a full set of patent application year fixed effects and industry-level stratification. We begin with firm characteristics. In the first column (3-1), we include each of the three location variables (allowing us to examine whether technologically "networked" locales achieve cooperative commercialization at higher rates (Saxenian, 1994)), and (3-2) includes both *firm age* and *VC funded* (thereby controlling for firm maturity, access to financial resources, and the potential for access to the VC network). While none of these control variables is individually significant (or even estimated to have a large impact), the underlying size and significance (at the 1% level) of the *post patent grant* coefficient persists. We then include each of the patent characteristic measures in (3-3) and, finally, include all control variables in a single specification in (3-4). The only significant coefficient is associated with patent *backward citation lag,* the number of years between patent grant and the average grant year of backward patent citations. Consistent with the interpretations of Narin (1994) and Markewicz (2005), the negative coefficient on this regressor suggests that, for technologies with longer technology cycle times (i.e., longer lags between technology generations), productive efficiency considerations may not be paramount. As such, firms may invest less in search in each period, resulting in a lower underlying licensing hazard rate. Robustness checks (available upon request) suggest that the results are robust to the following sub-samples of the data: start-ups that are "young" (below the median age in the sample), the "early" cohort of patent applications (before 1996), the "late" cohort of patent applications (after 1990), and in a time window that takes into account a patent "pre-announcement" effect (broadening the patent grant date to include the four months prior to the actual grant date). In each of these cases, the core finding of our analysis holds.

We now turn to our second hypothesis, and examine whether licensing behavior is "clustered" just prior to and just after patent grant. To do so, we estimate an industry-stratified model with application-year specific fixed effects (similar to (2-3)). In place of the *post patent grant* dummy variable, we estimate 8 mutually exclusive dummy variables covering the following time windows:

- Greater than 12 months prior to patent grant (normalized to 1.0)
- 12 months to 8 months prior to patent grant
- 8 months to 4 months prior to patent grant
- 4 months to patent grant month
- 1 month to 4 months after patent grant
- 4 months to 8 months after patent grant
- 8 months to 12 months after patent grant
- Greater than 12 months after patent grant

Our results are presented in Figure 3. In each four month period in the year prior to the patent grant date, there is an increase in the hazard rate of patent licensing. These increased hazard rates peak during the period from 1 to 4 months *after* the patent grant. After this peak four-month window, the hazard rate experiences a significant decline, and then regains a high level for periods greater than 12 months after the patent grant month. Not simply a qualitative pattern, these effects are estimated precisely: for example, it is possible to reject the null hypothesis that the coefficient in the four months prior to patent grant date is equal to earlier window coefficient, and it is also possible to reject equality between the coefficient associated with the first four months after patent grant and the subsequent two window periods (5-8 months, and 9-12 months after the patent grant). Overall, these results offer a significant refinement on our earlier analysis: not only does patent grant have a permanent impact on the licensing hazard, but the effect also seems to be most salient in the period just after the patent grant itself. Given that much of the uncertainty associated with patent scope is resolved several months prior to the official patent grant date, technology entrepreneurs may be seeking to license their technology after a sufficient degree of uncertainty has been resolved. It is possible that firms begin to aggressively search for and bargain over licensing deals in the months just prior to the official patent grant date.

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

The first column of Table 4 examines the complete set of *post patent grant*industry* interaction effects. Except for the interaction with the software industry dummy, the coefficient on *post patent grant* with each of the other three industry dummies is positive and significant. In other words, whereas patent grant has a significant impact in industries such as electronics and biotechnology, patent grant has no impact on licensing behavior in the software industry. This finding is consistent with key differences between these industries: technology cycle times in software are incredibly rapid and copyright protection offers a substitute mechanism for protecting IP in the context of licensing negotiations. The second column investigates the interaction between location and patent grant. Only one result stands out: the direct effect of locating in Silicon Valley is now positive and significant, the interaction between *Silicon Valley* and *post patent grant* is negative (and large in absolute value). While locating in Silicon Valley is associated with more than a doubling of the license rate, patent grant itself plays a much more muted role for Silicon Valley companies. Though there may be several explanations for this finding, these results suggest that in a highly networked environment such as Silicon Valley, licensing is much more rapid and the network (and the reputations underlying that network) mitigate the expropriation concerns that might delay licensing until formal IP rights have been granted. The final column of Table 4 examines two additional firm measures, *firm age* and *VC funded*. While *post patent grant* continues to be significant and positive, these measures neither have a significant direct impact nor a significant interaction with *post patent grant*.

