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Profiting from technological capabilities:

Technology commercialization strategy in a dynamic context

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Abstract

Profiting from technological capabilities: Technology commercialization strategy in a dynamic context

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This paper analyzes the technology commercialization strategy of an innovating firm when the incumbent firms possess specialized commercialization capabilities. According to the predominant framework, if the innovation is protected by a strong appropriabilty regime the optimal strategy is to license the innovation to an incumbent product firm. This paper argues by contrast that if the innovating firm has the ability to learn from its commercialization experience, its optimal strategy may be to commercialize alone or to pursue a hybrid arrangement (called co-promotion) whereby it licenses the innovation but retains the rights to participate in the commercialization process. The paper develops a game-theoretic model of the technology commercialization process and derives the conditions under which these different strategies are equilibrium outcomes. It then uses these to explain the pattern of arrangements pursued by biotech firms attempting to commercialize products in the pharmaceutical industry between 1978 and 2008. The results show that a firm is significantly more likely to use the hybrid strategy when there is a higher probability of commercializing a subsequent product in the same product field in future, when there are more firms competing to license the innovation, and when it is in a stronger financial position.

Keywords: technology commercialization, biotech, applied game theory, biotechnology, capabilites, innovation, entrepreneurship

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1. Introduction

A critical decision facing a technology-based firm that has generated an innovation is how to access the complementary assets necessary to bring a product to market. According to the framework developed by Teece (1986), if the innovation is protected by a tight appropriabilty regime but the innovating firm is in a disadvantaged position relative to the incumbent product firms with respect to those assets, an innovating firm's optimal strategy is to license the commercialize rights to an incumbent product. The alternative – integrating downstream into the complementary activities – is not only more risky but may also delay commercialization, reducing the rents it can capture from the innovation. Nevertheless, in exchange for access to the product firm's complementary assets, the innovating firm must share the returns from its innovation, and it remains in a disadvantaged position for commercializing subsequent innovations. If it does this for successive innovations it is unlikely to earn superior profits over the long term.[1]

In this paper I show that, when the innovating firm has specialized technological capabilities, so that it expects to innovate repeatedly in a particular field, and it has the ability to learn from its experience in the commercialization process, it may be better off commercializing alone. Moreover, under certain conditions its optimal strategy may be to pursue a hybrid between these two: contracting for access to the complementary assets but retaining rights to participate in the commercialization process.

To understand what drives the innovating firm's choice between these alternative commercialization strategies, I develop a dynamic game-theoretic model of a technology firm choosing its strategy in the situation where it has the opportunity to learn from its own commercialization experience and acquire capabilities from which it may benefit in subsequent commercialization attempts. I use the model to derive the conditions under which the both the innovating firm and an established product firm are willing to agree to a co-promotion arrangement vis-à-vis the traditional or "pure" licensing arrangement, or when the firms do not reach an agreement and the biotech firm attempts to commercialize the innovation alone.

I then use the conditions derived from the model to explain the pattern of technology commercialization arrangements pursued by biotech firms attempting to bring innovations to the pharmaceutical product market. Licensing has been the predominant commercialization mode since

[1] By superior profits I mean earnings above the costs of factor inputs that reward innovators for engaging in the uncertain process of innovation, or what are sometimes referred to as Schumpeterian rents.

the inception of the biopharmaceutical industry in 1978. However, in recent years, biotech firms have sought increasingly to retain rights to participate in the marketing and sales process in alliances with pharmaceutical firms (an arrangement known as "co-promotion"). I report evidence from interviews with biotech executives that suggest this arrangement is part of a strategy by which the biotech firms learn about the commercialization process and thereby acquire the capabilities necessary to commercialize future innovations alone. I then analyze the technology commercialization arrangements used in a dataset of 1591 instances in which a biotech firm held U.S. marketing rights to an identifiable biopharmaceutical product that was in clinical trials between 1978 and 2008. The results show that a biotech firm is significantly more likely to enter a co-promotion arrangement when there is a higher probability of commercializing a subsequent product in the same product field in future, when there are more firms competing to license the innovation, and when it is in a stronger financial position.

The next section explains this paper's relationship to the prior literature on technology commercialization strategy and alliance structure. Section 3 presents the model of a technology-based firm choosing its commercialization strategy and derives the conditions under which two firms are likely to agree to co-promotion. Section 4 describes the empirical analysis of the pattern of technology commercialization arrangements in the biopharmaceutical industry. I conclude in section 5 with implications for managers.

2. Related literature

The paper builds on the framework proposed by Teece in his seminal paper on "Profiting from Technological Innovation" (Teece, 1986). Teece framed the innovating firm's strategic decision as a choice between contracting with an established firm and integrating into the complementary assets to do the commercialization alone, and emphasized the role of the appropriabilty regime surrounding the innovation and the innovating firm's position relative to the complementary assets. He argued that if the innovating firm has tight appropriabilty over its innovation but the established product firms are better positioned with respect to the complementary assets then the innovating firm's optimal strategy is to contract with an established firm to commercialize the innovation. However, since the innovating firm innovates only once, Teece did not consider how the firm's choice of commercialization mode might affect its options for commercializing future innovations. Moreover, although he acknowledges that the innovating firm that contracts for access will have to share profits with the holders of the complementary assets, Teece did not explain how a technology-based firm can overcome its disadvantaged position and thereby earn superior profits over the long term. Furthermore, although Teece mentions that firms may use "mixed modes" in transitional phases (Teece, 1986, p.298), he did not explicitly consider how a firm may use a hybrid arrangement to establish a position of sustainable competitive advantage.

Subsequent research building on the Teece framework has concentrated primarily on how the firm's appropriabilty regime impacts the choice of commercialization strategy. In particular, Gans, Hsu & Stern (2002) and Gans & Stern (2003) posit that the innovating firm's ability to prevent a potential partner from imitating or 'inventing around' the innovation affects their relative bargaining power and therefore the range of commercialization strategies available to the innovating firm. However, they presume that the firms' positions relative to the complementary assets are fixed. (See also Arora & Merges (2004) for a formal treatment of the relationship between appropriabilty and commercialization strategy.)

One paper that focuses on how an innovating firm may strengthen its position relative to the requisite complementary assets is Jacobides, Knudsen, & Augier (2006). The authors argue that an innovating firm is unable to affect its position directly through a bilateral relationship with the holders of those assets, but may instead be able to use mechanisms such as standards-setting bodies to influence the industry architecture and thereby strengthen its position relative to the complementary assets. By contrast, this paper demonstrates how an innovating firm can strengthen its position directly though the way it structures its bilateral relationship with a firm that holds those assets.

This paper also contributes to the literature on the structure of alliance contracts. Most of the existing literature which has examined the structure of these arrangements in any detail has analyzed how they balance mitigating contractual hazards (governance) with providing the right incentives for investment (Pisano, 1989; Williamson, 1991; Oxley, 1997). A parallel literature, building on the 'property rights' framework (Grossman & Hart, 1986; Hart & Moore, 1990), has studied the extent to which contracts are designed to give the parties the optimal incentives for effort (e.g., Elfenbein & Lerner, 2003) and how their ability to do so is limited by the firms' financial position and/or relative bargaining power (e.g., Aghion & Tirole, 1994; Lerner & Merges, 1998; Higgins, 2007). Although interview research (discussed below) suggests that achieving governance and providing incentives are relevant considerations in this context, it reveals that the technology firm's primary motivation for retaining rights to participate in the commercialization process is acquiring the knowledge necessary to commercialize future products alone.

There is a large literature on learning through alliances (see, for instance, Hamel, 1991; Khanna, Gulati, & Nohria, 1998; Oxley & Sampson, 2004), a subset of which focuses on how the structure of

the alliance may affect learning (Kogut, 1988; Mowery, Oxley, & Silverman, 1996).[2] However, this literature is primarily focused on horizontal, 'knowledge sharing' alliances (in the parlance of Grant & Baden-Fuller, 2004) between firms with complementary technological portfolios, such as international technology alliances, in which learning from the other firm is the primary objective. By contrast, this paper focuses on the structure of vertical arrangements may affect learning, even when the primary objective is 'accessing' knowledge.

3. Theory and Hypothesis Development

In order to analyze the innovating firm's commercialization strategy in a context where it generates successive innovations, I develop a dynamic game-theoretic model of the technology commercialization process.

The set-up of the model is based on Gans (2010), which in turn builds on a framework developed by Segal & Whinston (2007). However, while Gans examined how the innovating firm's choice of commercialization mode affects its *ability to innovate in future periods* (and Segal & Whinston studied how *market concentration affected the incentive to innovate*), the model here is designed to analyze how the firm's choice of commercialization mode affects the firm's *ability to capture value from future innovations*. The structure of the technology commercialization game has been changed to more closely resemble the situation that exists in biotechnology industry and similar environments.

The value of building the model of the technology commercialization process is that it explicitly incorporates two important features of the environment that are difficult to analyze intuitively: (1) the dynamic nature of the environment, in which the technology firm learns from its commercialization experience; and (2) the strategic interaction between the technology and product firms in negotiating a commercialization agreement. Incorporating these two features makes it possible to be more precise about the specific conditions under which the technology firm will pursue the alternative commercialization strategies and thereby to generate insights that are not intuitively obvious.

[2] Kogut (1988) argues that joint ventures may be more effective for achieving knowledge transfer while Mowery at al (1996) show empirically that firms are more likely to achieve technological transfer through bilateral (vs unilateral) contracts.

3.1 Model Setup

The model contains a single technology firm (T) and N identical product firms ($P_1, \ldots, P_N$). T has generic technological capabilities, which enable it to generate innovations relating to a broad range of product fields, while each of the product firms P_i has technological capabilities that are specialized to the particular product field. At the same time, each of the product firms P_i has capabilities in commercialization (i.e., development and marketing) that are specialized to the particular product field while (at least initially) T has no special commercialization capabilities. All firms engage in innovation each period. However, while each of the product firms P_i generates innovation in the particular field with certainty, T generates an innovation related to the particular product field only with probability $\phi \in (0,1]$.[3]

This set up reflects the nature of the biopharmaceutical industry, where biotech firms tend to have broader technological knowledge that can be applied across a range of fields, while pharmaceutical firms' technological knowledge is more focused on generating products in the fields where they have marketing and distribution capabilities.

If T generates an innovation in the particular product field, it negotiates with each product firm about entering into a technology commercialization arrangement, either (1) a pure licensing arrangement (L) or (2) a co-promotion arrangement (CP). However, if it does not come to an agreement then it commercializes alone (NL). When there is more than one product firm (i.e., $N > 1$) T negotiates with all product firms simultaneously. Since all product firms are identical, they all offer the same tersm and – if they are acceptable – T randomly chooses to do a deal with one of the firms. Hence there is equal probability of it entering into an agreement with a specific product firm and from its perpective the identity of its partner is irrelevant.

Under a pure licensing arrangement (L), P_i pays T a fixed payment X^L, whether or not the commercialization is successful. In exchange T grants P_i the exclusive rights to attempt commercialization of the innovation and to capture any profits that result. Similarly, under a co-

[3] This implies that T innovates in another product field with probability $1-\phi$. However, since T and P_i's payoffs in this field are independent of the outcome in the other field it is possible to ignore this alternative in the analysis that follows.

promotion arrangement (CP), P_i pays T a fixed payment X^{CP} in exchange for T granting P_i the rights to attempt to commercialize the innovation and capture any profits. However, T also retains the right to participate in the commercialization process alongside P_i, which means it is able to learn from observing P_i's commercialization attempt. Finally if T does not license the innovation then it retains the rights to commercialize the innovation alone. If T enters into a technology commercialization arrangement, either licensing or co-promotion, it incurs transaction costs c_t (which reflect the costs of executing, monitoring, and enforcing the agreement).

This setup abstracts from the payment terms prevailing in the biopharmcetical industry, which often comprises not only upfront (i.e., fixed) payments, but also milestone payments (contingent on reaching intermediate development milestones), royalty payments (based on net sales), among others. However, since I assume that both parties are risk neutral, this simplfication should not significantly affect the results.

The notion of transaction costs in the model reflects the strength of the appropriability regime surrounding the firm's innovation highlighted in Teece (1986). If the appropriability regime were weak then we can suppose that T would incur a transaction cost in entering a license equivalent to the probability-weighted cost of the partner expropriating the innovation.

Once all negotiations have been concluded, the firms attempt to commercialize the innovations in their portfolios. Let σ_T^S be the probability of successfully commercializing T's innovation and $\sigma_{P_i}^S$ be the probability of successfully commercializing P_i's innovation under different strategies, where $S \in \{L, CP, NL\}$ represents the commercialization strategy followed by T.

Finally, once the commercialization attempts have been made, all the firms that have successfully commercialized their products compete for the market. I assume that there is only space for one product on the market in each period and that each product that has been successfully commercialized has an equal probability of capturing that position. Let λ_i^S be the probability that the innovation generated by firm $i \in \{T, P_i\}$ captures the market, given that T pursues the commercialization strategy $S \in \{L, CP, NL\}$. Then the values of λ_i^S are given by:

$$\lambda_T^S(\sigma_T^S, \sigma_{P_i}^S, N) = \sigma_T^S \sum_{k=0}^{N} \frac{1}{k+1} \binom{N}{k} \left(1-\sigma_{P_i}^S\right)^{N-k} \left(\sigma_{P_i}^S\right)^k \quad (1)$$

$$\lambda_{P_i}^S(\sigma_T^S, \sigma_{P_i}^S, N) = \sigma_{P_i}^S \sum_{k=0}^{N-1} \left(\frac{\sigma_T^S}{k+2} + \frac{1-\sigma_T^S}{k+1} \right) \binom{N-1}{k} \left(1-\sigma_{P_i}^S\right)^{N-k} \left(\sigma_{P_i}^S\right)^k \quad (2)$$

Additionally, I define λ_T^0 and $\lambda_{P_i}^0$ to represent the case when T does not innovate in the field in a particular period - in which case, $\sigma_T = 0$. These variables correspond to $\lambda_T^0(N) = \lambda_T(0, \sigma_1, N)$ and $\lambda_{P_i}^0(N) = \lambda_{P_i}(0, \sigma_1, N)$.

