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Licensing out under uncertainty: for which of their technologies do established firms use external markets?

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Abstract

Prior literature has emphasized that the licensing decision is mainly a choice of small firms because they require access to the complementary assets of established firms to develop and commercialize their technologies (Gans & Stern, 2003; Kollmer & Dowling, 2004; Teece, 1986). However, recently we have observed that not only small firms, but established firms such as AT&T, DuPont, and Merck also actively seek potential licensees to develop and commercialize their technologies. This runs counter the expectation that established firms, which are in possession of complementary assets, would develop technologies through their in-house R&D rather than licensing them out to another firm. Prior research has predominantly studied licensing decisions by established firms through a profit maximization lens in which the firm faces a dilemma of having to weigh the extra revenue it can generate through licensing (the revenue effect) versus the cannibalizing of revenues through the nurturing of new competitors (rent dissipation effect) (Arora & Fosfuri, 2003; Fosfuri, 2006). However, for more nascent technologies there remains uncertainty as to whether they will reach the commercial market and how much revenue and competition they will generate, which makes it difficult to do such an assessment. The goal of our paper is to introduce uncertainty in the licensing-out decision faced by established firms and to systematically explore which technologies these firms license out and which ones they keep in-house for further development. Using the real options theory, we conceptualize the licensing-out decision as a choice to keep the technology as an option for internal commercialization or to exchange the option for licensing revenue (McGrath, 1997). We propose that a firm will more likely license out technologies at later stages in their development when the level of uncertainty and, consequently, the option value of the technology have decreased. Furthermore, we acknowledge that licensing decisions are not taken in isolation (Nishimura & Okada, 2014) but that the firm's development and sales portfolio influence the licensing decision. We propose that a firm is more likely to license out a technology developed for a market for which the firm has

alternative technologies in its development portfolio, because the option values of the technologies may overlap. Conversely, a firm is more likely to license out a technology developed for a market in which the firm generates fewer sales relative to the sales portfolio because of the lower downside potential of the firm's core business being attacked by competition. We test our hypotheses in the pharmaceutical industry analyzing licensing deals of the 57 largest pharmaceutical firms during the years 1994 to 2008. We combine licensing data from the Recombinant Capital Biotech Alliance Database, project development data from the Pharma Project database and sales data from the Evaluate database. Our dataset allowed us to contrast 426 technologies that were licensed out to 9,354 technologies in the firm's development portfolio that were not licensed out. Our results confirm that taking into account uncertainty at both the technology and the portfolio levels profoundly shapes the licensing-out decision by established firms. References Arora, A., & Fosfuri, A. (2003). Licensing the market for technology. Journal of Economic Behavior & Organization, 52, 277–295. Fosfuri, A. (2006). The licensing dilemma: understanding the determinants of the rate of technology licensing. Strategic Management Journal, 27(12), 1141–1158. Gans, J. S., & Stern, S. (2003). The product market and the market for " ideas ": commercialization strategies for technology entrepreneurs. Research Policy, 32, 333–350. Kollmer, H., & Dowling, M. (2004). Licensing as a commercialisation strategy for new technology-based firms. Research Policy, 33(8), 1141–1151. McGrath, R. G. (1997). A real options logic for initiating technology positioning investments. The Academy of Management Review, 22(4), 974–996. Nishimura, J., & Okada, Y. (2014). R&D portfolios and pharmaceutical licensing. Research Policy, 43(7), 1250–1263. Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. Research Policy, 15, 285–305.

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Licensing out under uncertainty:

For which of their technologies do established firms use external markets?

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Abstract

Prior research has predominantly studied licensing-out decisions by established firms through a profit maximization lens, but for more nascent technologies it is difficult to do such an assessment due to uncertainty as to whether these technologies will reach the commercial market and how much revenue and competition they will generate. The goal of our paper is to introduce uncertainty in the licensing-out decision faced by established firms and to systematically explore which technologies these firms license out and which ones they keep in-house for further development. Using the real options theory, we conceptualize the licensing-out decision as a choice to keep the technology as an option for internal commercialization or to exchange the option for licensing revenue. We show that taking into account uncertainty at the technology, the development portfolio and the commercial portfolio levels profoundly shapes the licensing-out decision by established firms.

Key words: technology licensing, established firms, uncertainty, real options, technology portfolio

Introduction

Technology licensing has become an increasingly prevalent development and commercialization strategy in environments characterized by rapid technological change (Anand & Khanna, 2000). Following the idea of a division of innovation labor (Arora & Gambardella, 1994), prior literature has emphasized licensing out as a choice by nascent firms that in the absence of their own complementary assets need to tap into the complementary assets of external partners (Gans & Stern, 2003; Kollmer & Dowling, 2004; Teece, 1986). However, recently, we observed that not only small firms, but also established firms license out their technology despite being endowed with sufficient complementary assets. Established firms such as AT&T[1], DuPont[2], and Merck[3] have begun to systematically seek potential licensees for their technology by setting up dedicated departments. This runs counter to the expectation that established firms would develop and commercialize technologies using their in-house complementary assets rather than licensing them out to another firm. Hence, determining which technologies established firms are willing to develop and commercialize externally and which ones they prefer to develop in-house is an increasingly relevant question for managers and researchers.

Prior literature examining an established firm's decision to license out technologies has studied the decision using a profit maximization lens in which a firm faces a dilemma of having to weigh the extra revenue it can generate through licensing (the revenue effect) versus the cannibalizing of revenues through the nurturing of new competitors (rent dissipation effect) (Arora & Fosfuri, 2003; Fosfuri, 2006). However, this licensing framework requires firms to be able to make unambiguous net present value calculations on the revenue and rent dissipation effect. In the context of the initial development and commercialization, however,

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[1] http://www.att.com/gen/sites/ipsales?pid=17704
[2] http://dupont.t2h.yet2.com/t2h/page/homepage
[3] http://www.merck.com/licensing/

there exists inherent uncertainty regarding the technology's feasibility, its commercial potential and the risk of giving the technology to a possible competitor (Anderson & Tushman, 1990; Cassimon et al., 2011; Oriani & Sobrero, 2008). Hence, assigning a net present value for a technology which is still in development proves difficult. We therefore need a better understanding of how the revenue and rent dissipation effect ultimately drive the decisions of established firms to select one technology over another to be licensed-out versus to be being retained for further development and commercialization in-house under conditions of uncertainty.