Finally, in Table 5, we examine interactions between *post patent grant* and patent characteristics. Overall, these interaction effects are relatively noisy (compared with the more robust findings presented in Table 4). With that said, there are three significant interaction effects: *post patent grant*patent classes*, *post patent grant*originality*, and *post patent grant*backward citation lag*. While the first two of these effects are quite sensitive to the underlying specification (and can even change sign), the positive coefficient on *post patent grant*backward citation lag* is robust across a wide variety of specifications. While a higher *backward citation lag* is associated with a lower overall hazard rate, the impact of patent grant is more salient for technologies associated with slower technology cycle times. This evidence is consistent with our underlying theoretical hypothesis that the impact of patent grant should be particularly important in those economic environments where productive efficiency considerations are less important. In our final specification, we include all of our patent and firm characteristics, as well as all of the interaction effects. While some of the coefficients are noisier (and so are only significant at the 10% level), the overall pattern of results from Tables 4 and 5 remain. Specifically, the impact of patent grant is higher for firms in *biotechnology* and *electronics*, for technologies associated with a higher *backward citation lag*, and is lower for firms located in Silicon Valley.

Overall, these findings suggest that the receipt of a patent grant substantially increases the hazard rate of achieving a licensing agreement, and this effect is most salient in the time just prior to and just after the timing of the patent grant itself. Moreover, the degree to which patent grants matter in facilitating the market for ideas depends on the strategic environment in which firms operate. When productive efficiency effects are important (as when technology cycle times are short), frictions and imperfections in the technology market are relatively unimportant. As well, when alternate mechanisms are available in the marketplace for ideas, patent grants are also not as important. These mechanisms can be either formal (e.g., copyright protection as a substitute for patent protection in the software industry) or informal (e.g., reputation as a result of location in a “high trust” region such as Silicon Valley).

7. Conclusions

This paper considers the impact of delays in the granting of IP on the market for ideas. Specifically, we demonstrate that, to the extent that a patent grant resolves uncertainty regarding the strength of IP protection, delays in that grant may delay cooperative commercialization agreements. Such delays occur when there are underlying frictions in markets for ideas. These frictions might stem from information asymmetries between upstream innovators and downstream commercializers, search costs, and difficulties in achieving post-contractual tacit knowledge transfer. In the absence of such frictions, early cooperation is the equilibrium choice. In the presence of frictions, start-up innovators face a dynamic tradeoff in which early agreement decreases time to market, yet later agreements may enhance the innovator’s bargaining power and induce more effective technology transfer. In such an environment, the timing of cooperation becomes an important strategic choice for start-up entrepreneurs. Patent grants mitigate uncertainty about the scope of IP rights and enhances incentives for the innovator to share tacit knowledge with the licensee, facilitating trade in the market for ideas.

We test for the presence of frictions in markets for ideas by examining the empirical importance of patent grant dates on the timing of commercialization agreements. Our dataset joins licensing timing with patent application and grant timing for a random sample of 200 licensing deals across four technology intensive sectors: biotechnology, electronics, computer software, and scientific instruments. Three main empirical results stand out. First, both pre- and post-patent grant licensing takes place, reflecting the heterogeneity in technology and strategic environments which can influence the relative importance of productive efficiency benefits as weighed against frictions in contracting in the market for ideas. Second, the patent grant event doubles the hazard rate for licensing, which we interpret as evidence that patent scope resolution mitigates information asymmetries between licensor and licensee and/or strengthens economic incentives for licensors to disclose tacit information to licensees. Finally, the patent grant effect is moderated by: (1) short technology cycle times which will prevail in regimes of fast technical knowledge obsolescence, and (2) alternate reputation mechanisms mitigates the risk of expropriation and/or lowering search costs (e.g., Silicon Valley reputation networks).