The firm whose product captures the market earns π (for one period only) and the other firms earn nothing. If no firm commercializes an innovation successfully then all firms earn nothing in that period. Nevertheless, if T successfully commercializes its innovation, either alone or in a co-promotion arrangement, then it acquires the valuable commercialization experience, whether or not it ultimately captures the market.

This set up reflects the nature of product competition in the pharmaceutical industry. Since patent rights over pharmaceutical products are relatively strong, they usually prevent imitators from launching identical products (at least for the length of the patent protection). Meanwhile when multiple firms introduce similar products (i.e., those with different composition but similar properties) around the same time, they usually engage in a short battle before a dominant one emerges.

The subgame for any given period proceeds as follows:

1. All firms engage in innovation.

2. If T has generated an innovation in the product field, it negotiates with each of the product firms about entering into a technology commercialization arrangement.

3. The firms attempt to commercialize the products in their portfolios.

4. The firms that have successfully commercialized their products compete for the market.

5. Payoffs are realized.

At the end of each period, the subgame repeats. However, in each subsequent period the profit is reduced by a discount factor δ (i.e., profits in period $t+1$ are worth δ of the value in period t).

The only parameter in the model that changes from period to period is the value of σ_T^{NL}, which rises to $\sigma_{P_i}^{NL}$ if T has acquired superior commercialization capabilities (i.e., those equivalent to a product firm). (I refer to the process by which T acquires superior commercialization capabilities as

"experiential learning".) Hence there are only two states of the game: when T has superior commercialization capabilities and when it does not. Since the parameters are constant across periods within the same state, the optimal strategies are also constant across periods within the same state. However, the probability of transitioning between the 'inferior' and 'superior' states depends on the value of σ_T^S, which in turn depends on the parameter value and which strategy $S \in \{CP, NL\}$ is chosen. Therefore it is necessary to use an infinite-horizon model to allow the length of time in which T remains in the inferior state to vary.

To distinguish between the probabilities and payoffs under these two states of the game, I denote those after T has acquired superior commercialization capabilities by a hyphen (e.g., NL becomes NL'). Meanwhile, since the values of σ_T^S and $\sigma_{P_i}^S$ are constant within a particular strategy and state, to simplify notation I let $\lambda_T^S(N)$ and $\lambda_{P_i}^S(N)$ represent the values of $\lambda_T^S(\sigma_T^S, \sigma_{P_i}^S, N)$ and $\lambda_{P_i}^S(\sigma_T^S, \sigma_{P_i}^S, N)$ respectively, where $S \in \{L, NL'\}$. Moreover, since $\lambda_T^S(N) = \lambda_{P_i}^S(N)$ when $\sigma_T^S = \sigma_{P_i}^S$, I further simplify notation by defining $\lambda_{11}(N)$ such that

$$\lambda_{11}(N) = \lambda_T^L(N) = \lambda_{P_i}^L(N) = \lambda_T^{NL'}(N) = \lambda_{P_i}^{NL'}(N) \tag{3}$$

3.2 Solving for the equilibrium conditions

Having set up the model, I now solve for the conditions under which each commercialization strategy will be a unique outcome in equilibrium. Following Segal & Whinston (2007) and Gans (2010), I use a dynamic programming approach and search for Markov perfect equilibria.

I assume unrestricted bargaining between the parties (i.e., I assume that any of the parties is free to make an offer at any point in time) and do not make any explicit assumptions about the allocation of bargaining power between the parties. Instead I focus on conditions under which a particular strategy is Pareto optimal (i.e., maximizes the joint surplus from production). This means that if the parties choose that strategy there is no way to way to make one party better off without making another party worse off; by contrast, if the parties were to choose another strategy then there would be a way for one party to compensate the other and make both parties better off.

If a particular strategy is a Pareto optimum under the conditions derived below the parties will agree on that strategy in equilibrium regardless of whether the bargaining power is allocated to T or P_i or is somewhere in between. If there is more than one product firm, one might assume that T has the power to make a take-it-or-leave-it offer and thereby extract all the surplus. However, since it can

only do a deal with one firm and all firms are identical, this does not allow it to extract any more surplus than in the case with only one firm. Moreover, if the joint surplus would be maximized by not licensing/self-commercialization, then it would be better off not doing deal, regardless of how many product firms there were.

In the following paragraphs I sketch the approach to solving for the equilbirum conditions and report the conditions. The full details are in the Appendix.

3.2.1 Equilibrium conditions with $N = 1$ & $\phi = 1$

To begin with, I assume that $N = 1$ and $\phi = 1$ and solve for the equilibria under the case without experiential learning (i.e., where $\sigma_T^{NL} = \sigma_T^{NL'}$ and $\sigma_T^{CP} = \sigma_T^{CP'}$). The payoffs from co-promotion under this scenario are no different from licensing, so I restrict attention to the choice between licensing and not licensing/self-commercialization.

Let Π_T^L, Π_T^{NL}, $\Pi_{P_i}^L$, and $\Pi_{P_i}^{NL}$ denote T and P_i's present discounted profits under licensing and not licensing, respectively. The values of Π_T^L and Π_T^{NL} are given by the following expressions:

$$\Pi_T^L = X^L - c_t + \delta\Pi_T^L \tag{4}$$

$$\Pi_T^{NL} = \lambda_T^{NL}(1)\pi + \delta\Pi_T^{NL} \tag{5}$$

Meanwhile, the values of $\Pi_{P_i}^L$ and $\Pi_{P_i}^{NL}$ are given by:

$$\Pi_{P_i}^L = \lambda_T^L(1)\pi - X^L + \lambda_{P_i}^L(1)\pi + \delta\Pi_{P_i}^L \tag{6}$$

$$\Pi_{P_i}^{NL} = \lambda_{P_i}^{NL}(1)\pi + \delta\phi\Pi_{P_i}^{NL} \tag{7}$$

Licensing will occur in equilibrium if and only if there exist values of X^L that satisfy both of these conditions:

$$\Pi_T^L(X^L) \geq \Pi_T^{NL} \tag{8}$$

$$\Pi_{P_i}^L(X^L) \geq \Pi_{P_i}^{NL} \tag{9}$$

Solving for the conditions that satisfy these inequalities reveals that under this scenario the firms will prefer licensing to not licensing in equilbium if

$$c_t \leq 2\lambda_{11}(1)\pi - \lambda_{P_i}^{NL}(1)\pi - \lambda_T^{NL}(1)\pi \tag{10}$$

Next I allow for the possibility of experiential learning, but still restrict attention to the choice between licensing and not-licensing. The main difference under this scenario is that if T successfully commercializes an innovation (through its own efforts) then σ_T rises from σ_T^{NL} to $\sigma_T^{NL'} = \sigma_{P_i}^{NL}$.

With experiential learning, Π_T^L and $\Pi_{P_i}^L$ remain the same as before but Π_T^{NL} and $\Pi_{P_i}^{NL}$ become

$$\Pi_T^{NL} = \lambda_T^{NL}(1)\pi + \sigma_T^{NL}\delta\Pi_T^{NL'} + \left(1-\sigma_T^{NL}\right)\delta\Pi_T^{NL} \tag{11}$$

$$\Pi_{P_i}^{NL} = \lambda_{P_i}^{NL}(1)\pi + \sigma_T^{NL}\delta\Pi_{P_i}^{NL'} + \left(1-\sigma_T^{NL}\right)\delta\Pi_{P_i}^{NL} \tag{12}$$

where $\Pi_T^{NL'}$ and $\Pi_{P_i}^{NL'}$ are

$$\Pi_T^{NL'} = \lambda_{11}(1)\pi + \delta\Pi_T^{NL'} \tag{13}$$

$$\Pi_{P_i}^{NL'} = \lambda_{P_i}^{NL'}(1)\pi + \delta\Pi_{P_i}^{NL'} \tag{14}$$

Substituting these expressions in (8) and (9) and solving, it is possible to show that under this scenario licensing will occur in equilibrium if and only if

$$c_t \leq \frac{1-\delta}{1-\delta(1-\sigma_T^{NL})}\left[2\lambda_{11}(1)\pi - \lambda_{P_i}^{NL}(1)\pi - \lambda_T^{NL}(1)\pi\right] \tag{15}$$

Next I introduce the option of co-promotion. Under co-promotion, T licenses its innovation to P but retains the right to co-promote the product if the commercialization is successful. If so, T acquires knowledge of the commercialization process (i.e., σ_T^{NL} rises to $\sigma_T^{NL'} = \sigma_{P_i}^{NL}$ for all subsequent innovations) and thereafter will always prefer to commercialize its innovations alone.

Let Π_T^{CP} and $\Pi_{P_i}^{CP}$ denote the denote the T and P_i's payoffs from a co-promotion arrangement (before T has commercialized an innovation successfully). The values of Π_T^{CP} and $\Pi_{P_i}^{CP}$ are given by

$$\Pi_T^{CP} = X^{CP} - c_t + \sigma_T^{CP}\delta\Pi_T^{CP'} + \left(1-\sigma_T^{CP}\right)\delta\Pi_T^{CP} \tag{16}$$

$$\Pi_{P_i}^{CP} = \lambda_T^{CP}(1)\pi + \lambda_{P_i}^{CP}(1)\pi - X^{CP} + \sigma_T^{CP}\delta\Pi_P^{CP'} + \left(1-\sigma_T^{CP}\right)\delta\Pi_P^{CP} \quad (17)$$

The firms will prefer co-promotion to licensing in equilibrium if and only if there exist values of X^{CP} that satisfy the following conditions:

$$\Pi_T^{CP}(X^{CP}) \geq \Pi_T^{L}(X^{L}) \quad (18)$$

$$\Pi_{P_i}^{CP}(X^{CP}) \geq \Pi_{P_i}^{L}(X^{L}) \quad (19)$$

Solving for the conditions that satisfy these inequalities reveals that the parties will prefer co-promotion over licensing in equilibrium if

$$c_t \geq \frac{1-\delta}{\delta\sigma_T^{CP}}\left(2\lambda_{11}(1) - \lambda_T^{CP}(1)\pi - \lambda_{P_i}^{CP}(1)\pi\right) \quad (20)$$

Meanwhile, the parties will prefer co-promotion over not licensing/self-commercialization if

$$\Pi_T^{CP}(X^{CP}) \geq \Pi_T^{NL} \quad (21)$$

$$\Pi_{P_i}^{CP}(X^{CP}) \geq \Pi_{P_i}^{NL} \quad (22)$$

These inequalities are satisfied if

$$c_t \leq 2\frac{\delta\left(\sigma_T^{CP} - \sigma_T^{NL}\right)}{1-\delta(1-\sigma_T^{NL})}\lambda_{11}(1)\pi + \lambda_T^{CP}(1)\pi + \lambda_{P_i}^{CP}(1)\pi - \frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta(1-\sigma_T^{NL})}\left(\lambda_T^{NL}(1)\pi + \lambda_{P_i}^{NL}(1)\pi\right) \quad (23)$$

3.2.2 Equilibrium conditions with $N=1$ & $\phi \leq 1$

Now I relax the assumption that T innovates in the same product field in every period (i.e., $\phi \leq 1$). To solve the case with $\phi < 1$, we also need to consider the scenario where T does not innovate in the product field in a particular field. Hence, I let Π_T^0 and $\Pi_{P_i}^0$ be respective discounted profits in the scenario where does not innovate in the field.

T's payoffs under this scenario are given by

$$\Pi_T^{L} = X^{L} - c_t + \delta\left[\phi\Pi_T^{L} + (1-\phi)\Pi_T^{0}\right] \quad (24)$$

$$\Pi_T^{NL} = \lambda_T^{NL}(1)\pi + \delta\left\{\phi\left[\sigma_T^{NL}\Pi_T^{NL'} + \left(1-\sigma_T^{NL}\right)\Pi_T^{NL}\right] + \left(1-\phi\right)\Pi_T^0\right\} \tag{25}$$

$$\Pi_T^{CP} = X^{CP} - c_t + \delta\left\{\phi\left[\sigma_T^{CP}\Pi_T^{CP'} + \left(1-\sigma_T^{CP}\right)\Pi_T^{CP}\right] + \left(1-\phi\right)\Pi_T^0\right\} \tag{26}$$

$$\Pi_T^{NL'} = \lambda_T^{NL'}(1)\pi + \delta\left[\phi\Pi_T^{NL'} + \left(1-\phi\right)\Pi_T^0\right] \tag{27}$$

$$\Pi_T^0 = 0 + \delta\left[\phi\Pi_T^S + \left(1-\phi\right)\Pi_T^0\right] \tag{28}$$

where $S \in \left\{L, NL, CP, NL'\right\}$

Meanwhile the values of $\Pi_{P_i}^L$, $\Pi_{P_i}^{NL}$, $\Pi_{P_i}^{CP}$, Π_{P-i}^{CP}, $\Pi_{P_i}^{NL'}$, and $\Pi_{P_i}^0$ are given by

$$\Pi_{P_i}^L = \lambda_T^L(1)\pi - X^L + \lambda_{P_i}^L(1)\pi + \delta\left(\phi\left(\frac{1}{N}\Pi_{P_i}^L + \frac{N-1}{N}\Pi_{P_{-i}}^L\right) + \left(1-\phi\right)\Pi_{P_i}^0\right) \tag{29}$$

$$\Pi_{P_i}^{NL} = \lambda_{P_i}^{NL}(1)\pi + \delta\left\{\phi\left[\sigma_T^{NL}\Pi_{P_i}^{NL'} + \left(1-\sigma_T^{NL}\right)\Pi_{P_i}^{NL}\right] + \left(1-\phi\right)\Pi_{P_i}^0\right\} \tag{30}$$

$$\Pi_{P_i}^{CP} = \lambda_T^{CP}(1)\pi - X^{CP} + \lambda_{P_i}^{CP}(1)\pi + \delta\left\{\phi\left[\sigma_T^{CP}\Pi_P^{CP'} + \left(1-\sigma_T^{CP}\right)\Pi_{P_i}^{CP}\right] + \left(1-\phi\right)\Pi_{P_i}^0\right\} \tag{31}$$

$$\Pi_{P_i}^{NL'} = \lambda_{P_i}^{NL'}(1)\pi + \delta\left[\phi\Pi_{P_i}^{NL'} + \left(1-\phi\right)\Pi_{P_i}^0\right] \tag{32}$$

$$\Pi_{P_i}^0 = \lambda_{P_i}^0(1)\pi + \delta\left[\phi\Pi_{P_i}^S + \left(1-\phi\right)\Pi_{P_i}^0\right] \tag{33}$$

where $S \in \left\{L, NL\right\}$

Solving for the conditions that satisfy (8) and (9) reveals that under this scenario the firms will prefer licensing to not licensing/self-commercialization if

$$c_t \le \frac{1-\delta}{1-\delta\left(1-\delta\phi\sigma_T^{NL}\left(1-\delta\left(1-\phi\right)\right)\right)}\left(2\lambda_{11}(1)\pi - \lambda_T^{NL}(1)\pi - \lambda_{P_i}^{NL}(1)\pi\right) \tag{34}$$

