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Do firms with technological capabilities rush in? Evidence from the timing of licensing of Stanford inventions

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Keywords: technology licensing; technological capability; technological overlap; university technology; expropriation

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ABSTRACT

This study investigates the influence of licensees' technological capabilities on the timing of technology licensing in university technology commercialization. Drawing on the appropriation-collaboration tension from the literature on university technology licensing and intellectual property management, we propose that while the licensee's technological capabilities drive early licensing by averting technological obsolescence, this effect diminishes significantly with an overlap in the technological domain of the focal invention due to expropriation concerns. Cox regression analysis of Stanford University's invention dataset confirmed our hypotheses. This research reveals that technology licensing experiences delays with the most suitable licensees, namely, those with strong technological capabilities in the knowledge domain of the invention for licensing. This study contributes theoretical insights to the technology market literature and provides practical implications for licensing managers and industry partners in technology commercialization.

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HIGHLIGHT

- University technologies face the dilemma in the timing of licensing in relation to patenting.
- Early licensing induces expropriation but delayed licensing causes technological obsolescence.
- Licensee's technological capability induces early licensing prior to the patent improvement.
- Such relationship is weakened by technological overlap between the licensee and the technology.

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1. Introduction

Scientific knowledge is transferred from universities to industry and transformed into products and services through collaborative technology licensing (Mowery et al., 2020). Given the substantial impact of academic science on technological innovation (Arora et al., 2019; Klofsten et al., 2019; Messeni Petruzzelli & Murgia, 2022), there is an increasing focus on technology licensing as a key and frequent pathway for the commercialization of academic science.[1] Recent strategic management research has investigated the processes and outcomes of university technology licensing, including the effective organization of technology transfer (e.g., Baglieri et al., 2018; Good et al., 2019; Soares & Torkomian, 2021), the opportunity evaluation (Brown et al., 2022) and resource commitment decisions of university technologies (Kim et al., 2019a), licensing types and contract structures (Kotha et al., 2018; Shen et al., 2022), licensing revenues (Min et al., 2022; Jeong et al., 2024), cohort similarity in patenting and licensing (Modic & Suklan, 2023), and commercialization by startups and spin-offs (Soetanto & van Geenhuizen, 2019; Marx & Hsu, 2022). Despite a plethora of research, a gap persists in our understanding of the timing of licensing – specifically, how rapidly university technologies are licensed to industrial partners. The timing of licensing is crucial because delays can significantly reduce licensing income (Hegde, 2014), escalate the cost of commercialization (Llor, 2007), and increase the likelihood that innovations will be abandoned (Allain et al., 2016). Existing research primarily concentrates on the antecedents and

[1] The terms "academic science commercialization" and "university technology commercialization" have been used interchangeably in this study. As clarified in the paper, both terms typically denote the process of converting scientific and technological knowledge originating from universities into new or enhanced products or services for commercial applications (Fini et al., 2018; Hmieleski & Powell, 2018). Throughout this paper, we employ both terms interchangeably. When specifically referring to the practice of technology transfer through licensing-based market transactions, we use the term "technology licensing" (Meschnig & Dubiel, 2023).

consequences of licensing propensities (for a review, see Meschnig & Dubiel, 2023), overlooking the critical issue of timing. To address this gap, our study investigates a pivotal factor, i.e., the role of a licensee's capabilities in terms of intellectual property (IP) protection, influencing the timing of licensing in the context of university technology commercialization. Specifically, we inquire how a licensee's technological capabilities impact the timing of licensing by presenting a dilemma of either facilitating or delaying licensing throughout the progress of IP rights improvement.

University technology licensing involves navigating a delicate balance between collaboration with industry partners for commercialization and IP protection to prevent undue private gain. This dual objective is well documented in the IP management literature, which discusses the interplay between value creation and appropriation (Somaya, 2012), collaboration and competition (Holgersson et al., 2018), and collaborative and defensive strategies (Grimaldi et al., 2021; Greco et al., 2022). Recent empirical studies highlight the complementary nature of collaboration and protection, demonstrating that advancements in patent rights facilitate the collaboration of technology licensing (Gans et al., 2008; Arora & Gambardella, 2010; Hegde & Luo, 2018). However, a less-explored facet in the literature pertains to the timing dilemma associated with technology licensing in relation to patent protection. On the one hand, the process of obtaining patent protection is time-consuming, typically taking three years or more. Opting to wait for patent protection can lead to delays in licensing, resulting in significant losses in licensing income and posing a threat to the overall commercialization process (Llor, 2007; Hegde, 2014). Conversely, waiting for patent protection and delaying licensing may enhance the appropriability of the invention by mitigating concerns about expropriation (Gans et al., 2008) but at the expense of potential technological obsolescence. This intricate trade-off underscores the complexity associated with timing decisions in university technology licensing.

Given the presence of such a dilemma in the timing of technology licensing, this study suggests that the licensee's technological capabilities play a critical role in influencing the timing. Building upon the dilemma of early versus delayed licensing, we posit that the technological capability of the licensee plays a dual role in influencing the timing of licensing: while the technological capability of the licensee increases expectations of commercial development, it also raises concerns about expropriation. Consequently, we argue that a strong technological capability of the licensee encourages early licensing by strengthening mutual expectations of successful commercialization. However, this effect significantly weakens when the technological domains of the licensee overlap with the focal invention for licensing due to expropriation concerns. Our arguments suggest mutual hesitation by both the licensor and potential licensee to engage in early licensing with the most suitable licensees, namely, those with strong technological capabilities in the knowledge domain that is closely associated with the invention for licensing.

To test our predictions, we utilize a sample of 427 inventions patented and licensed at Stanford University. The Stanford Office of Technology Licensing (OTL), responsible for managing all university-generated patents, provides consistent and standardized data on the invention lifecycle, from disclosure to patenting and licensing. A significant proportion of this university's inventions are licensed before patents are granted, similar to a sample of inventions from previous research on university technologies (Elfenbein, 2007), allowing us to exploit sufficient variation in licensing timing. We analyze how the technological capabilities of licensee firms affect the timing of licensing in relation to patenting stages. Our empirical analyses reveal that the technological capabilities of licensee firms expedite licensing before patent rights improve. However, technological overlap between the invention to be licensed and the capabilities of the licensee firm reverses the positive relationship between technological capabilities and early licensing. These findings illuminate the dilemma created when considering the tradeoffs between licensing before patent rights improve (early licensing) and waiting until patent rights improve or are granted (delayed licensing).

Our research contributes to the research on the market for technology, addressing the call for studies exploring a deeper understanding of the matching partners and processes (Laursen & Salter, 2023) and specifically focusing on factors influencing licensing between pre- and postimprovement in patent rights (Gans et al., 2008). We focus on a contingent factor of licensee-side capability, which has been underexplored in the study of technology licensing (Brown et al., 2022; Meschnig & Dubiel, 2023). The joint consideration of patent protection and licensee capabilities enhances our understanding of the sorting between early licensing and delayed licensing.

2. Literature Review

2.1. University technology commercialization

A substantial body of literature has investigated knowledge interactions between academia and industry, exploring diverse aspects of university-industry collaborative research (e.g., Messeni Petruzzelli & Murgia, 2023) and academic engagement with industry (e.g., Perkmann et al., 2021; Marullo et al., 2022). At this university-industry interface, increasing attention has been directed toward the commercialization of university technologies, defined as the process of transforming scientific knowledge into new or improved products or services (Fini et al., 2018; Hmieleski & Powell, 2018). Scholars have underscored the importance of science in technological innovation, affirming its continued relevance as a valuable input to innovation (Arora et al., 2019). Science-based inventions have been associated with greater gains from trade and lower transaction costs (Arora et al., 2022), leading to a division of innovative labor between universities and corporations and facilitating the subsequent expansion of the technology market (Arora et al., 2019; Caviggioli et al., 2020).

Recent research on university technology commercialization has investigated multifaceted processes at various levels. At the technology level, licensing outcomes are intricately tied to appropriability regimes, encompassing factors such as patent strength, secrecy, and complementary assets (Shane, 2002; Dechenaux et al., 2008). Invention characteristics, such as scope, pioneering nature, and development stage, contribute to the complexity of commercialization dynamics (Nerkar & Shane, 2007; Öcalan-Özel, & Pénin, 2019). At the individual level, academic inventors significantly impact their technology commercialization by identifying potential licensees by leveraging their network (Siegel et al., 2003; Thursby & Thursby, 2004) as well as by directly involving in licensing strategies and commercialization processes (Agrawal, 2006; Wu et al., 2015). Furthermore, the goals, motives, and experiences of academic scientists play important roles in shaping university technology commercialization (for a review, Hmieleski & Powell, 2018). For instance, the intrinsic, not extrinsic, motivations of university inventors are positively linked to the licensing of their research outcome (Corsino & Torrisi, 2023). Research on team-level dynamics demonstrates that diverse knowledge backgrounds within inventing teams enhance commercialization, particularly with a moderate degree of interdisciplinary knowledge dissimilarity (Kotha et al., 2013; Ali & Gittelman, 2016; Marx & Hsu, 2022). At the organizational level, research has examined university technology transfer offices, identifying multiple business models of technology transfer (Baglieri et al., 2018) with different types of policies and effectiveness (Siegel & Wright, 2015; Kirchberger & Pohl, 2016). University technology licensing is found to be associated with university-level factors such as academic and research capabilities (Lee & Jung, 2021), climate to promote entrepreneurial activities (Tseng et al., 2020), and incentive schemes such as royalty sharing arrangements (Arqué-Castells et al., 2016). Professional licensing managers in technology transfer offices (TTOs) also play a crucial role in licensing propensities (Kim et al., 2019b), with their experiences influencing the design of licensing contract structures (Kotha et al., 2018). While extant research has covered technology, individual, and organizational factors in university technology commercialization, a dominant focus has been on the supply side, e.g., university technology characteristics, university scientists, and TTOs. The demand side factors, i.e., the roles of licensee characteristics, are less explored.