The goal of our paper is to introduce uncertainty in the technology licensing decision faced by established firms and to systematically explore which technologies firms license out to external partners and which ones they keep in-house for further development. To build a theoretical framework on the licensing-out decisions of established firms under uncertainty we draw upon the real options literature (Adner & Levinthal, 2004; Dixit & Pindyck, 1994; McGrath, 1997) and the literature on technology licensing by established firms (Arora & Fosfuri, 2003; Fosfuri, 2006; Nishimura & Okada, 2014).

Using the real options theory, we conceptualize a technology as a real option. Like an option, completing the development of the technology creates an underlying right but not the obligation to commercialize that technology (McGrath, 1997). This real options lens offers a way to evaluate technology opportunities under uncertainty and has received increasing attention in research studying R&D decision making (e.g. Adner & Levinthal, 2004; Cuervo-Cazurra & Un, 2010; Eggers, 2012; McGrath & Nerkar, 2004; Miller & Arikan, 2004). Importantly, it allows us to compare the alternatives of licensing out or keeping the option to develop the technology in-house under conditions of uncertainty. The real option theory argues that managers base decisions on the values of their options, and these option values depend on the level of uncertainty (Dixit & Pindyck, 1994; McGrath, 1997). Higher levels of uncertainty increase the option value of a technology. Following the real option theory's prediction, we propose that a technology that experiences higher levels of uncertainty has a higher option value and is therefore more likely to be kept for internal development rather than being licensed-out.

Using the licensing literature we identify sources of uncertainty relevant to the licensing-out decisions of established firms. In particular, we investigate how uncertainty in the revenue and rent dissipation effect (Arora & Fosfuri, 2003; Fosfuri, 2006) shapes those decisions. Uncertainty is gradually resolved as technologies move along the innovation value chain towards market launch. We propose that a firm is more likely to license out technologies at later stages in their development wherein the level of uncertainty and consequently the option value of the technology have decreased. Moreover, we take into account that licensing-out decisions are not made for a technology in isolation but in conjunction with alternative technologies in the product development portfolio (Nishimura & Okada, 2014). Using the real option lens, we suggest that the marginal option value of a technology decreases, when more overlap exists with alternative technologies the firm is developing for the same commercial market. We propose that firms are more likely to license out a technology that is developed for a market for which the firm has more alternative technologies in its development portfolio and hence a smaller marginal upside potential of generating revenues. While we expect established firms to license out technologies in markets where they have substantial alternatives in their development portfolio, we expect different considerations to apply when taking into account how the technology fits with its existing commercial portfolio. In particular, we suggest that when a technology is developed for a market that is important in terms of sales generation, the firm will take into account the downside potential of nurturing a future competitor. As a result, we expect that firms are more likely to license out a technology that is developed for a market in which the firm generates lower sales relative to its overall sales portfolio.

We test our hypotheses in the pharmaceutical industry, focusing on the 57 largest pharmaceutical firms over a 15 year timespan. The pharmaceutical industry allows us to examine a firm's ongoing innovation initiatives in the form of compounds in development and to observe which compounds were ultimately licensed out and which were kept for internal development. We contrast 426 compounds licensed out by the established pharmaceutical firms between 1994 and 2008 to 9,354 compounds in development which continued to be internally developed. Our results confirm our idea that taking into account uncertainty at both the technology and the portfolio level profoundly shapes what technologies established firms ultimately license out.

Our paper makes several contributions. First, we focus on the decisions of established firms to license out technologies. Previous research has predominantly focused on smaller firms licensing out and established firms licensing-in such technologies as they are in the possession of important complementary assets in the industry (Gans & Stern, 2003; Hill & Rothaermel, 2003; Kollmer & Dowling, 2004). More importantly, the few licensing out studies have solely focused on established firms licensing out ready-to-commercialize technologies for which they can readily assess tradeoffs in generating extra revenue versus rent dissipation by a possible competitor (Arora & Fosfuri, 2003; Fosfuri, 2006). Our paper complements this work by taking into account the inherent uncertainty established firms face when making licensing-out decisions for technologies for which it remains uncertain as to whether they can be commercialized. Our study reveals that when taking into account uncertainty, the revenue effect needs to not only includes the payments from the licensee to the licensor (Arora & Fosfuri, 2003; Fosfuri, 2006), but also the amount of revenue that a technology may generate in the commercial market. With respect to the rent dissipation effect, we reveal that the decision to license out a technology is affect by the presence of existing commercial activities. An established firm may resist licensing out a technology when it anticipates potential future dissipating effects in their key commercial markets.

Second, we study the licensing-out decision of a single technology in relationship to the rest of the firm's development and sales portfolio. Prior licensing literature finds that the firm's development portfolio matters in the licensing dilemma (Chan et al., 2007; Nishimura & Okada, 2014), but has not explicitly contrasted technologies that established firms license out versus those which are kept for internal development. By using technologies as a unit of analysis in our paper, we can relate technologies to the markets for which they are developed to other ongoing development attempts by the firm. In so doing, we reveal important interdependencies in the licensing-out decisions as a firm is more likely license out a technology developed for a market for which that firm has alternative technologies in its development portfolio. Moreover, we go beyond examining the licensing-out decision in relation to a firm's development portfolio, but also take into consideration the firm's overall commercial portfolio. This allows us to explicitly consider competition and the resulting rent dissipation effect, so that we can reveal that this effect substantially shapes licensing-out decisions by established firms.

Finally, we show that real options can be a powerful lens with which to make sense of licensing-out decision faced by an established firm for technologies in development as it allows us to incorporate both uncertainty in the revenue effect and uncertainty in the rent dissipation effect. Thus far, prior literature on the application of real option theory in technology licensing studies has taken a licensee perspective (Ziedonis, 2007). We extend this literature by considering the licensor perspective.