Our analysis also highlights the potential for inefficiencies in the patent system which would be hard to capture without assessing the equilibrium impact of delay. Reducing delays in the patent system would allow for earlier resolution of uncertainty, which should provide efficiency gains in the market for ideas. Overall, though prior theoretical and case analyses suggest that formal IP rights can enable the markets for ideas, the evidence presented here offers the first direct evidence that private-sector innovators are directly (causally) influenced by the receipt of IP rights, and so patent grants directly contribute to technology transfer.

The results suggest several possible directions for future research in this domain. First, a deeper understanding of very early licensing behavior would be interesting, as it could illuminate organizational complementarities and the associated mechanisms facilitating such early technology transfer. Second, it would be interesting to explore the importance of patent grants or other mechanisms in facilitating inter-organizational technology transfers in other forms of cooperative arrangements, for example in various types of strategic alliances. Finally, future efforts may wish to explicitly examine how variation in the characteristics of the technology recipients affects the nature and dynamics of the market for ideas.

Taken together, the findings in this paper suggest that imperfections and frictions in the market for ideas may be important. Therefore, securing IP protection may facilitate the operation of ideas markets. In addition, the management of cooperative commercialization will require a careful examination of frictions that might differ across industries and technologies.

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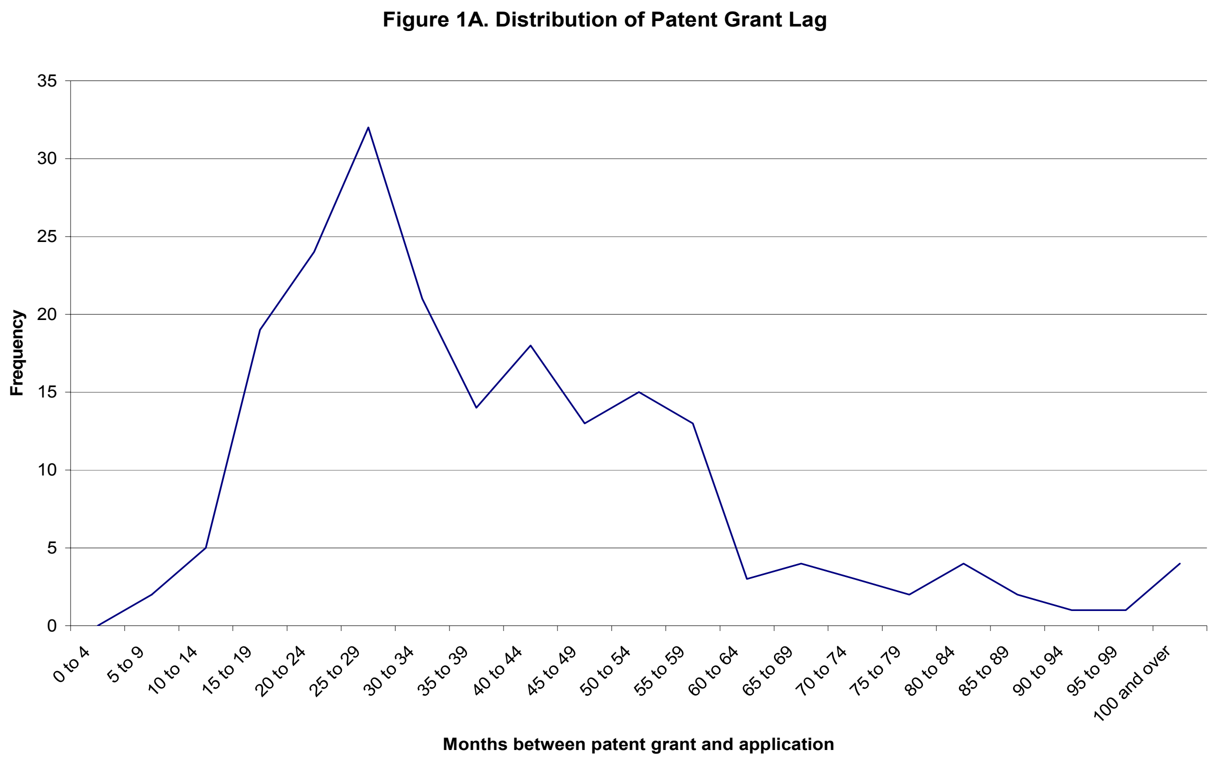
Figure 1: Timing Lag Distributions