Meanwhile, the parties will choose co-promotion over licensing in equilibrium if and only if

$$c_t \geq \frac{1-\delta}{\delta\phi\sigma_T^{CP}\left(1-\delta+\delta\phi\right)}\left(2\lambda_{11}(1)\pi - \lambda_T^{CP}(1)\pi - \lambda_{P_i}^{CP}(1)\pi\right) \tag{35}$$

Finally they will choose co-promotion over not licensing/self-commercialization if

$$\begin{aligned} c_t \leq\ & 2\frac{\delta\phi\left(1-\delta\left(1-\phi\right)\right)}{1-\delta+\delta\phi\sigma_T^{NL}\left(1-\delta\left(1-\phi\right)\right)}\left(\sigma_T^{CP}-\sigma_T^{NL}\right)\lambda_{11}(1)\pi + \lambda_T^{CP}(1)\pi + \lambda_{P_i}^{CP}(1)\pi \\ & -\frac{1-\delta+\delta\phi\sigma_T^{CP}\left(1-\delta+\delta\phi\right)}{1-\delta+\delta\phi\sigma_T^{NL}\left(1-\delta+\delta\phi\right)}\left(\lambda_T^{NL}(1)\pi + \lambda_{P_i}^{NL}(1)\pi\right) \end{aligned} \tag{36}$$

3.2.3 Equilibrium conditions with $N>1$ & $\phi=1$

Finally I allow for $N>1$, while setting $\phi=1$. From T's perspective, the scenario with $N>1$ is no different than when $N=1$ since all product firms are identical and if it agrees to license or co-promote then it randomly one firm.[4] However, from P_i's perspective this case is different because even if it is an equilibrium for T to license (or co-promote) it is not necessarily the case that P_i is the licensor. Hence we need to consider P_i's payoffs under the scenario where T licenses its innovation to a firm other than P_i. Let $\Pi_{P_{-i}}^{L}$ and $\Pi_{P_{-i}}^{CP}$ be the present value of P_i's expected profits when T licenses the product to another product firm and when T enters a co-promotion arrangement with another product firm P_{-i}, respectively [5]

The values of Π_T^L, Π_T^{CP}, Π_T^{NL} and $\Pi_T^{NL'}$ under this scenario are given by

$$\Pi_T^L = X^L - c_t + \delta\Pi_T^L \tag{37}$$

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[4] As discussed above, when $N>1$ it is reasonable to assume that T has the power to make a take-it-or-leave-it offer and thereby extract all the surplus. Nevertheless, because I solve for the conditions that maximize the joint surplus, these conditions will be unaffected.

[5] Nevertheless, since T will always (weakly) prefer to commercialize the innovation after it has acquired specialized commercialization capabilities, we only need to consider this additional case for the situation before T has successfully commercialized an innovation.

$$\Pi_T^{CP} = X^{CP} - c_t + \delta\left[\sigma_T^{CP}\delta\Pi_T^{CP'} + \left(1-\sigma_T^{NL}\right)\Pi_T^{CP}\right] \tag{38}$$

$$\Pi_T^{NL} = \lambda_T^{NL}(N)\pi + \delta\left[\sigma_T^{NL}\Pi_T^{NL'} + \left(1-\sigma_T^{NL}\right)\Pi_T^{NL}\right] \tag{39}$$

$$\Pi_T^{NL'} = \lambda_T^{NL'}(N)\pi + \delta\Pi_T^{NL'} \tag{40}$$

The values of $\Pi_{P_i}^{L}$, $\Pi_{P_{-i}}^{L}$, $\Pi_{P_i}^{CP}$, Π_{P-i}^{CP}, $\Pi_{P_i}^{NL}$, and $\Pi_{P_i}^{NL'}$ are given by

$$\Pi_{P_i}^{L} = \lambda_T^{L}(N)\pi - X^{L} + \lambda_{P_i}^{L}(N)\pi + \delta\left(\frac{1}{N}\Pi_{P_i}^{L} + \frac{N-1}{N}\Pi_{P_{-i}}^{L}\right) \tag{41}$$

$$\Pi_{P_{-i}}^{L} = \lambda_{P_{-i}}^{L}(N)\pi + \delta\left(\frac{1}{N}\Pi_{P_i}^{L} + \frac{N-1}{N}\Pi_{P_{-i}}^{L}\right) \tag{42}$$

$$\Pi_{P_i}^{CP} = \lambda_T^{CP}(N)\pi - X^{CP} + \lambda_{P_i}^{CP}(N)\pi + \delta\left[\sigma_T^{CP}\Pi_P^{CP'} + \left(1-\sigma_T^{CP}\right)\left(\frac{1}{N}\Pi_{P_i}^{CP} + \frac{N-1}{N}\Pi_{P_{-i}}^{CP}\right)\right] \tag{43}$$

$$\Pi_{P_{-i}}^{CP} = \lambda_{P_{-i}}^{CP}(N)\pi + \delta\left[\sigma_T^{CP}\Pi_P^{CP'} + \left(1-\sigma_T^{CP}\right)\left(\frac{1}{N}\Pi_{P_i}^{CP} + \frac{N-1}{N}\Pi_{P_{-i}}^{CP}\right)\right] \tag{44}$$

$$\Pi_{P_i}^{NL} = \lambda_{P_i}^{NL}(N)\pi + \delta\left[\sigma_T^{NL}\Pi_{P_i}^{NL'} + \left(1-\sigma_T^{NL}\right)\Pi_{P_i}^{NL}\right] \tag{45}$$

$$\Pi_{P_i}^{NL'} = \lambda_{P_i}^{NL'}(N)\pi + \delta\Pi_{P_i}^{NL'} \tag{46}$$

Under this scenario the parties will prefer licensing to not licensing/self-commercialization if

$$c_t \le \frac{1-\delta}{1-\delta(1-\sigma_T^{NL})}\left(\lambda_{11}(N)\pi - \lambda_T^{NL}(N) + \frac{N}{N-\delta\left(N-1\right)}\left(\lambda_{11}(N)\pi - \lambda_{P_i}^{NL}(N)\pi\right)\right) \tag{47}$$

Meanwhile they will prefer co-promotion over licensing in equilibrium if

$$\begin{aligned} c_t \le{}& \frac{\left(1-\delta\left(1-\sigma_T^{CP}\right)\right)\left(N-1\right)}{N-\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)}X^{L} + \frac{2N\left(1-\delta\right)-\delta\left(N-1\right)\left(1-\delta+\delta\sigma_T^{2CP}\right)}{\delta\sigma_T^{CP}\left(N-\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)\right)}\lambda_{11}(N)\pi \\ &+ \frac{\left(1-\delta\right)\left(1-\sigma_T^{CP}\right)\left(N-1\right)}{\sigma_T^{CP}\left(N-\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)\right)}\lambda_{P_{-i}}^{CP}(N)\pi - \frac{1-\delta}{\delta\sigma_T^{CP}}\left(\lambda_T^{CP}(N)\pi + \lambda_{P_i}^{CP}(N)\pi\right) \end{aligned} \tag{48}$$

Finally they will choose co-promotion over not licensing/self-commercialization if

$$c_t \le \lambda_T^{CP}(N)\pi + \lambda_{P_i}^{CP}(N)\pi + \frac{\delta\left(\sigma_T^{CP} - \sigma_T^{LN}\right)\left(2N - \left(1-\sigma_T^{CP}\right)(N-1)\right)}{1-\delta\left(1-\sigma_T^{NL}\right)\left(\left(N - \delta\left(1-\sigma_T^{CP}\right)(N-1)\right)\right)}\lambda_{11}(N)\pi$$
$$-\frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta\left(1-\sigma_T^{NL}\right)}\left(\lambda_T^{NL}(N)\pi - \frac{N}{\left(\left(N - \delta\left(1-\sigma_T^{CP}\right)(N-1)\right)\right)}\lambda_{P_i}^{NL}(N)\pi\right) \quad (49)$$
$$+\frac{\delta\left(1-\sigma_T^{CP}\right)(N-1)}{\left(N - \delta\left(1-\sigma_T^{CP}\right)(N-1)\right)}\lambda_{P-i}^{CP}(N)\pi$$

3.3 Propositions derived from the model

I use these results to derive a couple of testable propositions. I present the propositions and their intuition here. The proofs are in the Appendix.

The first proposition – presented here as a lemma – replicates the basic prediction of Teece (1986):

Lemma 1 *In a technology commercialization game without experiential learning (i.e., where* $\sigma_T^{NL'} = \sigma_T^{NL}$*), licensing will be the unique equilibrium if the product firm is better positioned with respect to the complementary assets (i.e.,* $\sigma_{P_i}^{NL} > \sigma_T^{NL}$*) where the transaction costs of licensing (*c_t*) are sufficiently low.*

The condition that the transaction costs are sufficiently low captures the notion in Teece (1986) that the appropriability regime is strong. Hence Lemma 1 states that – in a model without experiential learning – licensing will be the optimal strategy when the appropriability regime is strong and when the established product firms are better positioned with respective to complementary assets.

However, when we introduce the opportunity for experiential learning, it is more likely that not licensing will be the equilibrium outcome in a given situation.

Lemma 2 *There exist values of* c_t *at which not licensing is the unique equilibirum outcome in the technology commercialization game with experiential learning and licensing is the unique equilibirum outcome in a game without experiential learning.*

When there is the opportunity for experiential learning, T must trade off the upfront benefits of obtaining access to P_i's capabilities through licensing against the potential future benefits of obtaining commercialization experience through self-commercialization. In other words, licensing has

an opportunity cost in terms of foregone learning opportunities. This is reflected in the fact that, given a set of parameters $\left\{\sigma_i^S, \delta\right\}$, not licensing will be an equilibrium at a lower level of transaction costs in the game with experiential learning than in the game without.

Lemma 2 might nevertheless understate the opportunity costs of licensing because it does not incorporate the possibility that the product firm might also learn from its experience in commercialization. Pisano (1991) argued that if in the process of commercializing the innovation P_i develops specialized knowledge about the commercialization process or the product markets which increases its capabilities to commercialize future innovations, P_i may be in an even stronger bargaining position (relative both to T and to other product firms) in future negotiations to commercialize an innovation. Hence when P_i also has the opportunity to learn from experience T may have an even stronger motivation to attempt to commercialize its own innovation.

That said, commercializing alone is expensive and T's inexperience means that there is a higher risk of failure than if it licenses to P_i. It follows therefore that a hybrid arrangement in which T is able to obtain access to P_i's superior capabilities but at the same time acquire commercialization experience may be preferable to either straight licensing or self-commercialization under certain circumstances. Lemma 3 sets out the conditions under which co-promotion is an equilibrium outcome.

Lemma 3 *In the technology commercialization game with experiential learning, co-promotion is an equilibrium outcome if* $\sigma_T^{NL} = \sigma_0$, $\sigma_{P_i}^{L} = \sigma_{P_i}^{NL} = \sigma_{P_i}^{CP} = \sigma_T^{L} = \sigma_T^{NL'} = \sigma_1 > \sigma_0$, $\sigma_T^{CP} = \frac{1}{2}\left(\sigma_0 + \sigma_1\right)$ *and* $\sigma_1 \geq \frac{1-\delta}{\delta}$. *More generally, co-promotion is an equilibrium outcome if*

$$\frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta(1-\sigma_T^{NL})}\left(\frac{\sigma_{P_i}^{NL}\left(1-\frac{1}{2}\sigma_{P_i}^{NL}\right)\left(\delta\left(\sigma_T^{CP}-\sigma_T^{NL}\right)-\left(1-\delta\right)\right)}{\frac{-\delta\sigma_T^{CP}\left(\sigma_T^{NL}-\sigma_T^{NL}\sigma_{P_i}^{NL}+\sigma_{P_i}^{NL}\right)+\left(1-\delta(1-\sigma_T^{NL})\right)\left(\sigma_T^{CP}-\sigma_T^{CP}\sigma_{P_i}^{CP}+\sigma_{P_i}^{CP}\right)}{\delta\sigma_T^{CP}}\right)\pi \geq 0$$

From the relative payoffs, it is straightforward to see that – all else being equal – in general T is at least as well off relative to licensing on one hand and not licensing on the other. Relative to not licensing, co-promotion reduces the risk of failure in the short term, enabling T to bring its latest

innovation to market in a timely and cost-effective manner. Meanwhile, relative to licensing, co-promotion improves T's chances of acquiring superior commercialization capabilities.

Nevertheless, for co-promotion to be an equilibrium, P_i must also agree to enter this arrangement. Since it is more likely that T will acquire superior commercialization capabilities under co-promotion than if it were to commercialize alone, from P_i's perspective entering a co-promotion arrangement is equivalent to training a competitor. Hence P_i will only agree to co-promote if T compensates it sufficiently.

In the model I assume that T is not constrained financially and able to compensate P_i sufficiently whenever co-promotion is optimal or finance itself whenever not licensing is the optimal arrangement. However, as Aghion & Tirole (1994) showed, if T were constrained financially then this may not be the case and instead it is more likely that straight licensing would be the optimal outcome.

Assuming that T (but not P_i) has the opportunity for learn from its experience, and that that T is not constrained financially, I now derive the comparative statics.

Proposition 1 characterizes how the likelihood of licensing vs not licensing (or commercializing alone) changes with respect to ϕ, assuming for the moment that the opportunity for co-promotion is not available.