Theoretical background

Technology licensing by established firms

Technology licensing has become a more widely used commercialization strategy in various industries characterized by rapid technological change at all stages of the innovation cycle (Anand & Khanna, 2000). A technology license consists of a contract that affords the licensee the right to exploit the technology in exchange for an up-front fee or/and royalties.

Technology licensing has mainly been studied from the point of view of a small firm. In order to profit from innovation firms need access to the complementary assets (Teece, 1986) that small firms are less likely to possess. Small firms therefore often use licensing as their main commercialization strategy (Gans & Stern, 2003; Kollmer & Dowling, 2004) while established firms, in most cases, are the licensees (Ceccagnoli & Jiang, 2013; Laursen et al., 2010; Leone & Reichstein, 2012). However, increasingly, we observe that established firms also act as licensors as they deploy external markets so that their technologies are developed by external partners. This is surprising as, theoretically, established firms do not lack complementary assets and can develop their technological innovations internally (Hill & Rothaermel, 2003).

Prior literature has found several reasons that established firms license out their technology, such as to maximize the profits of a technology (Arora & Ceccagnoli, 2006; Arora & Fosfuri, 2003; Fosfuri, 2006); to access external knowledge through cross-licensing (Kim & Vonortas, 2006); or to balance the firm's R&D pipeline (Chan et al., 2007; Nishimura & Okada, 2014). We also know that while established firms have substantial resources at their disposal, they still need to make compensatory tradeoffs as to where to allocate such resources (Cyert & March, 1963), which may further motivate their licensing-out activities. As an example, in 1995 Eli Lilly, a fully integrated worldwide pharmaceutical firm, licensed-out an anti-inflammation compound for the treatment of psoriasis that was in a Phase I stage of

development to Vanguard Medica, a privately held integrated biopharmaceutical company (now Vernalis Group). Vanguard Medica would further develop and commercialize the compound. August M. Watanabe, president of Lilly Research Laboratories discussed the firm's motivations behind the licensing deal: *"This collaboration will provide Lilly with the opportunity to drive this compound forward through the efforts of the development team at Vanguard."* From the side of Vanguard Medica, CEO Robert Mansfield added: *"This agreement with Lilly is a superb example of how a pharmaceutical company can leverage its portfolio by utilizing the development resources and expertise of Vanguard."* [4]
Hence, with this licensing out agreement Eli Lilly aimed to leverage its development portfolio by making more rapid progress in the clinical trials through the utilization of an external partner.

Having an idea as to *why* established firms license out technologies, we can begin to investigate *which* technologies established firms license out. Prior literature examines the decision as to whether or not established firms license out a technology through a profit maximization lens. From this perspective this decision entails a tradeoff in which firms balance a revenue and a rent dissipation effect (Arora & Fosfuri, 2003; Fosfuri, 2006). The revenue effect is the present value of the money that flows to the licensor in the form of licensing payments, the net of all possible transactions costs. In the case of Eli Lilly, these would be the revenues generated through for instance royalties or milestone payments from Vanguard Medica during the development and commercialization processes. The rent dissipation effect is the loss of firm profits due to the increased competition in the product market after licensing. The rent dissipation effect is smaller if the licensee is in a distant product market or in a distant geographical market in which the licensor does not operate. In addition, granting others the right to use the firm's technology may enable them to develop

[4] Source: http://www.prnewswire.co.uk/news-releases/vanguard-medica-and-eli-lilly-collaborate-on-leukotriene-antagonist-156801065.html

new products that can make the licensed technology less profitable or even obsolete. In the case of Eli Lilly, these would be the foregone substantial profits (compared to developing the compound internally) if Vanguard successfully developed and commercialized the drug, and the increased risk of losing profits due to raising an additional competitor in the market for anti-inflammation.

Despite the insights gained from this licensing framework, the profit maximization perspective makes the important assumption that the underlying technology is ready to be commercialized which would allow the potential licensing revenue and rent dissipating effects to be calculated. However, the innovation process is a highly uncertain process, takes substantial time and needs a continuous flow of resource investment to develop and ultimately commercialize a technology (Schumpeter, 1934). Product development is associated with long development lead times and low probabilities of success. For instance, in the pharmaceutical industry, only one out of six drugs that enter clinical trials makes it to the market (Girotra et al., 2007). Novel technologies therefore have the inherent challenge that their ultimate commercial potential remains uncertain, and their potential revenue and potential rent dissipating effects in product markets remain difficult to calculate.

A real option lens of licensing out under uncertainty

Throughout the paper we take careful account of the role of uncertainty in the licensing-out decisions made by established firms. This is important as technologies in development have not yet reached commercial markets and hence are characterized by substantial uncertainty about their technological feasibility and commercial viability (Anderson & Tushman, 1990; Cassimon et al., 2011; Oriani & Sobrero, 2008).

Real options theory offers a tool to evaluate investments under this uncertainty. A real options valuation goes beyond the net present value calculation as it accounts for the flexibility in decision making by the owner of a technology. The real options lens allows us to compare licensing out of a technology to keeping the option to develop that technology in-house under conditions of uncertainty. First, it is important to precisely define the real option in the licensing dilemma. Real options are investments in real assets that give the firm the right, but not the obligation to undertake certain actions in the future. In the innovation literature, a technology may be conceptualized as a real option. Completing the development of the technology creates an underlying right but not the obligation to commercialize the technology. The exercise of this option involves the additional investment needed to commercialize the technology (McGrath, 1997). Prior literature has applied this conceptualization of a technology in development as a real option in various contexts such as the high-tech industry (Eggers, 2012), manufacturing industry (Cuervo-Cazurra & Un, 2010), the pharmaceutical industry (Hartmann & Hassan, 2006; McGrath & Nerkar, 2004), universities (Ziedonis, 2007) or in cross-industry studies (Oriani & Sobrero, 2008).