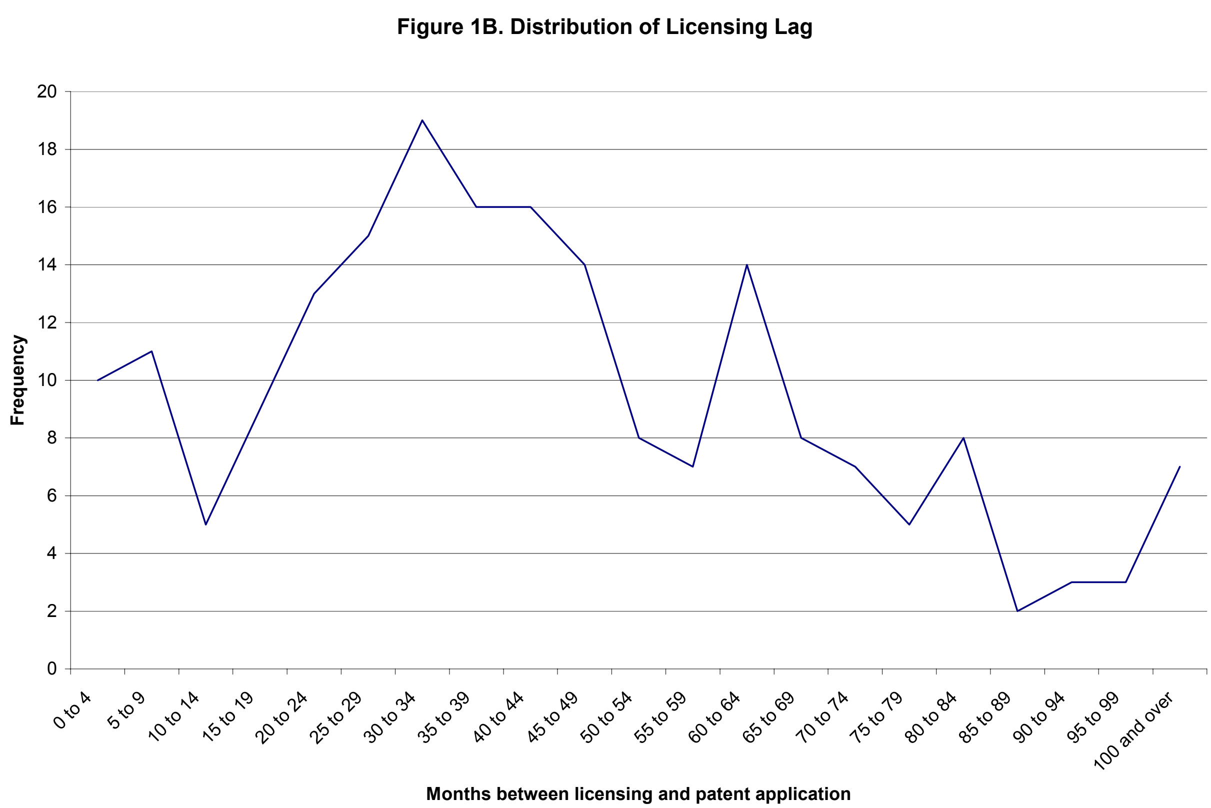


Figure 2: Distribution of Difference between Patent Grant and Licensing Dates

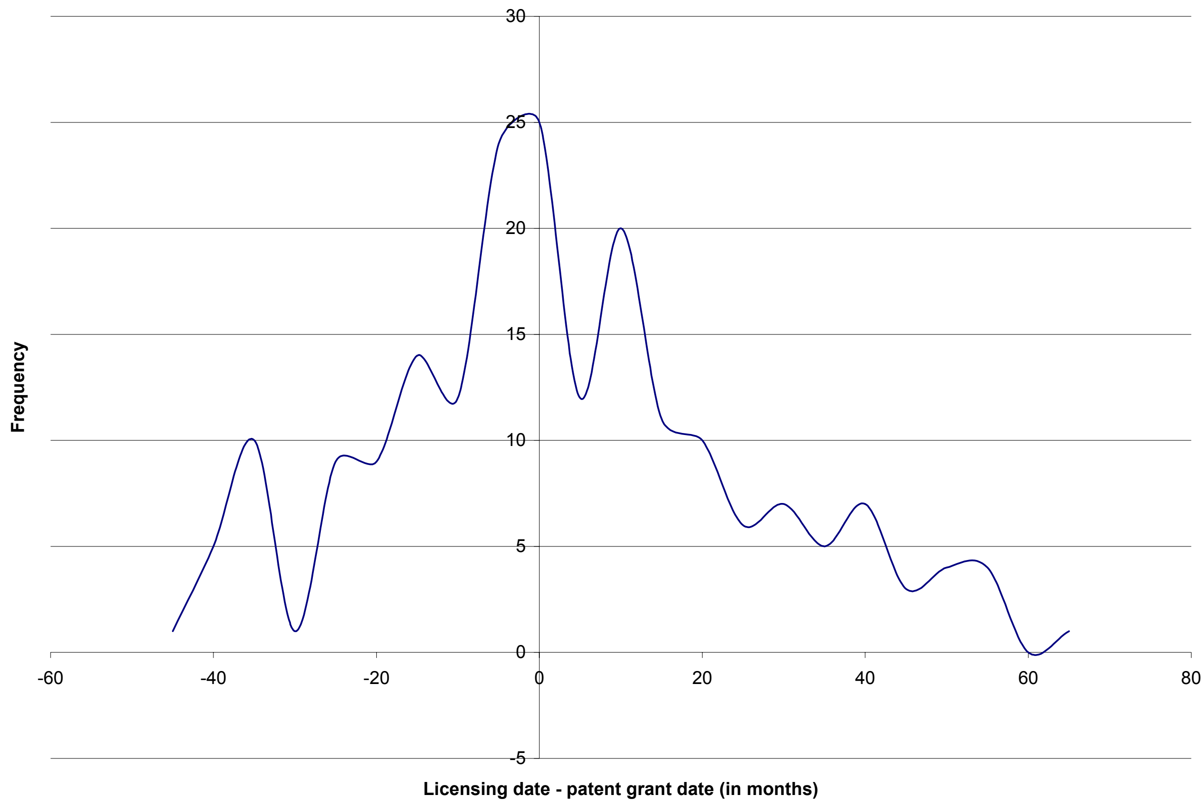


Figure 3
Licensing Hazard Ratio, Pre- vs. Post-Patent Grant

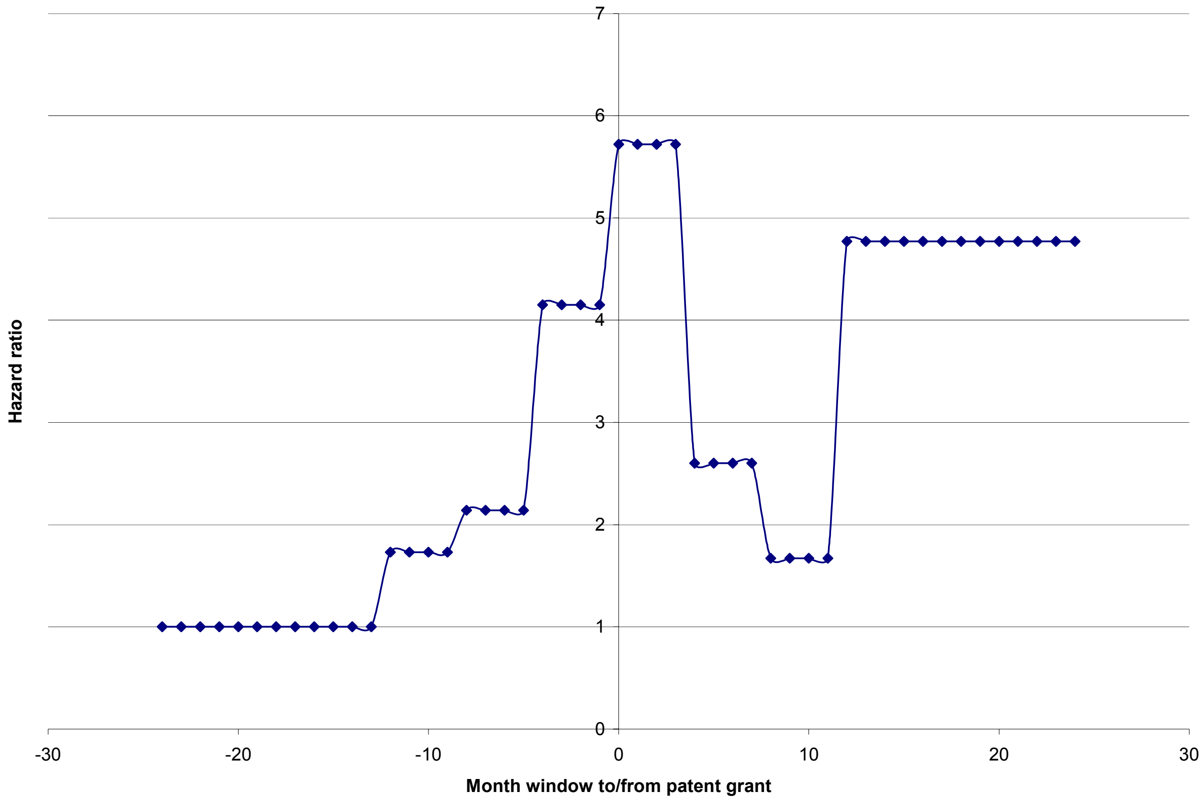


TABLE 1A
VARIABLE DEFINITIONS, MEANS, AND STANDARD DEVIATIONS

VARIABLE	DEFINITION	MEAN	SD
Timing Measures			
Patent application date	Date of patent application	1991.15	3.94
Patent grant date	Date of patent grant	1994.40	3.89
Licensing date	Date of patent licensing	1994.90	3.49
Patent lag	*Patent grant date – Patent application date* (in months)	39.25	20.65
Licensing lag	*Licensing date – Patent application date* (in months)	44.08	26.74
Post patent grant license	Dummy = 1 if *Licensing date > Patent grant date*	0.58	0.50
Patent Characteristics*			
Claims	# of claims made in the patent	20.82	19.63
Citations made	# of patent citations referenced in the patent	11.19	11.43
Patent classes	# of 3-digit patent classes to which the patent is assigned	1.91	1.07
Backward citation lag	# of years between patent grant and the average grant year of backward citations	7.56	4.32
Originality	1 – Herfindahl of referenced patent classes (based on backward patent citations)	0.42	0.27
Firm Characteristics			
Firm age	Age of the firm in years	5.97	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 are from Hall, Jaffe, and Trajtenberg (2001).