Proposition 1 *In a technology commercialization game with experiential learning the likelihood that licensing is chosen over not licensing (or self-commercialization) in equilibrium is decreasing in* ϕ.

Proposition 1 follows directly from T's tradeoff between the upfront benefits of obtaining access to P_i's capabilities through licensing and the potential future benefits of obtaining commercialization experience through self-commercialization. The upfront benefits are certain but the future benefits depend on how likely it is that T will generate an innovation in the same field in future. The higher the likelihood (i.e., the higher is ϕ), the greater the benefits to T of building commercialization expertise. Therefore the opportunity costs of licensing increase and the likelihood of licensing decreases, all else being equal.

Proposition 2 characterizes how the likelihood of licensing vs co-promotion changes with respect to ϕ, assuming that the choice is limited to these two options.

Proposition 2 *In a technology commercialization game with experiential learning the likelihood that the parties choose co-promotion over licensing in equilibrium is decreasing in* ϕ.

The intuition for Proposition 2 is very similar to Proposition 1. In entering a straight licensing agreement rather than a co-promotion arrangement, T's foregoes the opportunity to learn from the commercialization experience and thereby commercialize future innovations alone. At the same time, assuming $\sigma_T^L > \sigma_T^{CP}$, T benefits from a higher likelihood of its current innovation being commercialized. As ϕ increases, the benefits of T having its own commercialization experience – and therefore being able to commercialize innovations alone – increases because future innovations are more likely. Hence the parties are more likely to choose co-promotion, all else being equal.

4. Empirical analysis

I now examine how the predictions from the model relate to the pattern of arrangements in the biopharmaceutical industry.[6]

4.1 The biopharmaceutical industry

The biopharmaceutical industry can be traced to the founding of Genentech in 1976 to exploit the recombinant DNA techniques discovered by Herbert Boyer at the University of California at San Francisco and Stanley Cohen at Stanford in 1972. From the beginning, entering alliance with a pharmaceutical firm has been the predominant mode by which biotech innovations were commercialized. Genentech's first major project – a race with UCSF and Harvard University to clone human insulin, the key protein diabetics need to normalize their metabolism – resulted in an alliance with Lilly to commercialize the discovery ("Humulin") as a pharmaceutical product (Edwards & Hamilton, 1998).

The Genentech/Lilly alliance set the standard for interaction between the new "biotech" firms and the established pharmaceutical firms. The biotech firm licensed all product rights to an established pharmaceutical firm, and remained involved through the pre-clinical stages of development, but then passed all responsibility for the clinical development, marketing, and worldwide sales to the pharmaceutical firm. However, the structure of these commercialization arrangements has changed significantly over time, as biotech firms have increasingly sought to become more involved in the

[6] The biopharmaceutical or medical "biotech" industry is distinct from the agricultural and industrial "biotech" industries.

commercialization process.[7] As a first step, biotech firms began to participate in the clinical development stages of the alliance, both participating in management of the clinical trials and sharing the costs (and thereby also the profit or loss) from clinical development, an arrangement known as "co-development". More recently biotech firms have integrated even further downstream inside the alliance, retaining rights to participate in the marketing and sales of the alliance product, known as "co-promotion".[8] Under a co-promotion arrangement the biotech firm licenses the marketing rights to the pharmaceutical partner, but retains some rights to participate in the marketing and sales process alongside the partner. The two parties together develop a joint marketing strategy and sales force, sell under the same brand name, and pool – and ultimately split – revenues.[9]

4.2 Evidence from interviews

In order to understand the motivation for entering co-promotion arrangements, I conducted a series of interviews with biotech firm executives.[10] From the list of executives who attended Recombinant Capital's *Allicense* conference in San Francisco on 2-3 May, 2006, I selected executives from "start up" biotech firms whose firms either had retained co-promotion rights in recent agreements with

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[7] It was not uncommon in the early alliances for the biotech firm to retain rights to some territories (especially its home country) or, in a few cases, rights to specific indications. For instance, at the same time as Genentech entered the Lilly alliance, it also signed a deal with Kabi Pharmaceutical to commercialize human growth hormone but retained the rights to commercialize the product in the United States. Meanwhile, Amgen retained rights to sell to kidney dialysis patients in its alliance with Ortho Biotech to commercialize EPO.

[8] A well-known example is ImClone's 2001 arrangement with Bristol-Myers Squibb to commercialize its cancer drug Erbitux. Another is the deal between Idec Pharmaceuticals (now part of Biogen Idec) and Genentech in 1996 for the commercialization of Rituxan, a drug for non-Hodgkin's lymphoma, which has since become the largest selling monoclonal antibody drug and a significant contributor to the profits of both companies.

[9] Co-promotion can be contrasted against several other arrangements for commercializing biotech innovations. The most obvious contrast is the pure product license in which the biotech firm licenses all marketing & distribution rights to the pharmaceutical firm. However, one alternative which involves a greater degree of participation by the biotech firm is split territories (or, in a few cases, indications) under which the firms develop, market, and sell the same drug in separate (exclusive) territories. A third, if rare, alternative is co-marketing in which the firms develop, market, and sell the drug in same territory but with different marketing strategies, sales forces, and brand names.

[10] *Allicense* is the primary industry conference focusing on alliances between biotech and pharmaceutical firms, and is attended by the senior business development executives from all the major pharmaceutical and mature biotech firms, as well as CEOs and other senior executives from many start-up biotech firms.

established pharmaceutical firms or fully integrated biotech firms[11] or had recently entered licensing agreements without retaining co-promotion rights.[12] I invited them to speak with me, either generally about why start-up biotech firms retain co-promotion rights in alliances or specifically about the reasons their company chose to retain (or not to retain) co-promotion rights in its recent agreements. I conducted phone interviews with ten executives during late May/early June 2006.

The primary reason the executives cited for retaining co-promotion rights was the belief that the biotech firm would capture a larger share of the value from its technology by being involved in the marketing of the alliance product than if it merely licenses the marketing rights to a pharmaceutical firm. Many echoed the refrain that "Wall Street values 'decision rights' over 'revenue rights'".[13] They argued that companies which had only done licensing deals had not been very successful. Some claimed that the revenue the firm earned from the profit split (typically between 33% and 50%) that usually accompanies a co-promotion agreement was usually greater than it earns from the combination of upfront payments and royalties (typically in the range of 10% of net sales) that a firm can get from an equivalent pure-licensing deal. However, others argued that, even though a pure-licensing agreement could be structured to produce as much income as a co-promotion agreement, a co-promotion arrangement gave the biotech firm greater insight into the business of commercializing pharmaceutical products and therefore was more valuable.

The executives claimed that the primary benefit from entering co-promotion arrangements is that the biotech firm acquires valuable knowledge by participating in the commercialization process alongside the pharmaceutical firm. One executive explained that by retaining co-promotion rights the biotech firm is able to "piggy back" on the expertise of its alliance partner to build its own capabilities. Another stated that the way to "score big" was to "leverage the alliance partner's expertise internally" to learn the skills necessary to develop the next drug.

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[11] I distinguish between fully integrated biotech firms that already have pharmaceutical products on the market, and "start-up" biotech firms, which do not have products on the market and do not yet have the capabilities to commercialize product candidates alone.

[12] I only considered firms that I estimated were likely to have been in a position to retain such rights. I estimated the likelihood that the firm would have retained co-promotion rights through an informal inspection of their prior licensing experience, financial strength, and various other observable factors in Recap's Alliances database.

[13] This claim was made by Stephen R. Davis, Executive Vice President and Chief Operating Officer, Neurogen, at the *Allicense* conference in San Francisco on May 25, 2005.

A secondary benefit of retaining co-promotion rights is that the firm retains some control over the development and marketing process. Since neither firm knows at the outset the size of the potential market for the alliance product, a biotech firm's concern is that – if the potential market for the product turns out not to be sufficiently large – its alliance partner will not put in the resources necessary to commercialize it. Hence, it is important to have a voice at the table to make sure the drug gets developed on the biotech firm's timeframe. One executive claimed that retaining some rights to participate in the marketing enables the firm to be "the nag that makes sure the drug gets developed". Others explained that, while the deal could include "due diligence" or "best efforts" requirements, a lot of pharmaceutical firms would not agree to them because it was hard to define "best (or reasonable) efforts" and, if they did agree to such a clause, they were usually very vague and legally meaningless.

Some executives claimed that they would always retain co-promotion rights if they could, but others identified cases in which they would not seek co-promotion rights. If the firm needed cash, so was forced to enter an alliance at an early stage in the product's development, then retaining co-promotion rights was not usually worth the cost (in terms of money foregone). One executive quipped that the "first child" of the biotech firm typically had to be sold (i.e., licensed exclusively) to a pharmaceutical firm in order to fund the development of future products. Also, if the disease field on which the alliance product is focused was outside the firm's "strategic interests", or was in a very competitive field, then the biotech is likely to give up rights to the product.

The executives also explained why they believed pharmaceutical firms were willing to give up marketing rights, even though marketing is their specialty. They claimed that pharmaceutical firms often did not have the leverage (especially in negotiations over very promising technologies) to negotiate all the rights to market the product, and hence they were forced to agree to co-promotion in order to secure the biotech firm's agreement. Nevertheless, the pharmaceutical firm may seek to buy those rights back – or even purchase the technology firm outright – if and when the product gets to market.[14] Moreover, some companies had a policy of never agreeing to co-promote, especially when the biotech firm did not have the necessary experience.

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[14] Amgen's alliance with Abgenix is an example of this happening. In July 2000 Abgenix entered a deal with Immunex to co-promote Abgenix's product panitumumab, a drug for late-stage colorectal cancer therapies that was then in Phase I trials. However, after Amgen acquired Immunex and the product passed through Phase III trials, Amgen purchased Abgenix outright. One rationale for doing so is that Amgen thereby avoided having to share the marketing with a smaller firm.

4.3 Data

In order to test the predictions outlined in the previous section, I compiled a unique dataset of technology commercialization arrangements used by U.S. biotech firms attempting to commercialize products in the pharmaceutical industry.

The data comes from primarily from RecapRx and rDNA, two proprietary databases compiled by Deloitte Recap ("Recap"). RecapRx contains clinical development information for all biotech products that the 100 largest biotech companies have attempted to develop at some stage during the company's lifespan. It also contains links to licenses associated with these products on rDNA (Recap's Alliances database), and rDNA contains detailed licensing information including the date of the agreement, the territory licensed, and the major terms of the agreement.

Using these two data sources, I determined which company held the rights to market each biotech product (or, to be precise, each indication of each biotech product) in the United States at each point during the product's lifespan. I then selected those instances where a biotech firm held exclusive rights to market a specific indication of a biopharmaceutical product in the United States for some period of time between 1978 and 2008. By implication, I excluded all instances where a biotech firm held the rights to market the product outside (but not inside) the United States.

The dataset contains information on 1591 instances in which the biotech firm held exclusive US rights. In 343 of the 1591 instances, the biotech firm's rights ended when it entered a technology commercialization arrangement – either a straight licensing arrangement or a co-promotion arrangement – with a pharmaceutical firm.[15] Of the 1248 other instances, in 231 the biotech firm's product rights ended when it was acquired during clinical trials, 15 when the rights reverted to an earlier licensor, and 323 because the product development was terminated. In the remainder, the biotech firm still had the rights when it exited the analysis, either because the product was approved or the observation period ended (i.e., in December 2008).

I used RecapRx and rDNA to build proxies for the variables in the model and several control variables (described below). I also supplemented this with information on the biotech firm's valuation. For private firms I used the post-money valuation at the last round of financing from Recap's Financings

[15] However, since often one alliance involves more than one product-indication this corresponds to 164 unique alliances.

dataset (where available)[16] and for public firms I used the Markey capitalization from the University of Chicago's CRSP database.

What is unique about this dataset – and what distinguishes it from the numerous datasets used in previous research on alliances, many of which were based on Recap's rDNA database – is that all the alliances involve the transfer of U rights to an identifiable biopharmaceutical product. By contrast, in most previous analyses that use biotech alliance data the alliances include both technology- and product-related alliances. Mixing different types of alliances in the same analysis makes it much more difficult to determine what is causing the observed patterns. In this case, we can be much more confident that the parties to the alliances were negotiating over similar issues and therefore the observed patterns can be attributed to the same determinants.

4.4 Empirical specification

The empirical analysis aims is to determine what factors drive the biotech firm's choice of technology commercialization strategy. In the simplest terms, this involves estimating the following model:

$$\Pr(CS \mid X) = f(X, \beta) \tag{50}$$

where *CS* represents the biotech's commercialization strategy and *X* is a vector of explanatory variables.

4.4.1 Variables

The dependent variable (*CS*) is a discrete variable that captures whether the biotech firm licensed out the rights to the product in a given period, and – if it licensed the rights – whether it retained co-promote the product. For the latter, I rely on Recap's coding of the "Alliance Type" provided in the Alliance Summary on rDNA, and classify a license as a co-promotion arrangement (*CS=CP*) whenever the Alliance Type is indicated Co-Promotion, and as a straight licensing arrangement otherwise (*CS=L*). [17]

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[16] Recap compiles its Financings dataset from publicly filed documents, so in general it includes information on firms that made an Initial Public Offering or otherwise were required to disclose this information. However, in contrast to Venture Xpert and other similar sources that collect information from voluntary surveys, Recap's information comes from legally mandated filings and therefore should be more accurate.