An option may be traded for the price of the underlying technology, e.g. through licensing. In this context, a real option can be seen as an American call option; it can be exercised or traded any time during the technology's development trajectory (McGrath, 1997). If the firm chooses to license out the technology, it exchanges the option for licensing revenue. When the firm chooses not to license out the technology, it continues to develop the technology internally and to retain the option to exploit future internal commercialization[5].

Despite a well-developed theoretical literature and a fit to the empirical context, there has been little empirical work to verify the theory's predictions. Prior literature criticizes the real option theory for remaining ambiguous on the definition of the choice set of options, because the number of options of a firm may become unlimited (Adner & Levinthal, 2004). However, the product development portfolio of an established firm is confined to a limited number of

[5] A third possibility would be to discontinue investment in the technology. In this paper, we do not examine abandoned technologies and only take into consideration technologies in which an organization continues to invest resources.

alternatives, allowing us to apply the real options framework in a precise way. Namely, we consider each technology as a single option that can be exchanged for licensing value. Our theoretical and empirical structure, hence, allows us to capture a clear and comparable portfolio of technological options internally available to the established firm.

Key to real option reasoning is the insight that when the level of uncertainty is higher, the option value increases (Dixit & Pindyck, 1994). Uncertainty means that there is an upside as well as a downside potential associated with the technology. Since firms are flexible in terms of licensing, shelving, or aborting the development of the technology, holding an option of internal commercialization open allows them to exploit the upside potential of the technology when future conditions turn favorable while keeping the downside risk controllable when future conditions turn adverse. Consequently, the distribution of gains and losses of internal commercialization of technology has a favorably asymmetric shape. This asymmetric effect of uncertainty on the upside potential and downside risk raises the value of the option embedded in the technology.

In this study, we argue that high levels of uncertainty increase a technology's option value making a technology more attractive to keep for internal commercialization and less attractive for licensing out. More specifically, we focus on uncertainty in the amount of revenue and competition that a technology might generate. The first source considers the uncertainty regarding whether a technology in development will make it to the market, and if the technology is commercialized how much revenue it will generate. Hence, when we speak about uncertainty in the commercial potential of a technology, we not only consider the uncertainty in the licensing payments that the licensor will receive, but we predominantly speak about the uncertainty in the amount of revenue that a technology may generate in the product market. This is in sync with prior studies that show that from a licensee's point of view the uncertainty in the commercial potential of a technology increases this technology's option value and hence its likelihood to be licensed-in by a licensee (Ziedonis, 2007).

Furthermore, in addition to uncertainty in the commercial potential of the technology we also consider the effect of uncertainty in the amount of competition that a licensed technology might generate on the licensing-out decision. This type of uncertainty entails the downside potential of losing competitive advantage to the licensee.

Hypothesis development

We focus on three lenses to study the licensing-out decision under uncertainty. First, we analyze the licensing-out decision for a technology in isolation. Next, we study the technology in a context of the firm's development portfolio. Finally, we look at the competitive aspect of licensing by relating a technology to the firm's commercial portfolio.

The stage of development and the licensing-out decision

Once invented, a technology is not immediately ready to commercialize. It needs to go through a development and commercialization process before it can be launched on the market (Schumpeter, 1934). The distinction between invention (creation of new knowledge) and innovation (commercialization of new knowledge) allows us to understand the uncertainty that established firms face in translating their technology into product innovations. Prior literature has decomposed uncertainty relevant to innovation into commercial and technological uncertainty (Cassimon et al., 2011; Oriani & Sobrero, 2008). Commercial uncertainty refers to the variability of the expected level of demand for the firm's technology once it reaches the market. It may, for instance, entail uncertainty in potential market size, expected revenues, and expected cost structure (Cassimon et al., 2011) Technological uncertainty refers to uncertainty as to whether or not a technology will reach the market. It may entail the uncertainty of scientific feasibility (Cassimon et al., 2011) or the uncertainty of becoming the industry standard (Anderson & Tushman, 1990). These types of uncertainty in assessing the relationship between R&D investments and the expected economic pay-off of the technology are complicated. It is difficult to predict whether the technology will make it to the market, and if commercialized, how much revenue and competition the technology will generate.

We expect that, for a technology in an early stage of development, it is more difficult to assess its commercial potential than for a later-stage technology. An early-stage technology is more distant from the market than one in a later stage, and it is therefore subject to more technological and commercial uncertainty. For early-stage technology there are more diverse directions for potential research than for later-stage technology, because prior technological choices lock firms into development trajectories (Nelson, 1961). Managers may have crude estimates as to which markets to target, how much revenue an early-stage technology may generate, and how much competition the firm will face in the future market, but these estimates are often highly unreliable. However, over time the accuracy of these estimates improves as technological and commercial uncertainty resolve over time.

A key insight generated by the real options approach to investment is that higher uncertainty in the payoffs of the investment increases the value of managerial flexibility, or the value of the real option (Dixit & Pindyck, 1994). The intuition is that with higher payoff uncertainty, flexibility has a greater potential of enhancing the upside while limiting the downside potential. Using real option reasoning, we argue that higher uncertainty increases the option value of a technology. The higher option value makes a technology more attractive for in-house commercialization. Hence, an early-stage technology is more likely to be kept for in-house commercialization and less likely to be licensed-out than a later-stage technology.

Hypothesis 1: A firm is more likely to license out a technology that is in a later stage of development than a technology that is in an early stage of development.

The development portfolio and the licensing-out decision

The first hypothesis considers a technology in isolation but, in most cases the decision to license out a technology is made in the context of other technologies in development. Established firms often work on many projects across many markets. Prior research has shown that such a portfolio approach helps to increase innovative performance, because it increases the likelihood of developing a successful product for a certain market within a reasonable time frame (Nelson, 1961); allows for hedging against risk in case of individual project failure (Girotra et al., 2007); and permits investment decisions to be based on more information as firms are able to compare technologies and decisions can be made earlier when costs of R&D are still relatively low (Frankort et al., 2012). Hence, decisions about making investments in R&D are usually made in the context of a portfolio of other competing investments. Hence, we consider the technology relative to other technologies in the firm's development portfolio when analyzing the licensing-out decision.