2.2. Management of intellectual property rights

Recently, IP protection has gained prominence in management research, reflecting the contemporary competitive environments of knowledge-based economies. Initially, rooted in legal and economic disciplines, IP management has become a vital topic in management research, complementing technology management and business models (Grzegorczyk, 2020). IP management addresses various legal types of IP rights, including patents, copyrights, and industrial design, often combined with informal mechanisms relying on secrecy, lead time, and complementary assets (Cohen et al., 2000; James et al., 2013; Schilling, 2023). From the management perspective, IP protection is not automatic or exogenous but rather endogenously determined by strategic choices (Pisano, 2006), leading to different types of IP protection strategies (Somaya, 2012). These include offensive, defensive, and leveraging strategies involving actions ranging from patenting, publishing, and sharing to secrecy (Nelson, 2016; Holgersson & Wallin, 2017). These strategies are used in subsequent corporate actions such as technology acquisition (Grimpe & Hussinger, 2013) and the postacquisition division of IP rights (Holgersson et al., 2018). Patent protection, discussed predominantly as a tangible and exploitable form of IP rights, is frequently employed for proprietary and defensive purposes (Chung et al., 2019) as well as for preemption and blocking (Grimpe & Hussinger, 2013; Cappelli et al., 2023). Patent protection can be strategically exercised as a real option and utilized as a signal of a firm's IP capabilities across three broad domains: obtaining rights, licensing, and postgrant enforcement (Somaya, 2012).

An important tension found in contemporary IP management research is between appropriation and collaboration. On one hand, IP management aims to enhance protection mechanisms to capture rents from the IP (Teece, 1986, 2006; Dechenaux et al., 2008). On the other hand, the ultimate goal of IP management is value creation, in which managers collaborate with other players in innovation ecosystems (Teece, 2018; Laursen & Salter, 2023). Thus, IP management should pursue both value appropriation and value creation (Somaya, 2012), which invokes inherent tension between competition and collaboration in IP strategies (Holgersson et al., 2018). This tension has been expressed in the recent literature as defensive versus collaborative strategies in IP management (Grimaldi et al., 2021; Greco et al., 2022) and risk-dominant versus network-dominant logic in patent management (AlGhamdi & Durugbo, 2021). Similarly, the traditional focus on appropriation has been reformulated to include platform-based collaboration, especially in the digital economy (Teece, 2018). Consistently, the literature on open innovation has also recognized nuanced management between knowledge sharing and proprietary protection (Henkel et al., 2014), emphasizing the reconciliation of openness in collaboration with value appropriation strategies (de Oliveira et al., 2021; John & Ross, 2022).

In particular, extant research on technology licensing (i.e., the market transaction of IP) has investigated the appropriation-collaboration tension using a transaction cost framework. This approach focuses on the trade-off between internalization versus collaboration in technological innovation, generating a stream of investigations on the licensor's decision between in-house development and licensing (Meschnig & Dubiel, 2023). For instance, Fosfuri (2006) specified a licensor's trade-off between the revenue effect, i.e., revenue generation from licensing payments, and the profit dissipation effect, i.e., profit loss from increased competition, suggesting that market competition among technology suppliers can shift such trade-offs. What has been underexplored here is how the appropriation-collaboration tension affects the timing of licensing, especially in the context of specialized research producers such as universities that lack development capabilities and thus seek collaborative licensing arrangements with partners who have such capabilities. As a critical issue in this context, the timing of licensing is directly associated with the tension between value appropriation and collaboration benefits. On the one hand, delaying licensing until patent protection, which takes several years, enhances the appropriability of the invention by reducing concerns about expropriation (Gans et al., 2008). On the other hand, such licensing delays can lead to a significant loss in commercialization and jeopardize collaboration benefits (Llor, 2007; Hegde, 2014; Allain et al., 2016).

Building on the literature on university technology commercialization and IP management that we reviewed, the following section will elaborate how the decision on the timing of technology licensing can be influenced by the licensee's technological capabilities. We posit that the licensee's technological capabilities play dual roles in determining the timing of licensing by providing the benefit of technological collaboration and incurring the cost related to value appropriation.

3. Hypothesis

3.1. Research context: University technology licensing

The university technology licensing process begins with the disclosure of inventions by university scientists to the technology transfer office (TTO), which acts as an intermediary organization coordinating the technology transfer process (Siegel & Wright, 2015). The TTO subsequently seeks potential licensees in the technology market and pursues IP protection. On the market side, TTO's marketing arms distribute information about inventions through various channels, serving as liaisons between the university and industry. Upon identifying potential licensees, the TTO engages in negotiations for a licensing agreement, collaborating with university inventors. Simultaneously, on the IP protection side, the TTO prepares a patent application for the disclosed invention while searching for potential licensee firms. The pursuit of patent rights protection involves two crucial processes: filing a patent application and the allowance of patent rights[2] (Gans et al., 2008; Sherry & Teece, 2004). The filing of a patent application codifies inventive knowledge in sufficient detail to enable others to use and improve patented technology (Burk, 2008). Once filed, no other inventor can claim the same invention, and incomplete applications are often rejected. The subsequent patent prosecution involves an evaluation by patent examiners, considering criteria such as novelty, usefulness, and nonobviousness. Patent allowances reduce uncertainty regarding the invention's scope and pendency (Gans et al., 2008). In the context of university technology licensing, the timing of arranging a licensing agreement aligns with the progress of patent protection, indicating that the timing of licensing can occur in the following three periods: 1) before filing a patent application, 2) from filing to the preallowance stage, and 3) postallowance of a patent (Kim et al., 2019b). Some technologies undergo early licensing before securing patent protection, while others experience delayed licensing after the improvement of patent rights (Elfenbein, 2007). This study investigates the timing of technology licensing during these three patenting stages with a focus on a licensee's technological capabilities. We propose two hypotheses about these dual roles played by the licensee's technological capabilities in determining the timing of licensing during the three stages of patenting.

3.2. Licensee firm's technological capabilities and licensing timing

A firm's technological capabilities, defined as competences gained through experience in generating inventive knowledge, serve as a primary knowledge base guiding the search for and evaluation of external knowledge (Aharonson & Schilling, 2016; Nelson, 2019; Moeen & Mitchell, 2020). These capabilities facilitate organizational learning from external

[2] Patent allowance is a de facto decision-making for providing patent rights. While the gap between patent allowance and patent granting is only a few months, Gans et al. (2008) suggest that patent allowance tends to fixate the claims and therefore make the patent rights effective. We follow Gans et al. (2008) and use patent allowance instead of patent granting.

environments, promote innovative activities, and result in enhanced performance of new products (Zahra et al., 2007; Zhou & Wu, 2010; Wu et al., 2019). Developed through research and development, technological capabilities act as a preexisting knowledge base for a firm's absorptive capacity, allowing recognition, assimilation, and utilization of external knowledge (Cohen & Leventhal, 1990; Stuart & Podolny, 1996; Cuevas-Vargas, 2022).

Drawing on this literature, we argue that a licensee firm's technological capabilities play a crucial role in facilitating early licensing in the university technology market. First, strong technological capabilities enable a firm to effectively search for and evaluate university inventions, which are often early-stage proofs of concept or prototypes (Jensen & Thursby, 2001). Given the inherent uncertainty of university inventions compared to their industry counterparts, having a robust knowledge base is essential for distinguishing promising inventions from unpromising inventions (Bikard, 2018).

Second, a licensee's technological capabilities serve as a signal of the firm's readiness to commercialize university inventions. This readiness is crucial for assimilating licensed technologies into internal knowledge, enhancing the likelihood of joint development with internal knowledge (Leone et al., 2016; Moreira et al., 2020). Strong technological capabilities provide confidence to university inventors about a firm's qualifications for successful commercial development, reducing concerns about potential failure in the commercialization process.