[17] Recap defines a "Co-Promotion" agreement as "a commercialization venture in which two or more parties promote and sell a single product, with each party obtaining sales revenues and/or net profits from either party's

It is important to note that the commercialization strategy analyzed here reflects the action taken in a particular month, rather than the commercialization strategy that the biotech firm ultimately pursues or the strategy that the firm intends to put into action in the future. Even if a firm is classified as not licensing out the commercialization rights in a given month, it may still intend to – and may in fact – enter an alliance at a later point in time. At the same time, even if a firm enters a particular type of licensing arrangement in a given month, the parties may subsequently renegotiate or terminate the agreement so the commercialization strategy is not fixed for all time.[18]

The primary explanatory variables proxy for the parameters in the model. To proxy for the probability that the firm will innovate in the same product field in subsequent periods (ϕ), I use the proportion of biotech firm's prior alliances that were in the same disease field, as coded by Recap.[19] The resource-based theory of the firm (Penrose, 1959; Wernerfelt, 1984) posits that a firm's future activities are constrained by its existing set of resources and capabilities. The disease fields in which a firm has innovated in the past will be a function of its underlying resources and capabilities, and it is likely to rely on the same resources and capabilities to innovate in the future. Therefore the focus on a particular field in the firm's prior activity ought to be a good predictor of the focus of its future activity.[20]

To proxy for the number of product firms competing to license the innovation, I use a count of the number of product firms that licensed innovations in the same disease field in the 2 years before and one year after the alliance was signed.[21] The reason for including alliances signed within a year after the alliance is that an alliance usually takes 6-18 months to negotiate and during the negotiations the technology firm usually has some information on what other alternatives its potential partner is

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sales of the product". It codes an alliance as a co-promotion agreement whenever this is indicated in the public announcement or the filed contract(s).

[18] If a contract is renegotiated or terminated, in the empirical set-up the subsequent observations are treated as a comprising a new instance.

[19] I use the Recap's 23 broad disease categories, which includes Cancer, Cardiovascular, etc.

[20] An alternative measure of the probability that the firm will innovate in the product field would be some measure of the firm's R&D capabilities in particular product. One such measure might be its stock of patents. However, since patents protect an underlying technology rather than a specific product, it is difficult if not impossible to relate a firm's patent stock to particular product fields.

[21] I include all alliances where the "Client" (as per Recap's classification) was "Pharma" firm, or a "Biotech" firm that had a product on the market at the time of the deal.

considering.[22] Since I expect that the relationship between the number of product firms and the likelihood of retaining co-promotion rights is concave, I use the *log* value.

Since ϕ and N are measured for a specific disease field, the relevant comparison is to other observations in the same disease field and hence I include disease-field fixed effects.

I also include a number of explanatory variables that the industry context and/or the prior literature suggest to be relevant. Following Aghion & Tirole (1994), Lerner & Merges (1998), and Lerner, Shane & Tsai (2003), I include an estimate of the biotech firm's valuation (normalized to December 2008 dollars) to account for the financial position of the firm. For the publicly listed firms I use the market capitalization at the end of the previous month, obtained from CRSP. For the privately held firms, I use the valuation at the last private financing round (whenever it is available) obtained from the rDNA Financing database.[23] Since the likelihood of entering into a deal or retaining co-promotion rights will more closely related to a proportional increase in the valuation than an absolute increase, I use the log value.

I use the firm's age in months since founding and the log value of the count of prior alliances to control for the biotech firm's prior experience, and indicators for whether the biotech has the rights to market another product in the same or another disease field to capture the biotech firm's marketing capabilities in a particular area. I also use dummies for the product candidate's stage of clinical development to capture the product quality.

Table 1 presents summary statistics for the values of the primary variables used in the analysis. Panel A shows statistics for all monthly observations in which a biotech firm held the exclusive rights to commercialize a product (i.e., the full sample) while Panel B shows the statistics just for those monthly observations in which the biotech firm transferred in the particular month. The statistics indicate that at the point the observations in which the biotech firms licensed out the rights were very similar in terms of the two primary explanatory variables to all observations in which the biotech firm

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[22] This variable is an approximate measure of the potential licensees. An alternative measure of the number of firms competing to license the innovation would be a count of those firms that were actually marketing products in the specific disease field. This would be more direct evidence that it has the specific commercialization capabilities in the disease field. However, it would not account for pharmaceutical firms that had products in the pipeline that would be on the market in the coming years.

[23] The information on firm valuation is only available when disclosed in SEC filings, either because the firm was publicly listed or because this information was included in its IPO filing when it later went public.

held rights. They were also similar in terms of the product's stage of development. However, the biotech firms in these observations tended to be financially weaker, younger, have less experience, and fewer commercialization capabilities. The statistics also show that, for those observations in which the biotech firm licensed out the rights, it retained rights to co-promote the alliance product in 43% of the cases.

- Insert Table 1 about here -

Table 2 shows the correlations between the variables used in the analysis.

- Insert Table 2 about here -

4.4.2 Empirical specification

To estimate the relationship between the commercialization strategy and the explanatory variables I use a Cox-proportional survival (or hazard-rate) model where the base case – or "survival" – is the case where the biotech retains the rights to the innovation, the hazard or "failure" event is when the biotech licenses the innovation to a partner, and the underlying hazard of licensing is a function of calendar time. Since the licensing event may be either a straight licensing or a co-promotion arrangement, and as the model predicts these two events will be driven by different factors, I use a competing-risk set up, implying two separate Cox regressions in which straight licensing is the "failure" event and co-promotion is the competing risk in one case and vice versa in the other.

To compare the likelihood of entering a straight licensing arrangement against the likelihood of entering a co-promotion arrangement I conduct a Chi-squared test of the difference in the coefficients from these two regressions. As the outcomes relating to all observations of a particular product-indication – and potentially for all observations relating all indications of the same product – will be correlated, I cluster the standard errors by product. Moreover, since the outcomes across these two models are correlated, I adjust the standard errors using the "seemingly unrelated regression" method proposed by Zellner (1962), calculating them via a bootstrapping procedure (Efron & Tibshirani, 1993).

Since the competing-risk analysis only allows us to compare straight licensing and co-promotion indirectly, by comparing the effects measured relative to the base case of not licensing, as an alternative I also estimate the choice of straight licensing vs. co-promotion arrangement directly. Nevertheless, as the game-theoretic model illustrates, the choice of licensing arrangement is related to the decision whether or not to license and hence it is not appropriate to analyze the choice of licensing arrangement independently of the licensing decision. Hence, I use a two-stage Heckman selection model (1979) where the dependent variable for the first stage is the decision whether or not to license

and for the second stage it is the type of licensing arrangement chosen (conditional on having entered a deal).

Since the two-stage probit procedure proposed by Van de Ven & Van Pragg (1981) does not converge, I estimate this model using the two-step procedure proposed by Heckman (1979). The major difference is that the dependent variable in second stage is estimated using OLS rather than a probit model. However, since the mean value of the dependent variable is close to 0.5 (see Table 1 shows) this is unlikely to produce a significant distortion.

To identify the selection model, it is necessary to exclude at least one variable that appears with a non-zero coefficient in the first-stage (selection) equation from the second-stage equation (i.e., to impose an exclusion restriction). To achieve this I include an indicator for whether the deal was signed in the last month of the quarter or the last month of the year as an instrumental variable. Anecdotal evidence suggests that firms are under pressure to sign deals towards the end of the quarter or year so that they can be included in the quarterly and annual filings, and large firms regularly set quarterly and annual targets for the number of deals that their business development departments should achieve (Larkin, 2008). However, even if a firm can manipulate the date on which it signs a deal, it typically takes from 6 to 18 months to negotiate the terms of the deal, and the general terms are typically negotiated and specified in a term sheet months beforehand. Hence the particular month in which the firms sign the alliance should not directly affect whether the firms negotiate a co-promotion or a straight licensing arrangement.

To account for unobserved, time-varying factors that may affect the probability of licensing, I include the cumulative hazard ratio generated by the hazard model in the regression.

4.5 Results

Table 3 presents the results of the Cox proportional hazard-rate regressions. Model 1 is the simple Cox proportional hazard-rate regression where the dependent variable is whether the biotech firm licensed its rights or not in any specific month. Model 2 contains the competing-risk analysis. In the first column, the dependent variable is whether the biotech firm entered a straight licensing agreement and the competing risk is whether it entered a co-promotion arrangement. The third column contains the difference between the coefficients from the two models, with the Chi-squared in parentheses.

- Insert Table 3 about here -

Table 4 presents the results of the Heckman selection analysis. The first column contains the first-stage regression in which the dependent variable is whether the biotech firm licensed out the rights to commercialize the product, and the second column contains the second-stage regression where the

dependent variable is whether the biotech firm retained rights to co-promotion the product (conditional on having licensed).

- Insert Table 4 about here -

The results of the empirical analysis provide support for the predictions from the model. Proposition 1 posits that a technology firm will be more likely not to license the commercialization rights (i.e., to commercialize the innovation alone) when the probability that it will generate an innovation related to that product field in future (ϕ) is higher. The results of the simple hazard-rate analysis do not show any significant effect of ϕ, but when we distinguish between straight licensing and co-promotion arrangements in the competing-risk analysis we observe that biotech firms are significantly less likely to license when ϕ is higher. The coefficient on ϕ in the first stage of the Heckman analysis is also negative and significant, which is consistent with the prediction.

Proposition 2 posits that a firm will be more likely to retain co-promotion rights if there is a higher ϕ. The comparison of the results from the competing-risk analysis in Table 3 reveals that when a biotech firm has a higher proportion of prior alliances in the same field, it is significantly more likely to enter into a co-promotion arrangement than a pure licensing arrangement. Similarly the results of the Heckman analysis suggest that, conditional on entering into a licensing deal, the firms are significantly more likely to enter a co-promotion arrangement if the biotech firm has a higher proportion of prior alliances in the same field. Both findings are consistent with the prediction in Proposition 2.

The results from the simple hazard-rate regression and the first stage of the Heckman analysis show no effect of N on the likelihood of licensing, but the results of the competing risk analysis indicate that higher N increases the likelihood of licensing and co-promotion relative to not licensing (with the effect on co-promotion being marginally higher). This is likely to be because increasing N affects T's bargaining position. As discussed above, the model does not take into account how the number of firms affects the allocation of bargaining power among the firms or the allocation of the rents between the two parties. However, one would suppose that as N increases T would be able to capture a larger share of the surplus in entering a licensing arrangement. Moreover, having more potential partners may make it more likely that T can persuade one to agree to a co-promotion arrangement, as opposed to just a straight licensing arrangement. Meanwhile, increasing N will not have any corresponding effect on T's payoffs if it does not do a deal. Hence it appears logical that with increasing N T would be more likely to enter some licensing arrangement, and specially a co-promotion arrangement.

There results also show some interesting effects on the control variables. Both specifications provide evidence consistent with Lerner et al. (1998; 2003) that the biotech firm is more likely to retain control rights (i.e., in this case, co-promotion rights) when it is in a stronger financial position. Interestingly, I observe that being in a stronger financial position appears to have no relationship with whether the biotech firm commercializes the innovation alone or enters a co-promotion arrangement.

Meanwhile, firms that already have rights to market a product in the disease field (which is a proxy for having capabilities in that field) appear more likely not to license out the commercialization rights, and particularly not to enter a co-promotion arrangement. At the same time, firms that have rights to market a product in another disease field are more likely to license out the rights exclusively than to retain co-promotion rights to commercialize alone.

It is not surprising that such firms choose to commercialize alone rather than to co-promote since they have less need to acquire learn from a partner. However, it perhaps surprising that they appear no less likely to license than to commercialize alone. This may reflect the coarseness of the disease categories, and it may be that the firms commercialize alone when the product is close to their existing product and license out when not. This is consistent with the finding that they are more likely to license out the rights when the product is not in the same disease field as their existing products.

5. Conclusion

This paper formalizes, extends, and tests the framework for analyzing technology commercialization strategy presented in Teece (1986).

It nests the one-off commercialization choice imagined in Teece (1986) in a multi-period framework in which the innovating firm can learn from its experience in commercialization. Using the model it is possible to show that, contrary to the implication in Teece (1986), it may be optimal for the innovating firm to commercialize the innovation alone under certain conditions, even when the established product firms are much better positioned with respect to the requisite complementary assets. Moreover, the model also demonstrates that a hybrid strategy, in which the technology firm contracts with a product firm but retains the rights to participate in the commercialization process, may be preferable to either a straight licensing arrangement or no licensing (i.e., self-commercialization) under certain conditions. From the technology firm's perspective, this arrangement reduces the risk of failure in the short term, enabling it to bring its latest innovation to market in a timely and cost-effective manner, while at the same time giving it the opportunity to acquire the knowledge necessary to commercialize future innovations alone in the future. Nevertheless, to enter persuade the product firm to enter this arrangement it must compensate the product firm for training a competitor. Hence, the firm will only choose this arrangement if it is likely

to generate sufficient innovations in the same product field in future to recover the revenues foregone upfront.

Taken together, the empirical results provide evidence consistent with the model and the overall thesis of the paper: that the dynamic benefits of building its own specialized commercialization capabilities mean that an innovating firm is likely less likely to license out the commercialization rights (either whole or in part) even in conditions where Teece (1986) predicted that licensing would be the optimal strategy. In general, a firm is likely not to license its innovation when its R&D activities are more focused in a specific field, subject to being in a strong enough financial position to do so. Moreover, when it does license its innovation in such a field then it is likely to retain co-promotion rights. These are the fields in which it is likely to innovate in future and therefore the ones in which it is most likely to be able to leverage such capabilities.

That said, if it is already in the position to market a product in that field, it is more likely to retain the exclusive rights than to enter a co-promotion arrangement. In that case there is less benefit of learning and an opportunity cost of not exploiting its existing capabilities fully (Chan, Nickerson, & Owan, 2007). On the flip side, if the firm is in the position to market a product in *another* disease field, then it is more likely to license out the rights exclusively than to enter a co-promotion arrangement. Since commercialization capabilities are specific to a disease field, and are costly to develop and maintain, licensing out products in other areas enables it to concentrate its resources on building and maintaining commercialization capabilities in specific fields.

The findings have some pertinent implications for managers. While it may be necessary for a technology firm to partner with an established firm to obtain access to the requisite complementary assets, in negotiating such an alliance managers must also consider how the firm can achieve superior profitability over the long term. If the firm has specialized technological capabilities, so it expects to generate future innovations in the same product field, it is important to loosen the control that the established firms over the complementary assets necessary to commercialize an innovation. One way to do this is to use its leverage in alliance negotiations to acquire the knowledge necessary to build its own commercialization capabilities. Specifically, it can negotiate to the rights to participate in the commercialization process, and thereby learn directly from its alliance partner.