By developing multiple technologies for the same market, firm increase the probability of having at least one successful technology for a given market (Girotra et al., 2007). For instance, in the pharmaceutical industry, firms typically introduce the first compound that passes clinical trials, and then cease development of all other drugs targeted toward this market, because introducing several drugs for the same medical need earns the same sales as introducing only one successful compound (Ding & Eliashberg, 2002). Decisions about making R&D investments are therefore made in the context of a portfolio of other competing investments. Because options in a portfolio interact, making a decision with respect to one option affects the value of other options. When a portfolio is sub-additive with regard to its option value, the value of a portfolio of real options is less than the value of the options if they were independent (Vassolo et al., 2004). This can occur when solutions offered by different technologies to the market's challenges overlap. Some targeted markets are more represented by technologies than others, leading to redundancies. The option values of technologies developed for markets with many alternative technologies in the firm's development portfolio are more likely to overlap. This makes a technology developed for markets with many other alternatives more likely to be licensed out, because it has a lower marginal option value.

In addition, a firm is more likely to find a solution to the market's challenges in markets with many alternative technologies than in areas in which it has fewer development alternatives. Hence, a firm experiences less revenue uncertainty for technologies developed for markets with many alternative technologies, because it is more certain to obtain revenue given the large number of alternative technologies. A firm is therefore more likely to license out a technology when the firm retains sufficient alternative technologies to commercialize.

The portfolio of alternatives also shapes how well firms may evaluate and understand a focal technology. When a firm has many technologies in its development portfolio for a certain market, it is able to compare technologies and more accurately predict their commercial potential relative to the other technologies, which decreases the uncertainty in the technology's potential (Ziedonis, 2007). More technologies addressing the same market problem allow specialization of knowledge in distinct domains, which shapes the firm's evaluative capability. Cohen and Levinthal (1990) find that firms undertake R&D in order to improve their capability to monitor, assimilate, and exploit new technologies. Conversely, a lack of technological knowledge results in a high level of uncertainty concerning the technology's commercial potential due to the firm's inability to evaluate the commercial potential of technologies. From a licensee perspective, Ziedonis (2007) finds that licensees are less likely to license technology when they are less able to evaluate the technology's commercial potential. This is particularly relevant for technologies which have not yet been commercialized as a licensor without a strong development portfolio in a market domain may not be able to evaluate the commercial potential of the technology. This results in more uncertainty, thus increasing the option value of the technology while decreasing the likelihood that the firm licenses out that technology.

Finally, overlapping technologies not only dampen portfolio returns in good times, but market-specific common shocks make these technologies less effective hedges against downside risks in bad times (Li & Chi, 2013). Having many alternative technologies in the same market increases the downside potential when such a negative market shock occurs. This risk of common market shocks decreases the option values of technologies developed for a market with many alternatives technologies more than the option values of technologies developed for a market with fewer alternatives. Hence, a technology developed for a market with many alternative technologies is more likely to be licensed-out.

Hypothesis 2: A firm is more likely to license out a technology that is developed for a market for which the firm has more alternative technologies in its development portfolio.

The commercial portfolio and the licensing-out decision

In the second hypothesis we consider the technology relative to other technologies in the firm's development portfolio. We now consider the importance of a technology relative to the firm's sales portfolio in order to include the effect of licensing on the amount of competition into the licensing decision.

Innovation is not done in isolation; firms compete with other innovating firms for revenue. Firms do not have monopolistic access to innovation opportunities (Kulatilaka & Perotti, 1998) and failing to invest in a technology may lead some other firm to seize the opportunity. Prior literature finds that more competition stimulates firms to invest in technology options, because the fear of preemption decreases the value of the option to delay investment (Aguerrevere, 2009). Licensing could nurture competition, because giving a technology away may mean establishing the next competitor when this competitor successfully commercializes that technology. Hence, competition encourages the firm to retain technology options for internal commercialization.

Furthermore, a key premise of real options reasoning is that investments are sequential. Licensing out technology means that a firm stops investing in that technology. Failing to make an investment when others are investing creates the potential for lagging behind in the innovation race or even for a subsequent lock-out (Cohen & Levinthal, 1990). Hence, licensing out technology may lead to a downside potential that the firm will run behind in technology development compared to its competitors.

In addition, when licensing out a technology, the firm not only risks increased competition, but also chances weakening its ability to profit from technologies compared to competitors. Teece (1986) argues that a firm derives the maximum benefit from its technological achievements if it also possesses an appropriate set of complementary assets that improve its ability to manufacture, market, and distribute its new products. A firm's experience with product markets develops these complementary assets (Roberts & McEvily, 2005). Licensing out technology hampers the firm's development of complementary assets, and it also gives competitors the opportunity to develop its own set of complementary assets. Thus, the firm loses competitive advantage due to a weakened position in complementary assets.

In summary, when licensing out a technology, a firm risks increased competition, lagging behind in the innovation race, and weakening its ability to profit from innovation relative to the competitors. We argue that licensing out technology occurs more in markets in which the firm generates less sales relative to the firm's overall sales. These markets with relatively low sales may be considered as less important to the firm as they entail a more peripheral part of the firm's business. We expect higher resistance to licensing out technology in markets that are part of the firm's core business, as firms have more profit to lose to competition. The downside potential of licensing out of a technology meant to generate sales in a firm's peripheral business is smaller than the downside potential of a technology in market that is more central to the firm's business. Hence, competition is less likely to increase the option value of a technology developed for a more peripheral market making it less attractive to keep for internal commercialization and more likely to be licensed-out then a technology developed for a market that is more core to the firm's business. We therefore hypothesize that a technology that is developed for a market in which the firm generates relatively less sales is more likely to be licensed-out.

Hypothesis 3: A firm is more likely to license out a technology that is developed for a market that constitutes a low percentage of its overall sales.