TABLE 1B
MEANS OF TIMING MEASURES
BY INDUSTRY SECTOR

	Biotechnology	*Electronics*	*Software*	*Scientific Instruments*
# observations	82	44	37	37
Patent lag	45.65 (22.48)	33.39 (18.40)	37.68 (12.60)	33.59 (22.07)
Licensing lag	48.61 (28.51)	43.86 (26.33)	37.65 (21.32)	40.70 (27.16)
Post patent grant license	0.56 (0.50)	0.68 (0.47)	0.46 (0.51)	0.59 (0.50)

Table 2
Baseline Cox Hazards

Dependent Variable = LICENSE
(Robust standard errors are clustered by firm)

N = 7649

Independent Variables	**(2-1)**		**(2-2)**		**(2-3)**	
	Hazard Ratio	Coef.	Hazard Ratio	Coef.	Hazard Ratio	Coef.
Post patent grant	2.250** (0.385)	0.811** (0.171)	2.183** (0.379)	0.781** (0.173)	2.512** (0.456)	0.921** (0.182)
Patent application year			1.172** (0.025)	0.158** (0.021)	Fixed effects included	
Biotechnology			1.019 (0.207)	0.018 (0.203)	hazard rate stratified by industry	
Electrical equipment			0.906 (0.206)	-0.099 (0.227)		
Software			0.871 (0.187)	-0.138 (0.214)		
Log likelihood	-844.179		-818.259		-553.799	

** indicates statistical significance at the 1% level.

Table 3
Baseline Industry-Stratified Cox Hazards with Controls

Dependent Variable = LICENSE
(Robust standard errors are clustered by firm)
N = 7649

Independent Var.	**(3-1)**		**(3-2)**		**(3-3)**		**(3-4)**	
	Haz. Ratio	Coef.	Haz. Ratio	Coef.	Haz. Ratio	Coef.	Haz. Ratio	Coef.
Post patent grant	2.471** (0.453)	0.905** (0.183)	2.479** (0.444)	0.908** (0.179)	2.555** (0.489)	0.938** (0.191)	2.476** (0.473)	0.907** (0.191)
Silicon Valley location	1.135 (0.237)	0.126 (0.209)					1.120 (0.232)	0.113 (0.208)
Route 128 location	1.067 (0.228)	0.065 (0.214)					1.030 (0.257)	0.029 (0.249)
Canada location	1.102 (0.224)	0.098 (0.203)					1.062 (0.239)	0.060 (0.225)
VC funded			1.068 (0.166)	0.065 (0.155)			1.059 (0.182)	0.057 (0.172)
Firm age			1.006 (0.010)	0.006 (0.010)			1.008 (0.010)	0.008 (0.010)
Patent claims					1.001 (0.003)	0.001 (0.003)	1.001 (0.004)	0.001 (0.003)
Patent classes					0.996 (0.102)	-0.004 (0.103)	1.001 (0.106)	0.001 (0.106)
Patent citations made					0.998 (0.008)	-0.002 (0.008)	0.998 (0.008)	-0.002 (0.008)
Patent backward citation lag					0.929** (0.020)	-0.073** (0.022)	0.929** (0.021)	-0.073** (0.022)
Patent originality					1.326 (0.491)	0.282 (0.370)	1.275 (0.503)	0.243 (0.394)
Patent App. Yr. FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	-553.578		-553.563		-547.075		-546.648	

** indicates statistical significance at the 1% level.

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

Dependent Variable = LICENSE
(Robust standard errors are clustered by firm)
N = 7649