However, acquiring commercialization capabilities will only be worthwhile if the firm can generate sufficient innovations in the same product field. Building its own commercialization capabilities requires a substantial investment, which will only give a return over the longer term. At the same time, retaining rights to participate in the commercialization process is likely to involve sacrificing greater financial payments. While maintaining control over the commercialization process and acquiring its own capabilities may give the firm access to a greater revenue stream in the long term,

negotiating greater financial payments helps it to meet short-term obligations. If the firm is financially constrained, it may be better off giving up control of its innovations until it is in a stronger position. If the innovation is outside the firm's core focus then it is likely to be better off licensing the innovation and remaining out of the product field.

6. Appendix: Working to derive the equilibrium conditions

Building on the discussion in section 3.2, I now set out in more detail how I derive the conditions for each of the different strategies to be an equilibrium under the different scenarios.

6.1 Equilibrium conditions with $N = 1$ and $\phi = 1$

6.1.1 Equilibrium conditions without experiential learning

I start with the scenario when $N = 1$ and $\phi = 1$, and first solve for the case without experiential learning.

Substituting the values of $\Pi_{P_i}^{L}$ and $\Pi_{P_i}^{NL}$ from equations (4) and (5) into (8) means T will accept X^L if:

$$X^L \geq c_t + \lambda_T^{NL}(1)\pi$$

Meanwhile, substituting the values of $\Pi_{P_i}^{L}$ and $\Pi_{P_i}^{NL}$ from equations (6) and (7) into (9) reveals that P_i will offer X^L if

$$X^L \leq 2\lambda_{11}(1)\pi - \lambda_{P_i}^{NL}(1)\pi$$

Hence, under this scenario licensing will occur in equilibrium if and only if

$$c_t \leq 2\lambda_{11}(1)\pi - \lambda_{P_i}^{NL}(1)\pi - \lambda_T^{NL}(1)\pi$$

6.1.2 Equilibrium conditions with experiential learning

Solving equations (11) and (13) for Π_T^{NL} gives

$$\Pi_T^{NL'} = \frac{\lambda_{11}(1)\pi}{1-\delta}$$

$$\Pi_T^{NL} = \frac{\lambda_T^{NL}(1)\pi + \sigma_T^{NL}\dfrac{\delta}{1-\delta}\lambda_{11}(1)\pi}{1-\delta(1-\sigma_T^{NL})}$$

Meanwhile solving (12) and (14) for $\Pi_{P_i}^{NL}$ gives

$$\Pi_{P_i}^{NL'} = \frac{\lambda_{11}(1)\pi}{1-\delta}$$

$$\Pi_{P_i}^{NL} = \frac{\lambda_{P_i}^{NL}(1) + \frac{\delta}{1-\delta}\sigma_T^{NL}\lambda_{11}(1)}{1-\delta(1-\sigma_T^{NL})}\pi$$

As above, licensing will be preferred to not licensing equilibrium if there exists a X^L that satisfies equations (8) and (9) respectively. That is

$$X^L \geq c_t + \frac{1-\delta}{1-\delta(1-\sigma_T^{NL})}\left[\lambda_T^{NL}(1)\pi + \frac{\delta}{1-\delta}\sigma_T^{NL}\lambda_{11}(1)\pi\right]$$

and

$$X^L \leq 2\lambda_{11}(1)\pi - \frac{1-\delta}{1-\delta(1-\sigma_T^{NL})}\left[\lambda_{P_i}^{NL}(1)\pi + \sigma_T^{NL}\frac{\delta}{1-\delta}\lambda_{11}(1)\pi\right]$$

Under this scenario licensing will occur in equilibrium if and only if

$$c_t \leq \frac{1-\delta}{1-\delta(1-\sigma_T^{NL})}\left[2\lambda_{11}(1)\pi - \lambda_{P_i}^{NL}(1)\pi - \lambda_T^{NL}(1)\pi\right]$$

6.1.3 Equilibrium conditions with co-promotion

After T has successfully commercialized an innovation under a co-promotion arrangement, it has the same probability of commercialization as any potential product-firm partner and hence it will (weakly) prefer to not license the innovation but to develop the product alone. Hence $\Pi_T^{CP'} = \Pi_T^{NL'}$.

Substituting the value of Π_T^{NL} into equation (16) gives

$$\Pi_T^{CP} = \frac{X^{CP} - c_t + \frac{\delta}{1-\delta}\sigma_T^{CP}\lambda_{11}(1)\pi}{1-\delta\left(1-\sigma_T^{CP}\right)}$$

Meanwhile, since T will prefer not to license after it has successfully commercialized an innovation (as above), $\Pi_{P_i}^{CP'} = \Pi_{P_i}^{NL'}$. Substituting $\Pi_{P_i}^{NL'}$ for $\Pi_{P_i}^{CP'}$ gives

$$\Pi_{P_i}^{CP} = \frac{\lambda_T^{CP}(1)\pi - X^{CP} + \lambda_{P_i}^{CP}(1)\pi + \frac{\delta}{1-\delta}\sigma_T^{CP}\lambda_{11}(1)\pi}{1-\delta\left(1-\sigma_T^{CP}\right)}$$

Co-promotion vs. Licensing

First we consider the choice between co-promotion and licensing.

As outlined, T will prefer co-promotion to licensing if (18) is satisfied. This will be true if

$$X^{CP} \geq \frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta} X^{L} - \frac{\delta\sigma_T^{CP}}{1-\delta}\left(c_t + \lambda_{11}(1)\pi\right)$$

Meanwhile, P_i will prefer co-promotion to licensing if (19) is true. That is

$$X^{CP} \leq \frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta} X^{L} + \lambda_T^{CP}(1)\pi + \lambda_{P_i}^{CP}(1)\pi - 2\frac{1-\delta\left(1-\frac{1}{2}\sigma_T^{CP}\right)}{1-\delta}\lambda_{11}(1)\pi$$

As a consequence, the parties will choose co-promotion over licensing in equilibrium if and only if

$$c_t \geq \frac{1-\delta}{\delta\sigma_T^{CP}}\left(2\lambda_{11}(1) - \lambda_T^{CP}(1)\pi - \lambda_{P_i}^{CP}(1)\pi\right)$$

Co-promotion vs. Not Licensing/Self-commercialization

Now we consider the choice between co-promotion and not licensing/self-commercialization.

In accordance with (21), T will prefer co-promotion to not licensing/self-commercialization if

$$X^{CP} \geq c_t + \frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta(1-\sigma_T^{NL})}\lambda_T^{NL}(1)\pi - \frac{\delta\left(\sigma_T^{CP}-\sigma_T^{NL}\right)}{1-\delta(1-\sigma_T^{NL})}\lambda_{11}(1)\pi$$

Meanwhile, following (22), P will be willing to enter a co-promotion arrangement, rather than letting T commercialize alone, if

$$X^{CP} \leq \lambda_T^{CP}(1)\pi + \lambda_{P_i}^{CP}(1)\pi - \frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta(1-\sigma_T^{NL})}\lambda_{P_i}^{NL}(1)\pi + \frac{\delta\left(\sigma_T^{CP}-\sigma_T^{NL}\right)}{1-\delta(1-\sigma_T^{NL})}\lambda_{11}(1)\pi$$

Hence the parties will choose co-promotion over not licensing/self-commercialization if

$$c_t \le 2\frac{\delta\left(\sigma_T^{CP}-\sigma_T^{NL}\right)}{1-\delta(1-\sigma_T^{NL})}\lambda_{11}(1)\pi+\lambda_T^{CP}(1)\pi+\lambda_{P_i}^{CP}(1)\pi-\frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta(1-\sigma_T^{NL})}\left(\lambda_T^{NL}(1)\pi+\lambda_{P_i}^{NL}(1)\pi\right)$$

6.1.4 Equilibrium strategies when $\phi \le 1$

Solving these equations (24) to (28) gives

$$\Pi_T^0 = \frac{\delta\phi}{1-\delta\left(1-\phi\right)}\Pi_T^S$$

$$\Pi_T^L = \frac{1-\delta\left(1-\phi\right)}{1-\delta}\left(X^L - c_t\right)$$

$$\Pi_T^{NL'} = \frac{1-\delta\left(1-\phi\right)}{1-\delta}\lambda_{11}(1)\pi$$

$$\Pi_T^{NL} = \frac{1-\delta\left(1-\phi\right)}{1-\delta+\delta\phi\sigma_T^{NL}\left(1-\delta\left(1-\phi\right)\right)}\lambda_T^{NL}(1)\pi+\frac{\frac{\delta}{1-\delta}\phi\sigma_T^{NL}\left(1-\delta\left(1-\phi\right)\right)^2}{1-\delta+\delta\phi\sigma_T^{NL}\left(1-\delta\left(1-\phi\right)\right)}\lambda_{11}(1)\pi$$

$$\Pi_T^{CP} = \frac{1-\delta+\delta\phi}{1-\delta+\delta\phi\sigma_T^{CP}\left(1-\delta+\delta\phi\right)}\left(X^{CP}-c_t\right)+\frac{\frac{\delta}{1-\delta}\phi\sigma_T^{CP}\left(1-\delta\left(1-\phi\right)\right)^2}{1-\delta+\delta\phi\sigma_T^{CP}\left(1-\delta+\delta\phi\right)}\lambda_{11}(1)\pi$$

As above, we can let $\Pi_{P_i}^{CP'} = \Pi_{P_i}^{NL'}$.

Solving equations (29) to (33) gives

$$\Pi_{P_i}^0 = \frac{\lambda_{P_i}^0(1)\pi+\delta\phi\Pi_{P_i}^S}{1-\delta\left(1-\phi\right)}\text{, where } \Pi_{P_i}^S = \Pi_{P_{-i}}^S \text{ if } S = NL$$

$$\Pi_{P_i}^L = \frac{1-\delta\left(1-\phi\right)}{1-\delta}\left(\lambda_T^L(1)\pi - X^L + \lambda_{P_i}^L(1)\pi\right)+\frac{\delta\left(1-\phi\right)}{1-\delta}\lambda_{P_i}^0(1)\pi$$

$$\Pi_{P_i}^{NL'} = \frac{1-\delta\left(1-\phi\right)}{1-\delta}\lambda_{P_i}^{NL'}(1)\pi+\frac{\delta\left(1-\phi\right)}{1-\delta}\lambda_{P_i}^0(1)\pi$$

$$\Pi_{P_i}^{NL} = \frac{1-\delta(1-\phi)}{1-\delta+\delta\phi\sigma_T^{NL}(1-\delta(1-\phi))}\left(\lambda_{P_i}^{NL}(1)\pi + \frac{\delta\phi\sigma_T^{NL}(1-\delta(1-\phi))}{1-\delta}\lambda_{P_i}^{NL'}(1)\pi\right) + \frac{\delta(1-\phi)}{1-\delta}\lambda_{P_i}^{0}(1)\pi$$

$$\Pi_{P_i}^{CP} = \frac{1-\delta(1-\phi)}{1-\delta+\delta\phi\sigma_T^{CP}(1-\delta(1-\phi))}\left(\lambda_T^{CP}(1)\pi - X^{CP} + \lambda_{P_i}^{CP}(1)\pi\right)$$

$$+\frac{\delta}{1-\delta}\phi\sigma_T^{CP}\frac{(1-\delta(1-\phi))^2}{1-\delta+\delta\phi\sigma_T^{CP}(1-\delta(1-\phi))}\lambda_{P_i}^{NL'}(1)\pi + \frac{\delta}{1-\delta}(1-\phi)\lambda_{P_i}^{0}(1)\pi$$

Licensing vs. Not licensing/Self-commercialization

Licensing will be an equilibrium if

$$X^L \geq c_t + \frac{1-\delta}{1-\delta(1-\delta\phi\sigma_T^{NL}(1-\delta(1-\phi)))}\lambda_T^{NL}(1)\pi + \frac{\delta\phi\sigma_T^{NL}(1-\delta(1-\phi))}{1-\delta(1-\delta\phi\sigma_T^{NL}(1-\delta(1-\phi)))}\lambda_{11}(1)\pi$$

and

$$X^L \leq \left(1+\frac{1-\delta}{1-\delta(1-\delta\phi\sigma_T^{NL}(1-\delta(1-\phi)))}\right)\lambda_{11}(1)\pi - \frac{1-\delta}{1-\delta(1-\delta\phi\sigma_T^{NL}(1-\delta(1-\phi)))}\lambda_{P_i}^{NL}(1)\pi$$

Under this scenario licensing will occur in equilibrium if and only if

$$c_t \leq \frac{1-\delta}{1-\delta(1-\delta\phi\sigma_T^{NL}(1-\delta(1-\phi)))}\left(2\lambda_{11}(1)\pi - \lambda_T^{NL}(1)\pi - \lambda_{P_i}^{NL}(1)\pi\right)$$

Co-promotion vs. Licensing

T will prefer co-promotion to licensing if

$$X^{CP} \geq \frac{1-\delta+\delta\phi\sigma_T^{CP}(1-\delta+\delta\phi)}{1-\delta}X^L - \frac{\delta\phi\sigma_T^{CP}(1-\delta+\delta\phi)}{1-\delta}(\lambda_{11}(1)\pi + c_t)$$

Meanwhile, P_i will prefer co-promotion to licensing if

$$X^{CP} \leq \lambda_T^{CP}(1)\pi + \lambda_{P_i}^{CP}(1)\pi + \frac{\delta}{1-\delta}\phi\sigma_T^{CP}(1-\delta(1-\phi))\lambda_{P_i}^{NL'}(1)\pi$$

$$-\frac{1-\delta+\delta\phi\sigma_T^{CP}(1-\delta(1-\phi))}{1-\delta}\left(\lambda_T^{L}(1)\pi - X^L + \lambda_{P_i}^{L}(1)\pi\right)$$

Hence the parties will choose co-promotion over licensing in equilibrium if and only if

$$c_t \geq \frac{1-\delta}{\delta\phi\sigma_T^{CP}\left(1-\delta+\delta\phi\right)}\left(2\lambda_{11}(1)\pi - \lambda_T^{CP}(1)\pi - \lambda_{P_i}^{CP}(1)\pi\right)$$