Third, the technological capabilities of a licensee firm can mitigate IP protection concerns during technology licensing negotiations. The exchange of confidential information between the licensor and potential licensee is challenging due to the licensor's concern about leaking proprietary information before a licensing agreement is reached (Anton & Yao, 1994). A firm's technological capabilities help manage the sharing-secrecy tension around knowledge disclosure, reducing problems in communicating confidential information and negotiating licensing terms.

In summary, the strong technological capabilities of a licensee firm lower the cost of technological obsolescence and enhance the expected benefit of commercial success. Therefore, we suggest that a potential licensee's technology capabilities can facilitate technology licensing before the improvement of patent rights.

H1: When a university invention is licensed to a licensee with technology capabilities, technology licensing is likely to be arranged prior to the improvement of patent rights protection for the focal invention.

3.3. Technological overlap as a moderator

In the first hypothesis, we have articulated an argument on how the technological capabilities of a licensee influence the timing of licensing before the improvement of patent rights while holding other factors constant. Subsequently, we explore the contingent nature of the positive relationship between the technological capabilities of the licensee and early licensing, focusing on a specific aspect: technological overlap. We define technological overlap as the concentration of the licensee firm's technological knowledge in the subject domain of the focal invention (Grimpe & Hussinger, 2013; Sears & Hoetker, 2014; Bae & Lee, 2021). It captures the extent to which the licensee firm has developed capabilities around technological domains related to the focal invention considered for licensing.

The literature on interorganizational collaboration suggests that while collaboration generally aims for mutual gains among alliance partners, there is always a possibility that one partner can pursue private benefits by exploiting the knowledge acquired for its own purposes unrelated to the alliance's activities (Khanna et al., 1998; Katila et al., 2008). Value appropriation from the pursuit of private benefits in technological alliances is linked with partner opportunism and competitive behavior (Arslan, 2018). In a similar vein, a potential licensee can pursue possible private benefits from licensing by inventing around the invention or using the knowledge for its own future technology. As the knowledge overlap between the inventor and licensee can raise issues regarding future appropriation, the partner exploits subsequent opportunities from the focal invention, resulting in contractual issues in technology licensing (Ahuja et al., 2013; Laursen et al., 2017).

Such expropriation in the pursuit of private benefits is a particularly salient concern prior to securing patent rights. A potential licensee with technology capabilities and knowledge overlap may easily absorb even partial information about an invention, which may provide an opportunity for the company to translate the information into products or services without licensing the invention. Without patent rights, the licensee can either invent around or copy the invention (Gans et al., 2008). Attempting to license to firms with overlap in capabilities without a patent application or grant may pose undue risk to the inventor due to leakage and expropriation.

Technological overlap also presents a problem for potential licensee firms. These firms have extensive ongoing research in the focal invention domain when they commence licensing negotiations under confidential disclosure agreement (CDA) restrictions before patent rights are attained. The CDA used to negotiate prior to patent rights bars the use of any information disclosed in the negotiations other than for the purpose of evaluating the invention for licensing (Krattiger & Kowalski, 2007). This restriction may prevent licensees with overlapping knowledge capabilities from engaging in negotiations under a CDA. Furthermore, the potential licensee firm may be called upon to defend that no subsequent inventions resulted from the information disclosed under the CDA if the negotiations did not culminate in a license. Therefore, the greater the overlap in the potential licensee's capabilities with the focal invention's domain, the more subsequent inventions can be subject to questioning.[3]

[3] The risks of discussions under a CDA are illustrated in the legal dispute between Eli Lilly and Aradigm (Federal Circuit, 2004). In 1995 and 1996, scientists from both companies met to explore collaboration, but no formal agreement was reached. On January 31, 1997, Aradigm filed a patent application for an aerosol spray

Combined with the logic that we provided in the first hypothesis, we suggest that licensee firms with high technology capabilities and low technological overlap may enter into early licensing prior to patent rights improvement because their technological capabilities reduce the risk of obsolescence and because there are fewer concerns about the threat of future litigation. However, when a licensee has high technology capabilities and high technological overlap, twin concerns emerge from both the licensor and licensee: The licensor may worry about the ability of the licensee to circumvent the invention, whereas the licensee may worry about the threat of future litigation (Laursen et al., 2017). These concerns cast a shadow on the facilitation of early licensing and thus result in both preferring to delay licensing until patent rights are more demarcated. Hence, we posit the following:

H2: The positive relationship between a licensee with technology capabilities and early licensing is negatively moderated by the increase in technological overlap between the licensee and the focal invention for licensing.

4. Data and Methods

4.1. Sample

This study analyzed a sample of 427 inventions from the Stanford OTL database, disclosed between January 1981 and July 2002, tracking their time for licensing and patenting until 2014.[4] The database links each invention to the patents and licensing agreements it

administering Lilly's Lispro insulin drug. Two years later, Lilly sued, claiming its scientists should have been recognized as coinventors. Although Lilly did not prevail, this case highlights dangers: discussions under a CDA may be enough for claims over subsequent inventions. Once patent rights are clear, negotiations can proceed with less mutual concerns about expropriation.

[4] Our data period corresponds to the time window in which new technologies emerged in biotechnology and computing domains. Our sample includes internet search technologies such as page rank algorithm and biotechnology inventions such as recombinant DNA (rDNA) technique which are considered as important technological advancement. During this period, university technology transfer program has been established in entrepreneurial universities such as Stanford and MIT which have been diffused across research universities worldwide (Etzkowitz & Zhou, 2021). The significance of this periods, especially at Stanford, have been well documented in the literature (Feldman et al., 2015; Nelson, 2015; Kenney & Goe, 2004). For these reasons, studies on university technology commercialization have used the data from the periods that are similar to ours (Dechenaux et al., 2011; Kotha et al., 2018; Kim et al., 2019).

generated, providing crucial information for our analyses. We focused on inventions that generated U.S. patents and had signed licensing agreements, aligning with prior research on licensing timing (Gans et al., 2008). By matching licensee firms from the OTL database with patent assignees in the USPTO database via the NBER patent database, we selected inventions where the licensee firm held at least one patent at the time of licensing. This ensured a focus on technology-oriented firms engaged in technical activities. We excluded self-licensed cases, those licensed to research sponsors, or those arranged by option contracts to maintain consistency in appropriability concerns and the licensing process. The final analysis sample comprised 427 pairs of invention and licensee firms.

4.1.1. Dependent variable

The dependent variable in this study is the timing of the first licensing contract for an invention. To model licensing timing, we track the invention's timeline. First, we note the date when an invention is disclosed to the OTL, marking the start of the invention’s time clock. Second, we record the date of filing a patent application with the USPTO. Third, we note the date when the patent is allowed, known as the patent allowance date. The licensing date is when a licensing agreement is signed between the OTL and a licensee firm. Importantly, licensing can occur before the patent application is filed, after filing and before the patent allowance, or after the patent allowance. Thus, the only date that consistently precedes a licensing date in our sample is the disclosure date. Below, we detail how we construct variables corresponding to changes in patenting stages.

4.1.2. Explanatory variables

This study introduces three patenting stages to measure the improvement of patent rights: the prefiling stage, filing-to-allowance stage, and postallowance stage. Licensing events can occur during any of these three periods. The prefiling stage takes a value of 1 before the filing of the patent; otherwise, it is 0. In the sample, 21 percent of inventions were licensed during the prefiling period. The filing-to-allowance stage takes a value of 1 between patent filing and allowance and is 0 otherwise, with 54 percent of inventions being licensed in this period. The postallowance stage takes a value of 1 after the date of patent allowance and is 0 otherwise, with only 25 percent of inventions being licensed postallowance. The prefiling stage is used as the baseline in the estimations, serving as the omitted category.

Regarding the licensee capability variables, the study incorporates two moderating factors: licensee firms' technology capability and technological overlap. The licensee's technology capability is quantified by the number of patents assigned to the licensee firm at the date of licensing a focal invention. This measure reflects a firm's history of patenting new technologies, indicating its underlying capabilities to generate revenue-generating innovations (Chang et al., 2006; Henderson & Cockburn, 1994; Sorensen & Stuart, 2000). Due to the variable's skewed distribution, a log-transformation is applied for analysis.

The second moderating variable, technological overlap, gauges the knowledge alignment between the focal invention and the licensee firm's technological capabilities. This measurement is computed as the proportion of the licensee's patents before the date of licensing within the same primary technology class as the focal invention (Kavusan et al., 2016; Puranam et al., 2009; Ziedonis, 2007). To derive this metric, the study tallies the patents held by the licensee firm that fall under the same primary patent class as the invention being licensed at the date of licensing. The number of overlapping patents is then divided by the total number of patents held by the firm, producing a proportion measure bounded between 0 and 1. If none of the licensee firms' patents align with the main patent class of the focal invention, the proportion is 0; conversely, if all patents are within the same main class, the proportion is 1.