Independent Var.	**(4-1)**		**(4-2)**		**(4-3)**	
	Haz. Ratio	Coef.	Haz. Ratio	Coef.	Haz. Ratio	Coef.
Post patent grant			2.392** (0.426)	0.872** (0.178)	2.484** (0.441)	0.910** (0.178)
Silicon Valley location			2.341** (0.698)	0.851** (0.298)		
Route 128 location			1.553 (0.547)	0.440 (0.352)		
Canada location			1.633 (0.515)	0.491 (0.315)		
VC funded					1.023 (0.241)	0.023 (0.235)
Firm age					1.006 (0.014)	0.006 (0.014)
*Biotechnology * Post patent grant*	2.978** (0.798)	1.091** (0.268)				
*Software * Post patent grant*	1.206 (0.496)	0.187 (0.412)				
*Electronic equipment * Post patent grant*	3.451** (1.519)	1.239** (0.440)				
*Scientific instruments * Post patent grant*	2.212* (0.823)	0.794* (0.372)				
*Silicon Valley location * Post patent grant*			0.275** (0.116)	-1.291** (0.423)		
*Route 128 location * Post patent grant*			0.491 (0.231)	-0.711 (0.470)		
*Canada location * Post patent grant*			0.462 (0.189)	-0.772 (0.408)		
*VC funded * Post patent grant*					1.085 (0.328)	0.082 (0.302)
*Firm age * Post patent grant*					0.999 (0.022)	-0.001 (0.022)
Patent App. Yr. FE	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	-552.201		-548.273		-553.528	

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

Table 5
Industry-Stratified Cox Hazards: Patent and Firm Interaction Effects

Dependent Variable = LICENSE
(Robust standard errors are clustered by firm)
N = 7649

Independent Var.	**(5-1)**		**(5-2)**	
	Haz. Ratio	Coef.	Haz. Ratio	Coef.
Post patent grant	2.362** (0.465)	0.860** (0.197)		
Silicon Valley location			2.368** (0.754)	0.862** (0.319)
Route 128 location			1.428 (0.535)	0.356 (0.374)
Canada location			1.345 (0.485)	0.296 (0.361)
VC funded			0.866 (0.239)	-0.144 (0.277)
Firm age			1.020 (0.016)	0.020 (0.015)
Patent claims made	0.997 (0.007)	-0.003 (0.007)	0.993 (0.007)	-0.007 (0.007)
Patent classes	1.156 (0.114)	0.145 (0.098)	1.299 (0.133)	0.262 (0.102)
Patent citations made	1.009 (0.010)	0.009 (0.010)	1.012 (0.012)	0.012 (0.012)
Patent originality	0.585 (0.334)	-0.537 (0.572)	0.622 (0.374)	-0.475 (0.600)
Patent backward grant lag	0.830** (0.043)	-0.187** (0.052)	0.820** (0.048)	-0.198** (0.059)
*Biotechnology * Post patent grant*			2.486** (0.792)	0.911** (0.318)
*Software * Post patent grant*			1.182 (0.520)	0.167 (0.440)
*Electronic equip. * Post patent grant*			5.258** (2.607)	1.660** (0.496)
*Scientific instrum. * Post pat grant*			1.305 (0.525)	0.266 (0.402)
*Silicon Valley loc. * Post pat grant*			0.293** (0.127)	-1.227** (0.433)
*Route 128 loc. * Post patent grant*			0.585 (0.313)	-0.536 (0.535)
*Canada loc. * Post patent grant*			0.610 (0.274)	-0.494 (0.449)
*VC funded * Post patent grant*			1.178 (0.427)	0.164 (0.363)
*Firm age * Post patent grant*			0.984 (0.026)	-0.016 (0.026)
*Pat. claims made * Post patent grant*	0.981 (0.017)	0.006 (0.008)	1.010 (0.009)	0.010 (0.008)
Patent classes Post patent grant*	0.679* (0.111)	-0.387* (0.163)	0.593** (0.100)	-0.523** (0.169)
*Patent cit. made * Post patent grant*	0.981 (0.017)	-0.019 (0.017)	0.978 (0.018)	-0.023 (0.018)
*Patent orig. * Post patent grant*	4.557* (3.121)	1.517* (0.685)	4.123 (3.141)	1.417 (0.762)
*Pat. bkwrd. cit. lag * Post pat grant*	1.175** (0.066)	0.161** (0.056)	1.182** (0.074)	0.167** (0.063)
Patent App. Yr. FE	Yes	Yes	Yes	Yes
Log likelihood	-538.553		-530.928	

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