Co-promotion vs. Not Licensing/Self-commercialization

Finally T will prefer co-promotion to not licensing/self-commercialization if

$$X^{CP} \geq c_t + \frac{1-\delta+\delta\phi\sigma_T^{CP}\left(1-\delta+\delta\phi\right)}{1-\delta+\delta\phi\sigma_T^{NL}\left(1-\delta+\delta\phi\right)}\lambda_T^{NL}(1)\pi$$
$$-\frac{\delta\phi\left(1-\delta\left(1-\phi\right)\right)}{1-\delta}\left(\sigma_T^{CP} - \frac{1-\delta+\delta\phi\sigma_T^{CP}\left(1-\delta+\delta\phi\right)}{1-\delta+\delta\phi\sigma_T^{NL}\left(1-\delta+\delta\phi\right)}\sigma_T^{NL}\right)\lambda_{11}(1)\pi$$

Meanwhile P will be willing to enter a co-promotion arrangement, rather than letting T commercialize alone, if

$$X^{CP} \leq \lambda_T^{CP}(1)\pi + \lambda_{P_i}^{CP}(1)\pi - \frac{1-\delta+\delta\phi\sigma_T^{CP}\left(1-\delta\left(1-\phi\right)\right)}{1-\delta+\delta\phi\sigma_T^{NL}\left(1-\delta\left(1-\phi\right)\right)}\lambda_{P_i}^{NL}(1)\pi$$
$$+\frac{\delta}{1-\delta}\phi\left(1-\delta\left(1-\phi\right)\right)\left(\sigma_T^{CP} - \frac{1-\delta+\delta\phi\sigma_T^{CP}\left(1-\delta\left(1-\phi\right)\right)}{1-\delta+\delta\phi\sigma_T^{NL}\left(1-\delta\left(1-\phi\right)\right)}\sigma_T^{NL}\right)\lambda_{11}(1)\pi$$

Hence the parties will choose co-promotion over not licensing/self-commercialization if

$$c_t \leq 2\frac{\delta\phi\left(1-\delta\left(1-\phi\right)\right)}{1-\delta+\delta\phi\sigma_T^{NL}\left(1-\delta\left(1-\phi\right)\right)}\left(\sigma_T^{CP}-\sigma_T^{NL}\right)\lambda_{11}(1)\pi + \lambda_T^{CP}(1)\pi + \lambda_{P_i}^{CP}(1)\pi$$
$$-\frac{1-\delta+\delta\phi\sigma_T^{CP}\left(1-\delta+\delta\phi\right)}{1-\delta+\delta\phi\sigma_T^{NL}\left(1-\delta+\delta\phi\right)}\left(\lambda_T^{NL}(1)\pi + \lambda_{P_i}^{NL}(1)\pi\right)$$

6.1.5 Equilibrium conditions with $N>1$ & $\phi=1$

Solving equations (37) to (40) gives

$$\Pi_T^L = \frac{X^L - c_t}{1-\delta}$$

$$\Pi_T^{NL'} = \frac{\lambda_T^{NL'}(N)\pi}{1-\delta}$$

$$\Pi_T^{NL} = \frac{\lambda_T^{NL}(N)\pi + \frac{\delta}{1-\delta}\sigma_T^{NL}\lambda_T^{NL'}(N)\pi}{1-\delta\left(1-\sigma_T^{NL}\right)}$$

$$\Pi_T^{CP} = \frac{X^{CP} - c_t + \frac{\delta}{1-\delta}\sigma_T^{CP}\lambda_T^{NL'}(N)\pi}{1-\delta\left(1-\sigma_T^{CP}\right)}$$

Setting $\Pi_{P_i}^{CP'} = \Pi_{P_i}^{NL'}$ and solving equations (41) to (46) gives

$$\Pi_{P-i}^{L} = \frac{N\lambda_{P_i}^{L}(N)\pi + \delta\Pi_{P_i}^{L}}{N-\delta\left(N-1\right)}$$

$$\Pi_{P_i}^{L} = \frac{N-\delta\left(N-1\right)}{N\left(1-\delta\right)}\left(\lambda_T^{L}(N)\pi - X^{L}\right) + \frac{1}{1-\delta}\lambda_{P_i}^{L}(N)\pi$$

$$\Pi_{P_i}^{NL'} = \frac{\lambda_{P_i}^{NL'}(N)\pi}{1-\delta}$$

$$\Pi_{P_i}^{NL} = \frac{\lambda_{P_i}^{NL}(N)\pi + \frac{\delta}{1-\delta}\sigma_T^{NL}\lambda_{P_i}^{NL'}(N)\pi}{1-\delta\left(1-\sigma_T^{NL}\right)}$$

$$\Pi_{P_{-i}}^{CP} = \frac{N\left(\lambda_{P-i}^{CP}(N)\pi + \frac{\delta}{1-\delta}\sigma_T^{CP}\lambda_{P_i}^{NL'}(N)\pi\right) + \delta\left(1-\sigma_T^{CP}\right)\Pi_{P_i}^{CP}}{N-\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)}$$

$$\Pi_{P_i}^{CP} = \frac{\left(N-\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)\right)\left(\lambda_T^{CP}(N)\pi - X^{CP} + \lambda_{P_i}^{CP}(N)\pi\right)}{N\left(1-\delta\left(1-\sigma_T^{CP}\right)\right)}$$
$$+\frac{\frac{\delta}{1-\delta}N\sigma_T^{CP}\lambda_{P_i}^{NL'}(N)\pi + \delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)\lambda_{P-i}^{CP}(N)\pi}{N\left(1-\delta\left(1-\sigma_T^{CP}\right)\right)}$$

Licensing vs. Not-licensing/Self-commercialization

Licensing will be an equilibrium if

$$X^L \geq c_t + \frac{1-\delta}{1-\delta(1-\sigma_T^{NL})}\lambda_T^{NL}(N) + \frac{\delta}{1-\delta(1-\sigma_T^{NL})}\sigma_T^{NL}\lambda_T^{NL'}(N)\pi$$

and

$$X^L \leq \frac{\left(2N-\delta\left(N-1\right)\right)\left(1-\delta\right)+\delta\sigma_T^{NL}\left(N-\delta\left(N-1\right)\right)}{\left(N-\delta\left(N-1\right)\right)\left(1-\delta(1-\sigma_T^{NL})\right)}\lambda_{11}(N)\pi$$
$$-\frac{\left(1-\delta\right)N}{\left(1-\delta\left(1-\sigma_T^{NL}\right)\right)\left(N-\delta\left(N-1\right)\right)}\lambda_{P_i}^{NL}(N)\pi$$

Hence licensing will occur in equilibrium if and only if

$$c_t \leq \frac{1-\delta}{1-\delta(1-\sigma_T^{NL})}\left(\lambda_{11}(N)\pi - \lambda_T^{NL}(N) + \frac{N}{N-\delta\left(N-1\right)}\left(\lambda_{11}(N)\pi - \lambda_{P_i}^{NL}(N)\pi\right)\right)$$

Co-promotion vs. Licensing

T will prefer co-promotion to licensing if

$$X^{CP} \geq \frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta}X^L - \frac{\delta}{1-\delta}\sigma_T^{CP}\left(c_t + \lambda_T^{NL'}(N)\pi\right)$$

Meanwhile, P_i will prefer co-promotion to licensing if

$$X^{CP} \leq \lambda_T^{CP}(N)\pi + \lambda_{P_i}^{CP}(N)\pi - \frac{\left(1-\delta\left(1-\sigma_T^{CP}\right)\right)\left(2N-\delta\left(N-1\right)\right)-\delta N\sigma_T^{CP}}{\left(1-\delta\right)\left(N-\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)\right)}\lambda_{11}(N)\pi$$
$$+\frac{\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)}{N-\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)}\lambda_{P-i}^{CP}(N)\pi + \frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta}\frac{N-\delta\left(N-1\right)}{N-\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)}X^L$$

Hence the parties will choose co-promotion over licensing in equilibrium if and only if

$$c_t \leq \frac{\left(1-\delta\left(1-\sigma_T^{CP}\right)\right)\left(N-1\right)}{N-\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)}X^L + \frac{2N\left(1-\delta\right)-\delta\left(N-1\right)\left(1-\delta+\delta\sigma_T^{2CP}\right)}{\delta\sigma_T^{CP}\left(N-\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)\right)}\lambda_{11}(N)\pi$$
$$+\frac{\left(1-\delta\right)\left(1-\sigma_T^{CP}\right)\left(N-1\right)}{\sigma_T^{CP}\left(N-\delta\left(1-\sigma_T^{CP}\right)\left(N-1\right)\right)}\lambda_{P-i}^{CP}(N)\pi - \frac{1-\delta}{\delta\sigma_T^{CP}}\left(\lambda_T^{CP}(N)\pi + \lambda_{P_i}^{CP}(N)\pi\right)$$

Co-promotion vs. Not Licensing/Self-commercialization

T will prefer co-promotion to not licensing/self-commercialization if

$$X^{CP} \geq c_t - \frac{\delta\left(\sigma_T^{CP} - \sigma_T^{NL}\right)}{1-\delta\left(1-\sigma_T^{NL}\right)}\lambda_T^{NL'}(N)\pi + \frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta\left(1-\sigma_T^{NL}\right)}\lambda_T^{NL}(N)\pi$$

Meanwhile P will be willing to enter a co-promotion arrangement, rather than letting T commercialize alone, if

$$\begin{aligned} X^{CP} \leq \lambda_T^{CP}(N)\pi + \lambda_{P_i}^{CP}(N)\pi + \frac{\delta N\left(\sigma_T^{CP} - \sigma_T^{NL}\right)}{1-\delta\left(1-\sigma_T^{NL}\right)\left(\left(N-\delta\left(1-\sigma_T^{CP}\right)(N-1)\right)\right)}\lambda_{11}(N)\pi \\ -N\frac{1-\delta\left(1-\sigma_T^{CP}\right)}{\left(1-\delta\left(1-\sigma_T^{NL}\right)\right)\left(\left(N-\delta\left(1-\sigma_T^{CP}\right)(N-1)\right)\right)}\lambda_{P_i}^{NL}(N)\pi \\ +\frac{\delta\left(1-\sigma_T^{CP}\right)(N-1)}{\left(N-\delta\left(1-\sigma_T^{CP}\right)(N-1)\right)}\lambda_{P_{-i}}^{CP}(N)\pi \end{aligned}$$

Hence the parties will choose co-promotion over not licensing/self-commercialization if

$$\begin{aligned} c_t \leq \lambda_T^{CP}(N)\pi + \lambda_{P_i}^{CP}(N)\pi + \frac{\delta\left(\sigma_T^{CP} - \sigma_T^{LN}\right)\left(2N-\left(1-\sigma_T^{CP}\right)(N-1)\right)}{1-\delta\left(1-\sigma_T^{NL}\right)\left(\left(N-\delta\left(1-\sigma_T^{CP}\right)(N-1)\right)\right)}\lambda_{11}(N)\pi \\ -\frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta\left(1-\sigma_T^{NL}\right)}\left(\lambda_T^{NL}(N)\pi - \frac{N}{\left(\left(N-\delta\left(1-\sigma_T^{CP}\right)(N-1)\right)\right)}\lambda_{P_i}^{NL}(N)\pi\right) \\ +\frac{\delta\left(1-\sigma_T^{CP}\right)(N-1)}{\left(N-\delta\left(1-\sigma_T^{CP}\right)(N-1)\right)}\lambda_{P_{-i}}^{CP}(N)\pi \end{aligned}$$

6.2 Proofs of Propositions derived from the model

In this section I show the formal proofs for the various lemmas and propositions presented in section 3.3.

Proof of Lemma 1

From (10), licensing will be a equilibrium in the game without experiential learning if

$$c_t \leq 2\lambda_{11}(1)\pi - \lambda_{P_i}^{NL}(1)\pi - \lambda_T^{NL}(1)\pi$$

Substituting in the values of $\lambda_{11}(1)$, $\lambda_{P_i}^{NL}(1)$, and $\lambda_T^{NL}(1)$ into this expressions gives

$$c_t \leq \left(1-\sigma_{P_i}^{NL}\right)\left(\sigma_{P_i}^{NL}-\sigma_T^{NL}\right)\pi$$

By definition, $0 \leq \sigma_T^{NL} < \sigma_{P_i}^{NL} < 1$ and $\pi > 0$, so $\left(1-\sigma_{P_i}^{NL}\right)\left(\sigma_{P_i}^{NL}-\sigma_T^{NL}\right)\pi > 0$ and for all allowable values of σ_T^{NL} and $\sigma_{P_i}^{NL}$ there are non-negative values of c_t that satisfy this equation. Moreover, if $c_t = 0$ then the licensing will be the unique equilibrium for all allowable values of σ_T^{NL} and $\sigma_{P_i}^{NL}$.

Proof of Lemma 2

From (15), the parties will agree to licensing in the game with experiential learning if

$$c_t \leq \frac{1-\delta}{1-\delta(1-\sigma_T^{NL})}\left[2\lambda_{11}(1)\pi - \lambda_{P_i}^{NL}(1)\pi - \lambda_T^{NL}(1)\pi\right]$$

Substituting the values of $\lambda_{11}(1)$, $\lambda_{P_i}^{NL}(1)$, and $\lambda_T^{NL}(1)$ into these expressions gives

$$c_t \leq \frac{1-\delta}{1-\delta(1-\sigma_T^{NL})}\left(1-\sigma_{P_i}^{NL}\right)\left(\sigma_{P_i}^{NL}-\sigma_T^{NL}\right)\pi$$

Since $0 \leq \sigma_T^{NL} < \sigma_{P_i}^{NL} < 1$ by definition, $\frac{1-\delta}{1-\delta(1-\sigma_T^{NL})} < 1$ and therefore

$$\frac{1-\delta}{1-\delta(1-\sigma_T^{NL})}\left(1-\sigma_{P_i}^{NL}\right)\left(\sigma_{P_i}^{NL}-\sigma_T^{NL}\right)\pi \leq c_t \leq \left(1-\sigma_{P_i}^{NL}\right)\left(\sigma_{P_i}^{NL}-\sigma_T^{NL}\right)\pi$$

Hence the likelihood that licensing is an equilibrium outcome is lower in a technology commercialization game with experiential learning than without, or obversely the likelihood that not licensing is an equilibrium outcome is higher in a technology commercialization game with experiential learning than without.