Method

Context

We chose to conduct our study in the context of the pharmaceutical industry. In the pharmaceutical industry, technology licensing is a common practice. Traditionally, small innovative biotechnology firms license their technology to established firms having the requisite complementary assets while established firms license-in. However, over the past decades, we have observed a trend of established pharmaceutical firms licensing out their technologies as well. Firms such as Merck[6] and Abbott[7] have set up separate organizational units that are concerned with licensing practices. The number of licensing deals by established pharmaceutical firms increased substantially in the last decades (46% during the years 1994 to 2008[8]). These firms do not only license out ready-to-commercialize technology (i.e. approved drugs); a substantial proportion of the licensing deals (41%) involve technology in

[6] http://www.merck.com/licensing/
[7] http://www.abbott.com/partners/licensing.html
[8] Source: RECAP database

development [9](i.e. drugs in preclinical to clinical trials). The pharmaceutical industry therefore provides us with a sample of established firms that license out technology in development which enabled us to test our hypotheses. We focused our analysis on established pharmaceutical firms that were among the top 50 list of largest pharmaceutical firms based on sales during the years 1994 and 1999 and tracked their licensing out activities up to the year 2008. Initially, we considered 73 firms that were all active in licensing.

Second, the pharmaceutical industry allowed us to analyze the licensing-out decision using the technology as the unit of analysis. Namely, we were able to examine the product development portfolio of a firm and then identify which compounds firms opted to license out to other firms.

Finally, this industry allows us to track a range of rich characteristics of technologies in development. The product cycle is heavily regulated, making it necessary for firms to disclose substantial details about the product development initiatives.

Our dataset combined licensing data from the Recombinant Capital Biotech Alliance Database (Recap) database, product development data from the Pharma Projects database, and pharmaceutical sales data from the Evaluate database.

Sampling

Using the Recap database, we identified 871 licensing deals in which one of the 73 established firms licensed out a technology that was still in a development stage (i.e., in a preclinical or clinical trial). Hence, for the purpose of our study, the initial sample included neither ready-to-commercialize technology (i.e., approved drugs) nor technology for exploratory knowledge sharing (i.e., projects in a discovery or lead molecule phase).

[9] Source: RECAP database

We merged this licensing deal information with technology data from the Pharma Projects database. This database provided us with detailed information on the nature of the technology, its stage of development, and its potential therapeutic applications. In addition, we gathered sales data of the pharmaceutical firms from the Evaluate database to track the amount of sales generated in a technology's market.

We excluded licensing deals from our initial sample when we found no match of the licensed technology in the Recap database with the technologies in the Pharma Projects database. Another sample selection criterion was to only include licensing deals between the years 1994 and 2008. After deleting deals with missing data, our final sample contained 325 licensing deals from 57 established firms. Within a single licensing deal, multiple technologies can be licensed out. Our sample of 325 licensing deals contained 426 technologies that were licensed out.

Next, we complemented the dataset by adding technologies that were in the firm's portfolio in the year that a technology was licensed out. This made it possible to contrast the 426 licensed-out technologies to 9,354 technologies that were in the firm's development portfolio but that were not licensed out that year. Hence, our total sample contained 9,780 technology-year observations. Note that these 9,780 compounds are not unique compounds. We made cross sections of the firm's development portfolio in the year a licensing deal took place; a compound may therefore appear multiple times in our dataset as it may be part of the firm's portfolio over multiple years. Our dataset contains 5,043 unique compounds.

We had the opportunity to exploit the time dimension by creating panel data of the 57 firms over the years 1994 to 2008. There are two reasons that we aggregated the data into cross-sectional data. First, some variables, such as the 'alternatives in technology's market' and 'sales in technology's market', vary little from year to year. The low variance in the explanatory variables makes it difficult to test the relationships between dependent and explanatory variables. Second, our sample contains a low number of licensed technologies (4.3%). Transforming our cross-sectional data into panel data would mean that we created more 'no-licensing events' making the licensing event rarely to occur. Again, it would be more difficult to test the relationships between dependent and explanatory variables when the dependent variable highly skewed towards zero.

Dependent variable

The dependent variable of interest is the probability that a firm licenses its technology. In our dataset, firms license on average 4.3% of their overall development portfolio. Given the binary nature of our dependent variable, we modeled the technology licensing probability with a logit model as specified in (1):

$$P(Y_i = 1|X_i) = \frac{\exp(X_i\beta)}{1 + \exp(X_i\beta)} \quad (1)$$

where Y_i is a binary variable measuring whether a technology is licensed out or not, and X_i is a vector of independent variables and control variables. We estimated the model parameter β by using the maximum likelihood estimation method.

Independent variables

Stage of development: We defined the stage of development as a continuous variable. The value 0 indicates the preclinical phase, the value 1 indicates Phase I, the value 2 indicates Phase II, and the value 3 indicates a Phase III technology. In the preclinical phase, compounds are tested on animal models to uncover any possible safety concerns before testing on humans to determine if the drug's intended effects are strong enough to be worth human testing. In the next stage, Phase I, small amounts of the drug are administered to willing, healthy human participants to evaluate drug stability, dosage, and any side effects. In Phase II, the drug is tested on a relatively small sample of both healthy and diseased humans. In Phase III, the drug is tested on a large number of patients. Finally, after completing development, drugs are submitted for review by regulatory agencies and made ready for market launch.

Alternatives in technology's market: Established pharmaceutical firms have multiple compounds in their development portfolios aimed at the same market. Yet, for some markets, firms have more technologies in their development portfolio than for other markets. As a measure for the number of alternative technologies in a certain market, we constructed the variable 'alternatives in technology's market'. We used the 11 market categories (therapeutic areas) defined in Pharma Projects (alimentary/metabolic products, blood and clotting products, cardiovascular products, dermatological products, genitourinary products, hormonal products, anti-infective products, anticancer products, musculoskeletal products, neurological products, respiratory products, and sensory products). 'Alternatives in technology's market' is defined as the number of technologies in the same market category as the focal technology in year t as a percentage of the total number of technologies in all market categories in year t. We chose not to use an absolute number of alternative technologies, because this makes a comparison of development portfolios between firms difficult. The 'alternatives in technology's market' variable ranges for all firms between 0 and 1, displaying a spectrum of having 0% of the technologies developed for a certain market to having 100% of the technologies developed for a certain market.