4.1.3. Control variables

We measure a set of control variables for the focal invention and for the relevant players to control for possible confounding effects on the timing of licensing. We count the number of inventors listed on the inventions. We measure inventor experience as the log of the number of inventions disclosed by the lead inventor. Additionally, licensing manager experience is captured as the log of the number of inventions handled by the licensing manager prior to the focal invention. Patent agent experience, in contrast, is the log of the number of patent applications the patent law firm has prosecuted. We also include a set of patent characteristics that previous research has identified as important. The number of patent classes is the number of three-digit patent classes to which an invention is concurrently assigned. The number of claims is the number of claims made by the inventors in a patent. The backward citations variable is the number of the focal patent's citations of other patents. The patent originality and generality measures are the Herfindahl–Hirschman Index (HHI) of forward and backward citations across patent classes, respectively. We followed Gans et al. (2008) in omitting the number of forward citations as a control measure, as patents granted earlier may have a greater number of citations and hence may bias our analysis of licensing timing. Including the forward citations measure as an additional control in the estimations does not change the results for the theory variables.

We measure a host of control variables to prevent spurious correlations that could bias our results. Based on prior research on licensing, we construct the variable prior collaboration, which indicates prior collaboration among the inventor, licensing manager and patent attorney (Kim et al., 2018). If these three players have ever collaborated for licensing before the focal invention, this variable is coded as 1 and 0 otherwise. A repeated licensee is a firm that has previously licensed from the OTL. This variable takes a value of 1 if the firm is a repeated licensee and 0 otherwise. The licensing managers at the OTL mark an invention based on their expectations of its economic potential at the time of disclosure. Commercial potential refers to the licensing manager's ex ante expectation of an invention's commercial success and has a numerical value between 0 and 3, with 3 indicating the most promising inventions and 0 indicating the least promising inventions. We also control for licensee size, measured by the number of employees, and licensee age, calculated by licensing year minus the firm's founding year. Both size and age are log-transformed to correct the skewness in the distribution. We measure the patent regime following the lead of Shane (2001, 2002) and use the 7-point scale measure of the effectiveness of product patents in industry from the Yale survey of high-level R&D executives (Levin et al., 1987). We manually establish the concordance between the Yale survey's industries and the OTL inventions' technological domains. As an alternative, we use a similar measure from the Carnegie-Mellon survey of patent effectiveness as an appropriability mechanism for product innovation (Cohen et al., 2000), which provides consistent results. Finally, we included controls for the invention's disclosure year and the technology field of the invention: physics, chemistry, biology, medicine, computer science, electrical engineering, and others.

4.2. Estimation strategy

For each invention, we divide the data into daily observations starting from the date of invention disclosure. We set the licensing variable equal to 0 until the date of a licensing agreement, when the variable is then set to 1. The licensing event is the main focus of our analysis. We follow the estimation strategy used by Gans et al. (2008).[5] The indicator variables of the stages of patent rights (i.e., prefiling, filing-to-allowance, and postallowance) can be considered to capture the "treatment effect" of the patent stages on the timing of the licensing of an invention. Two features increase the possibility that the "treatment effect" can be captured by the estimation strategy. First, we account for the technology field and year fixed effects and

[5] To take account of the possible selection bias driven by unlicensed inventions, we use Heckman's two-stage estimation procedure following the procedure suggested by Hamilton and Nickerson (2003). In the first stage, we run a Probit model to estimate the licensing likelihood for an invention disclosed to the OTL in the sample period (1051 inventions). Then, we run the Cox regression of the timing of invention licensing using 427 final sample of licensed inventions by including inverse Mills ratio from the Probit model as a control variable.

control for other important explanatory variables so that the model is as close to a true model as possible. Second, we take steps to prevent a spurious correlation between the hazard of licensing and the time necessary for an invention to go from patent application to patent allowance. Gans et al. (2008: 991-992) suggested that by introducing the time lag variable as a control, it is possible to recover causal inference. Adopting their suggestion, we use two lag time variables as controls in all of our estimations: 1) the lag time between disclosure and patent filing to account (patent filing lag) and 2) the lag time between application and allowance (patent allowance lag). All else being the same, the prefiling variable should allow for the same level of causal inference as the preceding postallowance variable. Furthermore, as our empirical predictions focus on the joint effect of the relative shift in patent protection change and the moderators, akin to the difference-in-differences estimation, our moderation hypotheses allow unobserved factors to be netted out.

We use a Cox proportional hazard rate model with the aforementioned time-period indicator variables. The estimation incorporates a nonparametric baseline hazard rate and a multiplicative term, which allows the explanatory variables to have relative impacts compared to a baseline. The final model is represented by the following equation:

$$h(t, Z, P, L, X_1, X_2) = h_0(t) exp\ (\beta_1 Z + \beta_2 X_1 + \beta_3 X_2 + \beta_4 P + \beta_5 L + \beta_6 P * X_1 + \beta_7 P * X_2 + \beta_8 X_1 * X_2 + \beta_9 P * X_1 * X_2) \quad (1)$$

where $h_0(t)$ *is* an unspecified baseline rate, *Z* is the vector of the control variables, *P* is the vector of the indicator variables for the patenting stages, X_1 is the vector of the licensee's technology capability, X_2 is the vector of overlap in capability, and *L* represents the time lag variables (the patent filing lag and patent allowance lag). In the analyses, we use the two-way interaction between the patenting stage and the licensee's technological capability ($P * X_1$) to test hypothesis 1. Then, we use the three-way interaction among the patenting stage, the licensee's technology capability, and technological overlap ($P * X_1 * X_2$) to test hypothesis 2.

5. Results

Our empirical analyses reveal significant insights into the timing of technology licensing. In summary, we observe a notable impact of the technological capabilities of the licensee firm on early licensing, occurring before patent rights improve. However, this relationship is nuanced, as we identify a moderating effect related to the technological overlap between the invention slated for licensing and the capabilities of the licensee firm.

5.1. Descriptive statistics

Before delving into the main findings, Table 1 provides descriptive statistics for the variables, offering a comprehensive overview of their characteristics. Notably, licensing, on average, takes approximately 790.69 days from the invention disclosure, with the filing of the patent application and the notice of the patent allowance consuming 193.32 and 1092.69 days, respectively. This implies that, on average, licensing requires more time than does the patenting process. The summary statistics highlight substantial variation in the timing of licensing across the three patenting stages: prefiling (21%), filing-to-allowance (54%), and postallowance (25%). To visually represent these variations, Figure 1 displays the distribution of time lags between the licensing and patenting stages. Panels (a) and (b) depict the time lag distributions between licensing and patent application and between licensing and patent allowance, respectively. These distributions underscore the diverse distribution of licensing timing across patenting stages, setting the stage for our empirical analyses seeking to uncover the factors influencing such variation. Table 2 explores bivariate correlations between variables, with most correlations below 0.3. To address potential multicollinearity concerns, we conducted additional analyses, performing regressions by omitting highly correlated variables. The results remained consistent, confirming the robustness of our findings.

-------- INSERT FIGURE 1 AND TABLES 1 & 2 ABOUT HERE --------

5.2. Multivariate analyses

Moving on to Table 3, we delve into the outcomes of the Cox regression, where the "failure" event corresponds to the initial date of invention licensing. All models control for invention disclosure years and technology fields. In Model 1, we integrate control variables along with patent rights improvement stages (prefiling, filing-to-allowance, and postallowance). The omitted category is prefiling. Our analysis indicates no significant difference in the likelihood of licensing when comparing the prefiling period to the stage after filing and before the allowance ($p = .894$) or to the period after the patent allowance ($p = .529$). This result substantiates that the timing of university technology licensing is distributed across various patenting stages. This implies that licensing timing is subject to both delaying forces, associated with expropriation concerns, and facilitating forces, linked to technological obsolescence. The net effect appears to be neutral, emphasizing the intricate interplay of these factors in influencing licensing decisions.

-------- INSERT TABLE 3 ABOUT HERE --------

Moving to Model 2 in Table 3, we explore the contingencies of licensing timing by incorporating the licensee's technological capability. Testing our first hypothesis involves introducing a two-way interaction between patent rights improvement stages (filing-to-allowance and postallowance) and the licensee's technology capability. The results reveal significant interactions for both the filing-to-allowance ($\beta = -0.148$; $p = .001$) and postallowance ($\beta = -0.169$; $p < .001$) periods. To further interpret the findings, we illustrate the hazard ratio (HR) in Figure 2, comparing weak and strong technological capabilities.[6] For strong capability, licensing is most likely in the prefiling period (HR = 1.35), followed by the filing-to-allowance (HR = 1.00) and postallowance periods (HR = 0.77). Conversely, weak

[6] We use two values of one standard deviation above and below the mean value of the variables when we compare the marginal effects throughout the visualizations in Figures 2 and 3.

capability suggests that licensing is less likely in the prefiling period (HR = 0.85) than in the filing-to-allowance (HR = 1.28) and postallowance periods (HR = 1.10). These outcomes align with our assertion that, when licensees possess robust technological capabilities, licensing managers may prefer an expedited approach before patent rights improvement. Therefore, hypothesis 1 receives empirical support

-------- INSERT FIGURES 2 & 3 ABOUT HERE --------

Proceeding to Model 3 in Table 3, we evaluate the second hypothesis by introducing three-way interactions involving patent protection improvement, licensee technology capability, and technological overlap. As hypothesized, the three-way interaction terms prove positive and significant ($\beta = 1.354$; $p = .003$; $\beta = 1.653$; $p = .006$). These results align with the prediction that with increasing technological overlap, the positive association between technology capability and early licensing is reversed. To elucidate the marginal effects, hazard ratios are calculated and compared in Figure 3. In panel (a), representing strong capability, licensing is more likely to have a low overlap (HR = 1.29) than a high overlap (HR = 0.25) during the prefiling period. However, this pattern reverses in the filing-to-allowance or postallowance periods. In panel (b) of weak capability, differences between high and low overlap are less pronounced. The comparison across panels in Figure 3 underscores that while licensee technological capability prompts early licensing, this tendency diminishes with high technological overlap. This comprehensive analysis substantiates support for hypothesis 2.