Proof of Lemma 3

From (20) and (23), in the game with experiential learning where $\phi = 1$ and $N = 1$, co-promotion will be an equilibrium outcome if

$$c_t \geq \frac{1-\delta}{\delta\sigma_T^{CP}}\left(2\lambda_{11}(1)\pi - \lambda_T^{CP}(1)\pi - \lambda_{P_i}^{CP}(1)\pi\right)$$

and

$$c_t \leq \lambda_T^{CP}(1)\pi + \lambda_{P_i}^{CP}(1)\pi + 2\frac{\delta\left(\sigma_T^{CP} - \sigma_T^{NL}\right)}{1-\delta(1-\sigma_T^{NL})}\lambda_{11}(1)\pi - \frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta(1-\sigma_T^{NL})}\left(\lambda_T^{NL}(1)\pi + \lambda_{P_i}^{NL}(1)\pi\right)$$

Combining these two constraints and substituting the values of $\lambda_{11}(N)$ and $\lambda_{P_i}^{NL}(N)$ from equations (1) and (2) this means that co-promotion will be an equilibrium outcome if

$$\frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta(1-\sigma_T^{NL})}\left(\frac{\sigma_{P_i}^{NL}\left(1-\frac{1}{2}\sigma_{P_i}^{NL}\right)\left(\delta\left(\sigma_T^{CP}-\sigma_T^{NL}\right)-(1-\delta)\right)}{\frac{-\delta\sigma_T^{CP}\left(\sigma_T^{NL}-\sigma_T^{NL}\sigma_{P_i}^{NL}+\sigma_{P_i}^{NL}\right)+\left(1-\delta(1-\sigma_T^{NL})\right)\left(\sigma_T^{CP}-\sigma_T^{CP}\sigma_{P_i}^{CP}+\sigma_{P_i}^{CP}\right)}{\delta\sigma_T^{CP}}}\right)\pi \geq 0$$

Substituting in the values of $\sigma_{P_i}^{L} = \sigma_{P_i}^{NL} = \sigma_{P_i}^{CP} = \sigma_T^{L} = \sigma_T^{NL'} = \sigma_1$, $\sigma_T^{NL} = \sigma_0 < \sigma_1$ and $\sigma_T^{CP} = \frac{1}{2}(\sigma_0 + \sigma_1)$, we can see that

$$(1-\sigma_1)(\sigma_1-\sigma_0)(\delta\sigma_1 - 1 + \delta)(\delta\sigma_0 + \delta\sigma_1 + 2 - 2\delta) \geq 0$$

which is true when $\sigma_1 \geq \frac{1-\delta}{\delta}$. Hence co-promotion is an equilibrium outcome if $\sigma_T^{NL} = \sigma_0$, $\sigma_{P_i}^{L} = \sigma_{P_i}^{NL} = \sigma_{P_i}^{CP} = \sigma_T^{L} = \sigma_T^{NL'} = \sigma_1 > \sigma_0$, $\sigma_T^{CP} = \frac{1}{2}(\sigma_0 + \sigma_1)$ and $\sigma_1 \geq \frac{1-\delta}{\delta}$. More generally, co-promotion is an equilibrium outcome if

$$\frac{1-\delta\left(1-\sigma_T^{CP}\right)}{1-\delta(1-\sigma_T^{NL})}\left(\frac{\sigma_{P_i}^{NL}\left(1-\frac{1}{2}\sigma_{P_i}^{NL}\right)\left(\delta\left(\sigma_T^{CP}-\sigma_T^{NL}\right)-(1-\delta)\right)}{\frac{-\delta\sigma_T^{CP}\left(\sigma_T^{NL}-\sigma_T^{NL}\sigma_{P_i}^{NL}+\sigma_{P_i}^{NL}\right)+\left(1-\delta(1-\sigma_T^{NL})\right)\left(\sigma_T^{CP}-\sigma_T^{CP}\sigma_{P_i}^{CP}+\sigma_{P_i}^{CP}\right)}{\delta\sigma_T^{CP}}}\right)\pi \geq 0$$

Proof of Proposition 1

From (34), in the game with experiential learning where $\phi \leq 1$ the parties will choose licensing over letting *T* commercialize alone if

$$c_t \leq \frac{1-\delta}{1-\delta\left[1-\delta\phi\sigma_T^{NL}\left(1-\delta\left(1-\phi\right)\right)\right]}\left(2\lambda_{11}(1)\pi - \lambda_T^{NL}(1)\pi - \lambda_{P_i}^{NL}(1)\pi\right)$$

The derivative of the right hand side with respect to ϕ is

$$\frac{\partial}{\partial\phi}(\cdot) = \frac{-\delta^2\sigma_T^{NL}\left(1-\delta\left(1-2\phi\right)\right)}{\left\{1-\delta\left[1-\delta\phi\sigma_T^{NL}\left(1-\delta\left(1-\phi\right)\right)\right]\right\}^2}\left(2\lambda_{11}(1)\pi - \lambda_T^{NL}(1)\pi - \lambda_{P_i}^{NL}(1)\pi\right)$$

Since $0 < \sigma_T^{NL} < 1$ and $0 < \phi < 1$ by definition, the derivative with respect to ϕ is always negative and hence the right-hand of (34) is decreasing in ϕ. This means that as ϕ increases, there will be fewer values of c_t for which licensing is an equilibrium and hence the likelihood that licensing in an equilibrium decreases, all else held equal.

Proof of Proposition 2

From (35), in the game with experiential learning where $\phi \leq 1$ the parties will choose co-promotion over licensing in equilibrium if

$$c_t \geq \frac{1-\delta}{\delta\phi\sigma_T^{CP}\left(1-\delta+\delta\phi\right)}\left(2\lambda_{11}(1)\pi - \lambda_T^{CP}(1)\pi - \lambda_{P_i}^{CP}(1)\pi\right)$$

The derivative of the right hand side with respect to ϕ is

$$\frac{\partial}{\partial\phi}\left(\frac{1-\delta}{\delta\phi\left(1-\delta+\delta\phi\right)}\frac{1}{\sigma_T^{CP}}\left(2\lambda_{11}(1)\pi - \lambda_T^{CP}(1)\pi - \lambda_{P_i}^{CP}(1)\pi\right)\right)$$
$$= \left(2\lambda_{11}(1)\pi - \lambda_T^{CP}(1)\pi - \lambda_{P_i}^{CP}(1)\pi\right)\frac{-\delta\sigma_T^{CP}\left(1-\delta\right)\left(1-\delta+2\delta\phi\right)}{\left(\delta\sigma_T^{CP}\phi\left(1-\delta+\delta\phi\right)\right)^2}$$

Since $\sigma_T^{CP} \in (0,1)$, $\delta \in (0,1)$, and $\phi \in (0,1]$, the right-hand side of (35) is always negative. This means that the threshhold level of transaction costs at which it becomes more profitable to co-promote goes down as ϕ increases. Hence co-promotion becomes more likely relative to straight licensing as ϕ increases, or the likelihood of co-promotion is increasing in ϕ.

7. Tables & Figures

Table 1: Summary statistics

	Panel A				*Panel B*			
	All observations (N=81067)				*Observations with licenses (N=343)*			
	mean	*s.d.*	*min*	*max*	*mean*	*s.d.*	*min*	*max*
Biotech retains rights to co-promote the alliance product	-	-	-	-	0.43	0.50	0	1
Number of product firms active in disease field[1]	122.22	62.59	1	218	125.50	67.06	1	218
Proportion of biotech firm's prior alliances in disease field	0.24	0.22	0	1	0.27	0.26	0	1
Valuation ($M)[2,3]	16388.70	30596.34	-1022.477	105902.20	4283.45	14781.83	-32.274	83300.00
Age (months since founding)	215.99	93.51	1	720	172.00	76.91	4	489
Count of biotech's prior alliances	84.84	85.17	1	370	47.74	55.49	1	309
Biotech has marketing rights to approved product in same disease field (d)	0.39	0.49	0	1	0.19	0.40	0	1
Biotech has marketing rights to approved product in another disease field (d)	0.17	0.38	0	1	0.18	0.38	0	1
Product passed Phase I (d)	0.64	0.48	0	1	0.62	0.49	0	1
Product passed Phase II (d)	0.35	0.48	0	1	0.33	0.47	0	1
Biotech equity market index	588.88	287.95	66.27	1022.82	548.35	295.88	93.37	1022.82
Year	2002.22	4.77	1981	2008	2001.35	5.06	1985	2008

Notes:

1. All pharmaceutical firms or biotech firms with marketing rights to an approved product that have a transaction in product field in two years prior or year following the alliance.
2. In December 2008 US dollars.
3. For publicly listed firms, market valuation at end of prior month; for private firms, post-money value at end of last financing round.

Table 2: Correlation matrix

		(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(0)	Biotech retains rights to co-promote the alliance product	1.00										
(1)	Number of product firms active in disease field (log)[1]	0.14	1.00									
(2)	Proportion of biotech firm's prior alliances in disease field	0.19	0.31	1.00								
(3)	Valuation ($M, log)[2,3]	-0.09	-0.05	-0.14	1.00							
(4)	Age (months since founding)	-0.16	0.24	-0.21	0.41	1.00						
(5)	Count of biotech's prior alliances (log)	-0.14	0.10	-0.28	0.71	0.58	1.00					
(6)	Biotech has marketing rights to approved product in same disease field (d)	-0.20	0.17	0.05	0.34	0.31	0.39	1.00				
(7)	Biotech has marketing rights to approved product in another disease field (d)	-0.09	-0.09	-0.28	0.07	0.26	0.15	-0.23	1.00			
(8)	Product passed Phase I (d)	-0.05	0.18	0.16	0.08	0.24	0.14	0.26	-0.11	1.00		
(9)	Product passed Phase II (d)	-0.16	-0.05	0.07	0.10	0.15	0.06	0.31	-0.08	0.55	1.00	
(10)	Year of alliance	0.12	0.61	0.09	0.09	0.46	0.27	0.23	-0.06	0.34	0.09	1.00

Notes:

1. All pharmaceutical firms or biotech firms with marketing rights to an approved product that have a transaction in product field in two years prior or year following the alliance.
2. In December 2008 US dollars.
3. For publicly listed firms, market valuation at end of prior month; for private firms, post-money value at end of last financing round.

Table 3: Cox proportional hazard-rate analysis

	Model 1	Model 2a	Model 2b	Model 2b - Model 2a†
	L=1	L=1 & CoP=0	L=1 & CoP=1	
Proportion of biotech firm's prior alliances in disease field	-0.563	-1.184	0.299	1.483
	(0.387)	(0.429)***	(0.447)	(4.82)**
Number of product firms active in disease field (log)[1]	0.596	1.936	4.095	2.159
	(0.543)	(0.534)***	(1.556)***	(1.42)
Valuation ($M, log) [2,3]	-0.134	-0.225	0.00937	0.234
	(0.0626)**	(0.0535)***	-0.0951	(4.34)**
Firm age	-0.0037	-0.00228	-0.00537	-0.003
	(0.00153)**	(0.00143)	(0.00201)***	(1.300)
Count of biotech's prior alliances (log)	-0.0551	0.0331	-0.0819	-0.115
	(0.139)	(0.148)	(0.174)	(0.260)
Biotech has marketing rights to approved product in same disease field (d)	-0.496	0.0487	-1.352	-1.401
	(0.276)*	(0.281)	(0.587)**	(5.050)**
Biotech has marketing rights to approved product in another disease field (d)	0.350	0.704*	-0.277	-0.981
	(0.340)	(0.381)*	(0.442)	(3.260)*
Product in at least Phase III trials (d)	0.418	0.549	0.0746	-0.474
	(0.141)***	(0.146)***	(0.230)	(2.170)
Disease field fixed effects	Y	Y	Y	
Number of firm-product-indication monthly observations	81067	81067	81067	
Number of firm-product-indications	1591	1591	1591	
Number of products	757	757	757	
Number of alliances	343	194	148	
Standard errors, clustered by product, in parentheses				
† difference in coefficients, chi-squarred in parentheses				
*** p<0.01, ** p<0.05, * p<0.1				

Notes:

1. All pharmaceutical firms or biotech firms with marketing rights to an approved product that have a transaction in product field in two years prior or year following the alliance.
2. In December 2008 US dollars.
3. For publicly listed firms, market valuation at end of prior month; for private firms, post-money value at end of last financing round.

Table 4: Heckman selection analysis

	Model 3	
	L=1	CoP=1|L=1
Proportion of biotech firm's prior alliances in disease field	-0.201	0.596
	(0.100)**	(0.268)**
Number of product firms active in disease field (log)[1]	-0.0599	0.295
	(0.122)	(0.151)*
Valuation ($M, log) [2,3]	-0.0504	0.128
	(0.0143)***	(0.0529)**
Firm age	-0.00141	0.000527
	(0.000343)***	(0.00131)
Count of biotech's prior alliances (log)	-0.0155	0.0105
	(0.0308)	(0.0682)
Biotech has marketing rights to approved product in same disease field (d)	-0.155	-0.0451
	(0.0598)***	(0.180)
Biotech has marketing rights to approved product in another disease field (d)	0.121	-0.336
	(0.0607)**	(0.159)**
Product in at least Phase III trials (d)	0.128	-0.301
	(0.0451)***	(0.141)**
Baseline hazard of outlicensing	0.298	
	(0.244)	
Last month of quarter or last quarter of year (d)	0.0950	
	(0.0380)**	
Inverse Mills ratio		-1.723
		(0.877)**
Disease field fixed effects	Y	Y
Constant	-2.245	4.521
	(0.378)***	(2.477)*
Number of firm-product-indication monthly observations	81066	81066
Number of firm-product-indications	1591	342
Number of products	757	211

Standard errors, clustered by product, in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Notes:
1. All pharmaceutical firms or biotech firms with marketing rights to an approved product that have a transaction in product field in two years prior or year following the alliance.
2. In December 2008 US dollars.
3. For publicly listed firms, market valuation at end of prior month; for private firms, post-money value at end of last financing round.

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