Sales in technology's market: Established pharmaceutical companies generate sales in different markets. As a measure for the amount of sales relative to the sales portfolio, we constructed the variable 'sales in technology's market'. For this, we again used the 11 market categories defined in Pharma Projects. The 'sales in technology's market' variable is measured as the firm's amount of sales in market m in year t relative to the firm's total amount of sales in year t. It ranges for all firms fell between 0 and 1, displaying a spectrum of having 0% of the sales generated in a certain market to having 100% of the sales generated in a certain market.

Control variables

Market share: Prior literature argued that there is a direct effect of the licensor's market share in the product market on its incentive to license, because of its impact on the amount of competition (Fosfuri, 2006). Firms that have a high market share risk losing more profit. The downside potential of licensing is larger for firms with high market shares, making them less likely to license out technology than firms with a low market share. The firm's market share is measured as the amount of sales of a firm in market m in year t relative to the total sales of all pharmaceutical firms in market m in year t. We again used the 11 market categories defined in the Pharma Projects database to compute the product market share.

Demand growth: A rising demand creates more profit potential in the market and therefore may decrease the negative effect on the licensor's profits due to increased competition. We expected to observe a positive relationship between demand growth and the technology licensing probability. We used sales as a proxy for demand and growth rate measure for demand growth, because this measure is comparable across markets as we corrected for market size. Demand growth is measured as the difference between the sales of all pharmaceutical firms in market m in year t and the sales of all pharmaceutical firms in market m in year $t-1$ as a percentage of the sales of all pharmaceutical firms in market m in year $t-1$. We used sales data from the Evaluate database and grouped these sales data into the 11 market categories defined earlier.

Firm size: Like Fosfuri (2006), we controlled for the effect of firm size on the technology licensing probability. Larger firms may have stronger bargaining power in licensing negotiation, which may give these firms a greater incentive to license out technology. We followed Fosfuri's proxy for firm size, and used aggregated sales, which were measured as the logarithm of the total sales of a firm in year t.

Market effects: To control for market heterogeneity (e.g., the cardiovascular versus neurology market), we included 10 binary variables indicating the 11 market categories.

Technology effects: Pharmaceutical firms work on different types of technologies, such as biological compounds, chemical compounds, gene therapies, natural products, or molecular antibodies. To control for technology heterogeneity, we included 6 binary variables to capture the 7 technology categories defined in Pharma Projects (BI-OTHER, BI-P, CH, CH-SY-P, GT, MAB, NP, REC, and SC).

Firm and year effects: We included 56 binary variables to control for firm-specific heterogeneity and 14 binary variables to control for year-specific heterogeneity.

Results

In Table 1, we report the means, standard deviations and correlations among the dependent, independent, and control variables. In our sample, 4.3% of the technologies are licensed out.

Table 1. Descriptive statistics

Variable	Mean	S.D.	1	2	3	4	5	6
1. Technology licensing probability	0.043	0.204						
2. Stage of development	0.936	1.093	0.060					
3. Alternatives in technology's market	0.191	0.130	0.104	0.030				
4. Sales in technology's market	0.126	0.149	-0.016	0.007	0.340			
5. Market share	0.036	0.052	-0.059	-0.009	0.037	0.500		
6. Demand growth	0.094	0.089	0.008	0.018	0.079	0.051	0.006	
7. Firm's total sales (log)	8.127	3.002	-0.023	-0.010	-0.108	0.031	0.364	-0.013

Table 2 shows the results of the logistic regressions on the probability that a technology is licensed using the data from the pharmaceutical industry. Model 1 omits the covariates of interest, showing only the baseline model with the control variables. Models 2-4 show the regression results for one of the covariates of interest and the control variables. Model 5 shows the full model with all independent variables of interest.

Hypothesis 1 predicted that firms are more likely to license out a later-stage technology than an early-stage technology. We expected a positive coefficient for the stage of development variable. In both model 2 and in the full model 5, we find positive and significant effects at a significance level smaller than 0.01. The effect sizes and standard errors of the stage of development variable are similar in models 2 and 5, indicating a stable result. These findings support hypothesis 1.

Hypothesis 2 predicted that a firm is more likely to license out a technology that is developed for a market for which the firm has more alternative technologies in its development portfolio. We expected a positive coefficient for the variable 'alternatives in technology's market'. This variable is a proxy for the relative number of alternative technologies in the firm's development portfolio. In both model 3 and model 5, we find positive and significant effects at a significance level smaller than 0.01. The effect sizes and standard errors of the 'alternatives in technology's market' variable are similar in models 3 and 5, indicating a stable result. These findings support hypothesis 2.

Hypothesis 3 predicted that a firm is more likely to license out a technology that is developed for a market in which the firm generates less sales relative to their sales portfolio. We expected a negative coefficient for the variable 'sales in technology's market'. This variable is a proxy for the amount of sales in the technology's market relative to the sales portfolio. In both models 4 and 5, we find the expected negative sign. The standard errors are similar in models 4 and 5, but the effect size is more negative in model 5 than in model 4. Hence, we find a non-significant negative effect of 'sales in technology's market' in model 4, and a significant negative effect at a 0.05 significance level in model 5. A possible explanation for these unstable results might be the strong correlation between the 'sales in technology's market' and market share variables, as shown in Table 1. The model estimates show that the effect size of market share becomes less negative and standard errors slightly increase when the 'sales in technology's market' variable is added in model 4 and 5. Comparing the model fit parameters of models 1 and 4, we see that the model only slightly improves when the 'sales in technology's market' variable is added to the model with control variables only. The variance inflation factors (VIF) for the 'sales in technology's market' and market share variables are 1.58 and 1.62 respectively. Both VIF values are below a critical threshold of 5, indicating that the multicollinearity problem is not severe. As a robustness check, we estimated a model with the 'sales in technology's market' variable and the control variables, omitting the market share variable. The effect size of the 'sales in technology's market' variable is -1.164 and its standard error is 0.352. In this model, the variable is negative and significant at a 0.01 significance level. Including the market share variable in the model makes the size of the sales development portfolio coefficient less negative, but does not influence the sign of the coefficient. Hence, we find support for hypothesis 3, although the effect of 'sales in technology's market' on the licensing probability overlaps with the effect of the market share variable. We will discuss this result in more detail in the discussion session.