5.3. Additional analyses

For a robustness check, we conducted additional analyses utilizing an alternative measure for licensee technology capability. This measure incorporates forward citation information, signifying the patent's importance and utility (Fleming & Sorenson, 2001), which is often employed to gauge a firm's stock of technological knowledge (Laursen et al., 2010; Yayavaram & Chen, 2015; Ziedonis, 2007). To address right-sided truncation concerns, we utilized normalized patent citations from the NBER patent database (Hall et al., 2001). Summing the citations by firm-year yielded the firm-level technology capability measure in the year of licensing. In Model 2 of Table 4, we present interaction terms between filing-to-allowance and citation-based capability ($\beta = -0.169$; $p < .001$) and between postallowance and citation-based capability ($\beta = -0.181$; $p < .001$). These results align with hypothesis 1, indicating that when licensees possess robust technology capabilities, licensing tends to occur before patent rights improve. Moving to Model 3, which introduces the three-way interaction among patent improvement stages, citation-based capability, and technological overlap, we find consistent and unchanged results. This reaffirms the robustness of our findings.

-------- INSERT TABLE 4 ABOUT HERE --------

6. Discussion

We examined how the technology capabilities of licensee firms influence the timing of licensing across patenting stages. Empirical analyses revealed that licensee firms' technology capabilities expedite licensing before patent rights improve. However, the positive association between technology capabilities and early licensing is reversed when there is technological overlap between the invention to be licensed and the capabilities of the licensee firm. These findings highlight a dilemma in navigating the trade-offs between early licensing before patent rights improve and delayed licensing after improvement. Our research reveals a strategic dilemma in the timing of licensing, stemming from the dual nature of licensee capabilities.

6.1. Theoretical contributions

This research contributes to the literature on university technology licensing by highlighting the pivotal roles played by licensee characteristics. As most of the existing research on university technology licensing takes the licensor's perspective with the implicit assumption that licensees are homogeneous (Aulakh et al., 2013), there has been a recent call to investigate licensee characteristics in the process of technology licensing (Brown et al., 2022; Meschnig & Dubiel, 2023). Our research responded to this call by showing the importance of licensee-side variation in technological capabilities. According to our findings, licensees' capabilities are important because they serve as a knowledge base for inducing early licensing, but close overlap in the knowledge domain can lead to licensing hesitation. In our research, the licensee's technological capabilities serve as both inducers and restrainers of early licensing. While capabilities can be seen as a bundle of resources according to a resource-based view (Meschnig & Dubiel, 2023), they can send signals that are believed to convey information about future prospects (Kotha et al., 2018) under conditions of high uncertainty and information asymmetry, such as university inventions (Hagedoorn & Hesen, 2007; Hsu et al., 2021). Our research showed that the licensee's technological capabilities can send dual signals that can offer not only commercial prospects but also appropriation concerns and thus influence both the licensor and licensee's decisions to time licensing. By paying attention to a licensee-side factor and its dual nature, our research highlights the understudied factors of demand-side conditions in university technology commercialization.

Our finding on the dual role of the licensee's technological capabilities in technology licensing is linked to the literature on competitive tension in interorganizational alliances. This literature reveals the double-edged nature of knowledge similarities among potential alliance partners. While knowledge similarities may help to create common ground for mutual understanding (Puranam et al., 2009), they simultaneously provoke concerns about appropriation among alliance partners, which prevents the formation of collaborative relationships under either weak patent protection (Dushnitsky & Shaver, 2009) or anticipated hostile actions (Bae & Lee, 2021). Consistent with the literature, we show how the dual nature of licensee capabilities can both facilitate and delay licensing. We capture the two faces of licensee capabilities to reveal a dilemma in the decision of licensing timing: Licensors may prefer fast commercialization because of the risk of obsolescence but may also want to avoid expropriation concerns at the same time. In our exploration of this dilemma, we extend the literature on the inherent tension in interfirm collaboration to the context of technology licensing.

Our research highlights the timing of technology licensing to the literature on the market for technology (Arora & Gambardella, 2010; Arora et al., 2022). Prior research on technology licensing has neglected the timing issue, mainly focusing on licensing propensities, i.e., whether to license, under the framework of transaction cost economics. This stream of research, taking the licensor's perspective, has investigated the decision of in-house development versus licensing out (for a review, see Meschnig & Dubiel, 2023) to be associated with technological characteristics such as patent scope, pioneering nature, and development stage (Nerkar & Shane, 2007; Ocalan-Ozel & Penin, 2019) and IP regimes such as patent strength (Shane, 2002; Dechenaux et al., 2008). Complementing this stream of research on technology licensing, our study examines the timing of licensing by elaborating on the trade-off between early licensing and delayed licensing. While inherent tension between appropriation and collaboration resides in the licensor's dilemma of licensing-out versus internal development (e.g., Fosfuri, 2006), our research highlights that such tension can also be found in the timing of licensing. Early licensing can jeopardize innovation appropriability whereas delayed licensing suffers from technological obsolescence. By paying attention to the time spent on university technology commercialization (Kalantaridis & Küttim, 2023), our research presents a new type of licensing dilemma about its timing to the literature on the market for technology.

Our findings have implications for the literature on IP management. The extant literature on patent protection has a dominant focus on cross-sectional variation in patent effectiveness, e.g., employing measures of cross-field or cross-industry variation in patent regime effectiveness (Cohen et al., 2000; Schilling, 2023). While multiple mechanisms of appropriability, including patents, secrecy, lead time, and complementary assets, have been recognized (Cohen et al., 2000; Katila et al., 2008), empirical investigations have investigated cross-sectional variation in patent protection standalone, triggering a call for joint considerations of multiple mechanisms. For instance, in a review of patent strategy and management, Somaya (2012) emphasized that patent protection is not the only appropriability mechanism and thus should be considered in combination with other kinds of protection mechanisms. Recently, Laursen and Salter (2023) proposed investigating complex interactions between informal intellectual property protection (such as secrecy) and formal intellectual property protection (such as patents). In this literature, we elucidated the temporal process of patenting stages combined with the timing of licensing and licensee characteristics. Our research suggests that patent protection in technology licensing needs to be considered jointly with the licensing timing and the licensee partners in transactions.

6.2. Practical implications

Our research has practical implications for steering the effective management of university technology licensing amidst the uncertainties inherent in early-stage inventions. Disagreements between universities and corporations on value creation contributions often arise due to these uncertainties (Kotha et al., 2018). TTO managers, therefore, must adeptly navigate licensing negotiations, emphasizing a nuanced understanding of timing contingencies. While the promptness of university technology licensing is acknowledged for its pivotal role in successful commercialization (Markman, 2005), our findings advocate for a contingent approach. TTO managers should exercise caution when considering licensing after patent applications or allowances. This strategy is particularly relevant when engaging with licensees possessing strong technological capabilities closely associated with the focal technology, utilizing the demarcation of patent rights as a catalyst for technology licensing.

Our research highlights managerial insights for corporations venturing into licensing university technologies. Corporations involved in licensing academic science need to have professional licensing managers well versed in university collaboration. This is often the case in large and established firms with their own IP management function and cumulative experiences in external knowledge sourcing. However, despite their innovation competence, small and medium-sized enterprises (SMEs) and startups often lack IP management resources (Holgersson et al., 2016). Our findings underscore that technology licensing encounters its most substantial challenge when aligning with a closely related licensee, a scenario frequently faced by SMEs and startups with a narrow technological scope. To navigate this challenge effectively, SMEs and startups should focus not only on their internal IP protection but also on adeptly transacting external IP, keen to carefully use CDA and licensing negotiations.

In the technology market, an exclusive emphasis on IP protection may not suffice for value creation. Successful technology transactions necessitate collaboration to maximize utilization, particularly in university technology commercialization where broader societal impacts are sought (Fini et al., 2018). Acknowledging universities' societal role, IP management should transcend narrow appropriation, evolving toward broader utilization (Holgersson & Aaboen, 2019). Our research advocates coupling IP management with a comprehensive understanding of collaboration management. This dual focus enables a balanced approach, harmonizing collaboration and appropriation in university technology commercialization. Achieving mutual benefits in collaborative licensing requires a deep comprehension of both the legal aspects of IP protection for value appropriation and strategic IP management for value creation by both the TTO and corporate managers (Somaya, 2012; Kotha et al., 2014; Soares and Torkomian, 2021).

6.3. Limitations and future research

This research acknowledges several limitations that, in turn, open avenues for future exploration. First, our focus on the licensee's technological capabilities in determining the timing of licensing can be extended to include other aspects of licensee characteristics. Future research could investigate the licensee's absorptive capacity in identifying and leveraging external knowledge (Tzokas et al., 2015), as suggested by Brown et al. (2022). Additionally, examining licensee characteristics, such as complementary capabilities in areas such as development, manufacturing, or marketing, could provide further insights into the strategic timing of licensing (Ceccagnoli et al., 2010; Moreira et al., 2023). Second, while our research focuses on the licensing timing, the timing is intricately linked to the structure of the licensing arrangement. Investigating how different types of licensing, payment structures, and postlicensing considerations can influence the timing of licensing could be a fruitful avenue for future exploration (Shen et al., 2022; Kotha et al., 2018; Dechenaux et al., 2011). Third, our exploration focused on the antecedents of licensing timing, leaving room for future research to scrutinize the consequences of strategic timing. Understanding how the timing of licensing influences subsequent commercialization development is a promising direction for inquiry (Leone & Reichstein, 2012). Fourth, while our study concentrated on licensee-side factors, the timing of licensing may also be influenced by academic scientists with diverse motivations and behaviors in university technology commercialization (Hmieleski & Powell, 2018; Corsino & Torrisi, 2023). Combining microfoundations related to academic scientists could offer a valuable perspective. Relatedly, as academic entrepreneurship is another important mechanism for university technology commercialization (Soetanto & van Geenhuizen, 2019; Messeni Petruzzelli & Murgia2022), it would be an intriguing avenue to investigate academic scientists' motivation and behavior to generate their own startups, as opposed to licensing to existing firms (Baglieri et al., 2018). Finally, our empirical analyses were confined to inventions from a single institution—a special case with elite science and engineering programs situated in regions with well-developed entrepreneurial ecosystems. Recognizing the diverse business models of technology transfer among universities (Baglieri et al., 2018), future research may benefit from expanding the sample to encompass a broader spectrum of university characteristics and surrounding environments to investigate potential variations in the dynamics of technology licensing and IP management.

7. Conclusions

This study enriches the technology licensing literature by examining the strategic timing dilemma in university technology commercialization. Focusing on the trade-off between expropriation and obsolescence in technology licensing, empirical evidence reveals that a strong technological capability of the licensee facilitates early licensing (prior to patent rights improvement), while technological overlap with the licensee introduces a significant delay factor. This dilemma may result in unwanted delays in licensing when dealing with the most suitable licensees possessing a strong technological base in the domain. For academics, our research extends the understanding of technology licensing by emphasizing the decision-making process in collaborative licensing timing and the strategic challenges faced by specialized research producers such as universities. For practitioners, effective university technology licensing management should prioritize timing to maximize mutual benefits in collaboration.

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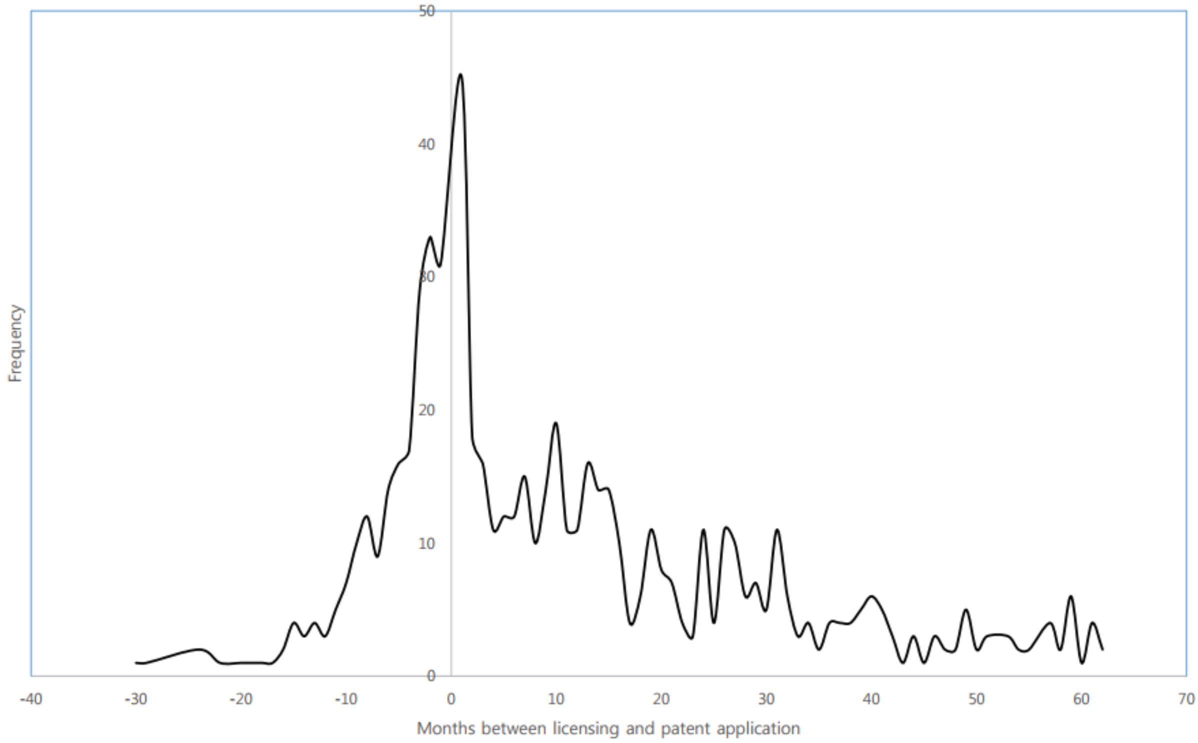
Figure 1. Licensing-Patenting Time Lag Distributions

(a) Time Lag between Licensing and Patent Application



(b) Time Lag between Licensing and Patent Application

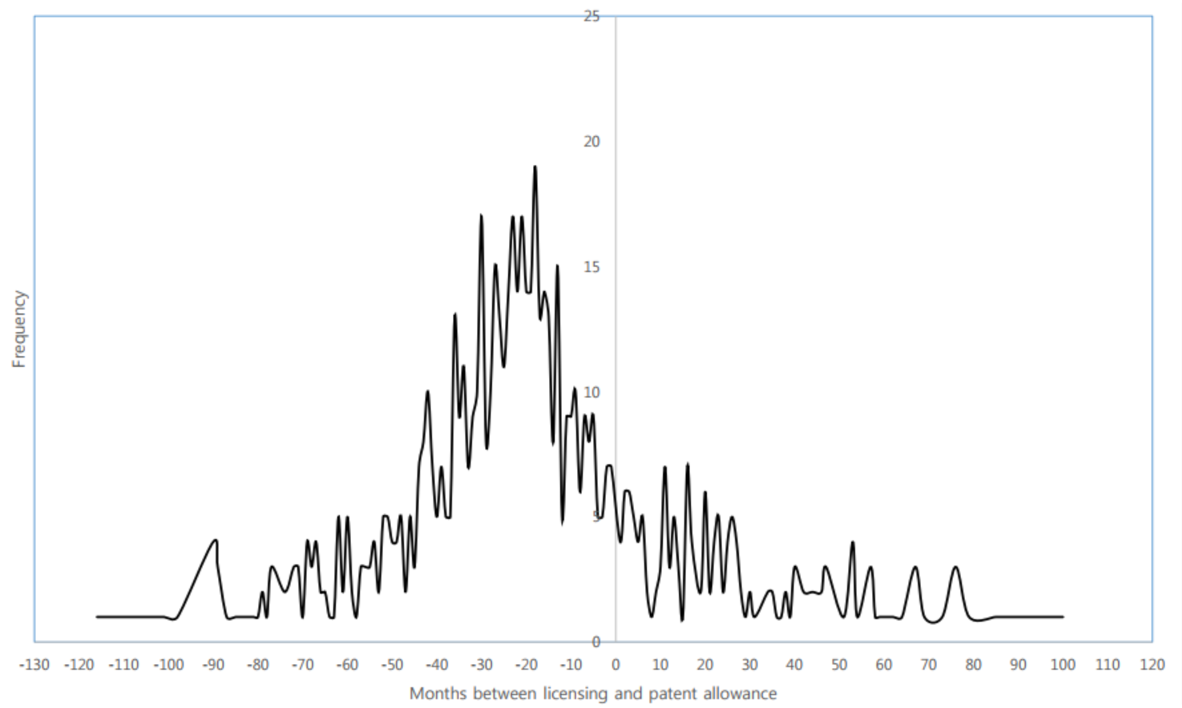


Figure 2. Patenting Stages and Licensing Hazard: Moderation by the Licensee's Technology Capabilities