For the control variable market share, we find a negative and significant coefficient. This complements the finding of Fosfuri (2006), who also found a negative and significant effect of market share on the technology licensing rate of ready-to-commercialize technology. We find the same effect for technologies in development. For the control variable, demand growth, we find a positive but not significant coefficient. This finding does not contradict the findings of Fosfuri (2006), who found a positive and significant effect of demand growth. For the control variable, firm's total sales, we find a non-significant effect on the technology licensing rate, a result also found by Fosfuri (2006).

We conducted a number of robustness checks, the results of which can be found in the appendix. First, given that only 4.3% of the technology in our dataset is licensed out, we used the complementary log-log model to correct for potential biases for rare events. We find no differences in signs and significance between the logit and complementary log-log model. Second, we standardized the variables to control for potential multicollinearity. We find that the sign and the significance of the coefficients do not change. The overlapping effects of the variables 'sales in technology's market' and market share do not have an effect on the sign of the coefficients. We also mean-centered the variables and this led to similar results. We will discuss the correlation between the two variables in more detail in the discussion session. Third, we conducted the logistic regression analysis with data on a licensing deal level instead of an analysis with data on the technology level. For most of the observations in our dataset, a technology had a one-to-one relation with a licensing deal. However, some of the licensing deals comprised multiple technologies, in which case, we took the covariate values of the technology that was most advanced in its development. We excluded 101 technologies that were part of licensing deals with one or more other technologies from the sample. We find no differences between the results based on deal level data and the results based on technology level data.

Table 2. Logistic regression results for the technology licensing probability

Model	(1)		(2)		(3)		(4)		(5)	
Constant	-5.176	***	-5.401	***	-5.774	***	-5.102	***	-5.959	***
	(0.737)		(0.740)		(0.757)		(0.738)		(0.763)	
Stage of development *(H1)*			0.204	***					0.211	***
			(0.046)						(0.046)	
Alternatives in the technology's market *(H2)*					2.179	***			2.448	***
					(0.497)				(0.509)	
Sales in the technology's market *(H3)*							-0.522		-0.980	**
							(0.436)		(0.453)	
Market share	-5.844	***	-5.648	***	-6.974	***	-4.400	**	-4.152	**
	(1.585)		(1.595)		(1.664)		(1.968)		(2.025)	
Demand growth	0.471		0.383		0.444		0.504		0.443	
	(0.745)		(0.749)		(0.750)		(0.747)		(0.757)	
Firm's total sales (log)	0.015		0.018		0.017		0.010		0.014	
	(0.035)		(0.035)		(0.034)		(0.035)		(0.034)	
Market effects	yes		yes		yes		yes		yes	
Technology effects	yes		yes		yes		yes		yes	
Firm effects	yes		yes		yes		yes		yes	
Year effects	yes		yes		yes		yes		yes	
N	9,780		9,780		9,780		9,780		9,780	
Log-likelihood	-1,588		-1,578		-1,577		-1,587		-1,565	
Chi-squared	328		347		348		329		373	
Pseudo R^2	0.094		0.099		0.099		0.094		0.107	

*p<0.1; ** p<0.05; *** p<0.01

Conclusion, discussion and implications

In this study, we aimed to investigate the role of uncertainty in the licensing dilemma by using the real options theory. We tested the idea that technologies with a higher level of uncertainty have a higher option value and are therefore more likely to be kept by the firm for internal commercialization instead of being licensed out. We also did not only consider the licensing-out decision for a technology in isolation but also as part of the development and sales portfolio.

We found that a firm is more likely license out technologies at later stages in their development where the level of uncertainty and, consequently, the option value of the technology have decreased. We also found that a firm is more likely to license out a technology developed for a market for which the firm has alternative technologies in its development portfolio, because the option values of the technologies may overlap. Conversely, a firm is more likely to license out a technology developed for a market in which the firm generates less sales relative to the sales portfolio because of the lower downside potential of being attacked by competition in the firm's core business. However, this latter effect is difficult to distinguish from the effect that a firm's market share has on the licensing probability. We also found that firms are more likely to license out a technology that is developed for a market in which the firm has a low market share. One explanation of these overlapping results is the similarity in the way we measured the dependent variables. We used the amount of sales in a certain market relative to the firm's total amount of sales in all markets to test hypothesis 3, while we used the amount of sales in a certain market relative to the total amount of sales of all competitors in that market. Hence, the numerator of the two measures is the same, which explains the high correlation between the two variables. Another explanation is that the amount of sales relative to the firm's sales portfolio and the firm's market share both represent a similar argument to explain their effect on probability of licensing out. Markets with relatively low sales as well as those with a relatively low market share may be considered less important to the firm as they entail a more peripheral part of the firm's business. We expect higher resistance to licensing out technology in markets that are part of the firm's core business, as firms have more profit to lose to competition. When both variables are included in the model, their effect sizes become less negative, which may due to the possibility that both variables explain the same part of the variance in the licensing-out probability.

Our study also has several limitations. First, we restricted our sample to established firms in the pharmaceutical industry. In the pharmaceutical industry, the market position of established pharmaceutical firms has remained stable over the years, with only small changes in market leadership (Gans & Stern, 2003). The effect of licensing on competition that we studied in the pharmaceutical context may therefore be different in a context where there is less stability in established firms' market share, because the competition is more dynamic. Future research may aim to study the licensing dilemma in industries wherein market shares of established firms are less stable.

Finally, our analysis focused on technology in development, i.e., technology that has not generated any sales in the commercial market. Future research may study the role of uncertainty in the licensing decision for ready-to-commercialize technology. We know little about what sources of uncertainty might influence the licensing decision for this type of technology.

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