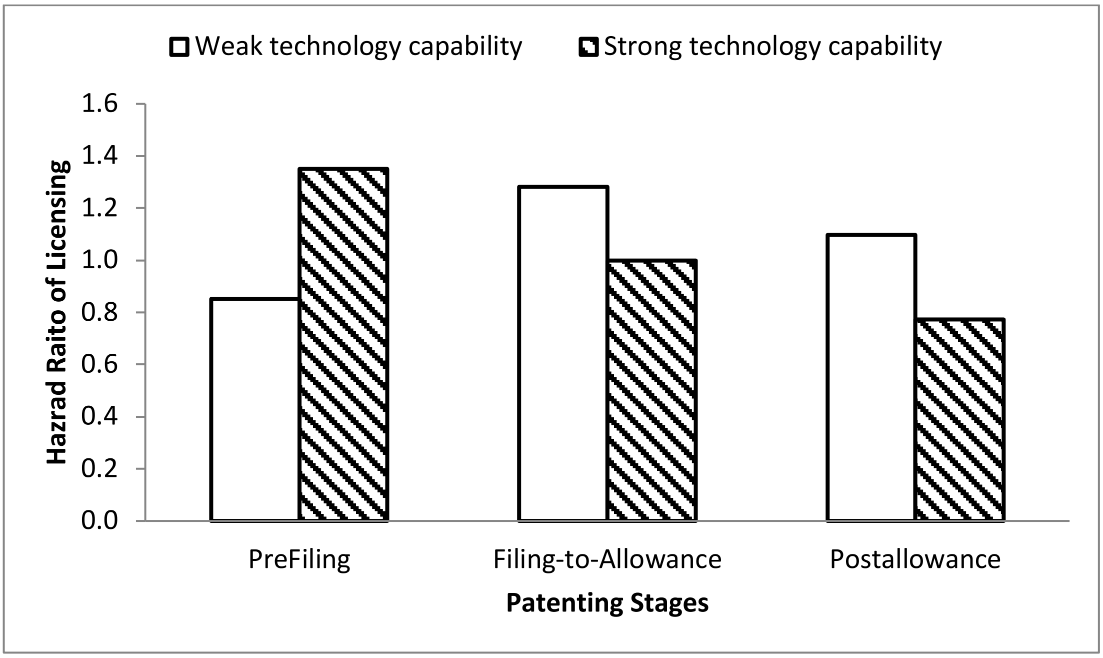
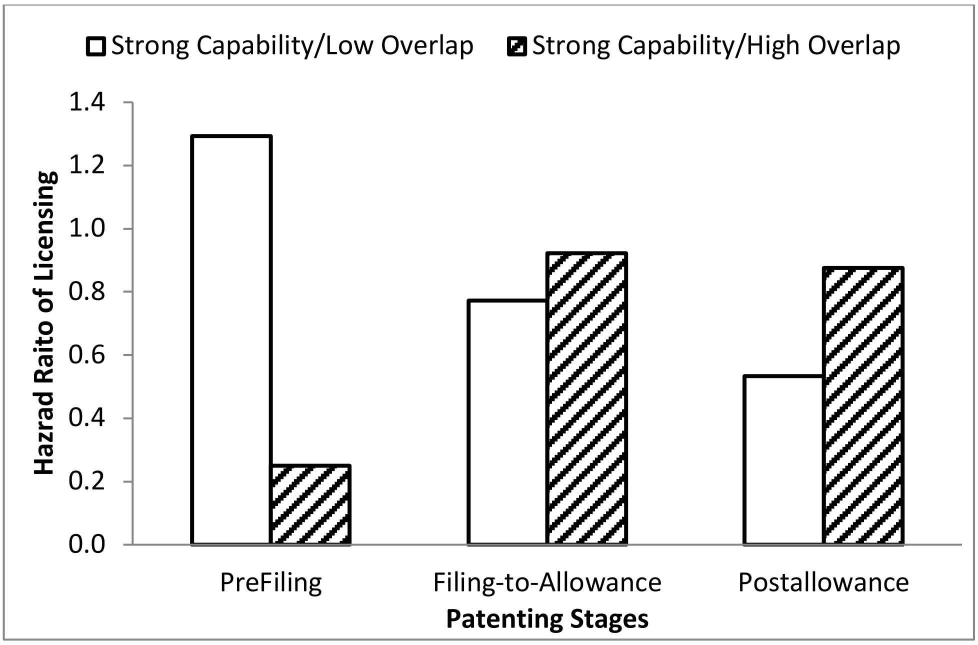


Figure 3. Patenting Stages and Licensing Hazard: Moderation by the Licensee's Technology Capabilities and Technological Overlap

(a) Case of Strong Technology Capabilities



(b) Case of Weak Technology Capabilities

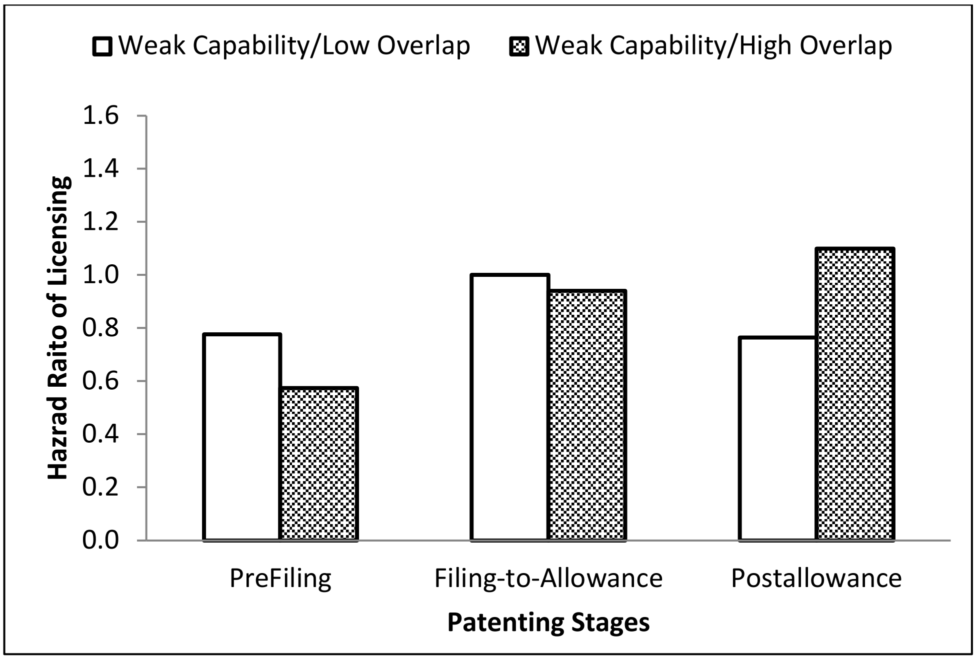


Table 1. Variable Definitions, Means, and Standard Deviations

Variable	Mean	Std. dev.
Timing measures		
Licensing lag	790.69	778.21
Patent application lag	193.32	217.28
Patent allowance lag	1092.69	644.86
Prefiling	0.21	0.41
Filing-to-allowance	0.54	0.50
Postallowance	0.25	0.44
Moderators		
Technology capability	3.23	2.40
Technological overlap	0.09	0.20
Control Variables		
# of inventors	2.59	1.35
Inventor experience (ln)	1.23	1.09
Licensing manager experience (ln)	3.57	1.12
Patent agent experience (ln)	0.38	0.49
Prior collaboration	2.02	2.75
# of patent class*	1.05	0.57
# of patent claims*	23.64	21.79
# of backward citations*	7.7	14.56
Patent generality*	0.63	0.23
Patent originality*	0.63	0.28
Patent regime	4.46	1.26
Commercial potential	1.31	0.88
Repeated licensee	0.32	0.47
Licensee size (ln)	6.45	4.39
Licensee age (ln)	2.49	1.89

These data are from the NBER patent database (2006) downloaded from sites.google.com/site/patentdataproject.

Table 2. Bivariate Correlations

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	# of inventors																				
2	Inventor exp (ln)	0.22																			
3	Licensing manager exp (ln)	0.24	0.44																		
4	Patent agent exp (ln)	0.05	0.28	0.26																	
5	Prior collaboration	0.04	0.62	0.27	0.26																
6	# of patent class	0.09	-0.19	-0.27	-0.18	-0.17															
7	# of claims	0.24	0.00	0.05	0.02	-0.05	0.23														
8	# of prior cites	0.24	-0.03	0.12	0.00	-0.06	0.18	0.34													
9	Patent generality	0.14	0.01	-0.03	-0.01	-0.02	0.19	0.13	0.10												
10	Patent originality	0.09	-0.06	-0.06	-0.06	-0.03	0.20	0.15	0.11	0.22											
11	Patent regime	0.10	-0.22	-0.22	-0.23	-0.22	0.26	-0.03	-0.01	0.06	0.05										
12	Commercial potential	0.15	-0.09	0.13	0.01	-0.10	0.08	0.04	0.06	-0.01	0.05	0.14									
13	Repeated licensee	-0.12	0.21	-0.06	0.12	0.24	0.02	-0.04	-0.06	-0.05	-0.15	-0.14	-0.17								
14	Licensee size (ln)	-0.11	0.00	0.06	-0.15	0.02	0.01	-0.06	0.05	0.00	-0.09	0.01	-0.12	0.15							
15	Licensee age (ln)	-0.16	0.04	-0.08	0.01	0.16	0.05	-0.18	-0.11	-0.02	-0.08	-0.09	-0.16	0.32	0.57						
16	Patent application lag	0.02	0.16	0.01	0.07	0.07	-0.06	0.03	-0.01	-0.05	0.02	-0.14	-0.09	0.05	-0.04	-0.03					
17	Patent allowance lag	0.09	0.02	0.14	0.08	0.07	-0.20	0.08	0.00	0.02	0.07	0.03	0.06	-0.08	-0.08	-0.10	-0.10				
18	Technology capability	-0.14	-0.01	-0.05	0.08	0.05	0.03	-0.07	-0.07	0.08	-0.08	-0.12	-0.05	0.14	0.48	0.58	-0.05	-0.03			
19	Technological overlap	-0.01	-0.16	-0.11	-0.21	-0.17	0.09	0.03	-0.02	-0.07	0.02	0.34	0.08	-0.13	-0.03	-0.11	-0.09	0.00	0.00		
20	Filing-to-allowance	0.01	-0.04	-0.03	-0.03	-0.03	0.02	0.02	0.00	0.03	0.01	0.07	0.02	-0.02	-0.04	-0.03	-0.10	0.09	-0.01	0.04	
21	Postallowance	-0.01	0.00	-0.01	-0.01	-0.01	0.00	-0.02	-0.01	0.00	0.00	-0.02	0.00	-0.02	-0.02	-0.01	0.00	-0.05	0.00	0.00	-0.65

Correlation coefficients greater than .04 or less than -.04 are significant at the five percent level.

Table 3. Cox Regression of the Timing of Invention Licensing

	M1	M2	M3
# of inventors	0.033	0.030	0.030
	(0.049)	(0.050)	(0.050)
Inventor exp	-0.143	-0.134	-0.150
	(0.140)	(0.140)	(0.139)
Licensing manager exp	-0.017	-0.033	-0.040
	(0.081)	(0.081)	(0.080)
Patent agent exp	-0.055*	-0.059*	-0.055*
	(0.025)	(0.024)	(0.024)
Prior collaboration	0.221	0.224^{+}	0.240^{+}
	(0.136)	(0.135)	(0.134)
# of patent class	0.146	0.135	0.140
	(0.126)	(0.126)	(0.125)
# of claims	0.001	0.002	0.002
	(0.002)	(0.002)	(0.002)
# of prior cites	0.006	0.006	0.006
	(0.006)	(0.006)	(0.006)
Generality	-0.252	-0.244	-0.220
	(0.256)	(0.258)	(0.255)
Originality	0.191	0.224	0.250
	(0.209)	(0.209)	(0.209)
Patent regime	-0.017	-0.009	-0.006
	(0.054)	(0.056)	(0.059)
Commercial potential	-0.168*	-0.156^{+}	-0.152^{+}
	(0.082)	(0.083)	(0.084)
Repeated licensee	0.622***	0.614***	0.601***
	(0.133)	(0.134)	(0.134)
Licensee size	0.009	0.010	0.009
	(0.018)	(0.018)	(0.018)
Licensee age	0.102*	0.100*	0.096*
	(0.043)	(0.044)	(0.046)
Patent application lag	-0.026**	-0.025**	-0.026**
	(0.010)	(0.010)	(0.010)
Patent allowance lag	-0.005	-0.005	-0.005
	(0.005)	(0.005)	(0.005)
Technology capability	-0.030	0.096*	0.128**
	(0.030)	(0.044)	(0.045)
Technological overlap	-0.021	-0.037	0.114
	(0.233)	(0.239)	(1.001)
Inverted Mill's ratio	0.170	0.111	0.148
	(0.788)	(0.792)	(0.781)
Patenting stages (reference=prefiling)			
Filing-to-allowance	0.025	0.527*	0.445^{+}
	(0.184)	(0.251)	(0.255)
Postallowance	-0.177	0.389	0.201
	(0.281)	(0.331)	(0.336)

(Table 3. Continued)

	M1	M2	M3
Filing-to-allowance * Technology capability (H1)		**-0.148****	**-0.192*****
		(0.045)	**(0.047)**
Postallowance * Technology capability (H1)		**-0.169*****	**-0.217*****
		(0.048)	(0.053)
Filing-to-allowance * Technological overlap			-0.525
			(1.161)
Postallowance * Technological overlap			-0.147
			(1.469)
Technology capability * Technological overlap			-1.151**
			(0.427)
Filing-to-allowance * Technology Capability * Overlap (H2)			**1.354****
			(0.449)
Postallowance * Technology Capability * Overlap (H2)			**1.653****
			-0.525
Log likelihood	-2105.98	-2100.90	-2090.50
Chi-squared	150.57	167.28	199.02
Number of Licensed Invention	427	427	427

Regression coefficients are reported with their robust standard errors in parentheses. All models include dummy variables for an invention's disclosure year and technology field but are omitted for the sake of brevity. Significance level: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4. Cox Regression of the Timing of Invention Licensing: Using a Citation-based Measure of Technology Capabilities

	M1	M2	M3
# of inventors	0.029	0.027	0.024
	(0.050)	(0.051)	(0.051)
Inventor exp	-0.143	-0.132	-0.143
	(0.139)	(0.140)	(0.140)
Licensing manager exp	-0.021	-0.041	-0.053
	(0.081)	(0.081)	(0.079)
Patent agent exp	-0.056*	-0.060*	-0.055*
	(0.025)	(0.024)	(0.024)
Prior collaboration	0.200	0.208	0.236+
	(0.135)	(0.135)	(0.133)
# of patent class	0.149	0.144	0.161
	(0.126)	(0.129)	(0.129)
# of claims	0.001	0.002	0.002
	(0.002)	(0.002)	(0.002)
# of prior cites	0.005	0.005	0.006
	(0.006)	(0.006)	(0.006)
Generality	-0.225	-0.221	-0.204
	(0.256)	(0.258)	(0.254)
Originality	0.193	0.213	0.241
	(0.209)	(0.209)	(0.208)
Patent regime	-0.027	-0.018	-0.013
	(0.055)	(0.057)	(0.059)
Commercial potential	-0.164*	-0.150+	-0.143+
	(0.082)	(0.083)	(0.084)
Repeated licensee	0.604***	0.599***	0.583***
	(0.134)	(0.134)	(0.135)
Licensee size	0.016	0.015	0.015
	(0.018)	(0.018)	(0.019)
Licensee age	0.112**	0.112*	0.106*
	(0.042)	(0.044)	(0.046)
Patent application lag	-0.026**	-0.025*	-0.026**
	(0.010)	(0.010)	(0.010)
Patent allowance lag	-0.005	-0.005	-0.004
	(0.005)	(0.005)	(0.005)
Citation-based technology capability	**-0.055+**	**0.085***	**0.128****
	(0.028)	**(0.041)**	**(0.043)**
Technological overlap	0.020	0.008	2.040
	(0.235)	(0.241)	(1.422)
Inverted Mill's ratio	0.202	0.116	0.117
	(0.789)	(0.802)	(0.794)

(Table 4. Continued)

	M1	M2	M3
Patenting stages (reference=prefiling)			
Filing-to-allowance	0.025	0.731**	0.730**
	(0.184)	(0.272)	(0.275)
Postallowance	-0.174	0.574+	0.460
	(0.281)	(0.341)	(0.347)
Filing-to-allowance * Citation-based capability(H1)		**-0.169*****	**-0.232*****
		(0.043)	**(0.045)**
Postallowance * Citation-based capability (H1)		**-0.181*****	**-0.246*****
		(0.045)	**(0.050)**
Filing-to-allowance * Technological overlap			-2.861+
			(1.652)
Postallowance * Technological overlap			-2.748
			(2.069)
Citation-based capability * Technological overlap			-1.377**
			(0.436)
Filing-to-allowance * Citation-based capability * Overlap (H2)			**1.649*****
			(0.468)
Postallowance * Citation-based Capability * Overlap (H2)			**1.919****
			(0.598)
Log likelihood	-2104.62	-2097.52	-2084.74
Chi-squared	154.22	172.00	209.00
Number of Licensed Invention	427	427	427

Regression coefficients are reported with their robust standard errors in parentheses. All models include dummy variables for an invention's disclosure year and technology field but are omitted for the sake of brevity. Significance level: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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