Managing licensing in a market for technology[♣]

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Abstract

Technology licensing is an important means for companies to extract more value from their intellectual assets. We build a model that helps understand how licensing activity should be organized within large corporations. More specifically, we compare decentralization—where the business unit using the technology makes licensing decisions—to centralized licensing. The business unit has superior information about licensing opportunities but may not have the appropriate incentives because its rewards depend upon product market performance. If licensing is decentralized, the business unit forgoes valuable licensing opportunities since the rewards for licensing are (optimally) weaker than those for product market profits. This distortion is stronger when production-based incentives, especially private benefits of business unit managers, are more powerful, making centralization more attractive. Surprisingly, we find that inter-dependency across business units may result in more, not less, decentralization. Further, even though centralization results in less information, centralized licensing deals are larger. Our model conforms to the existing evidence that reports heterogeneity across firms in both licensing propensity and organization of licensing.

Keywords: Licensing, markets for technology, organization design

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1. Introduction

In the management of innovation, the traditional logic, where innovation was closed off from outside ideas and technologies, is being challenged by the *open innovation* paradigm: Firms need not rely only on their own ideas, and may pursue new avenues for exploiting in-house technology (e.g., Laursen and Salter 2006), often by participating in the market for technology (Arora et al., 2001). Indeed, many firms, including IBM, Texas Instruments, Hitachi, Dow, Kodak, Eli Lilly, and Proctor and Gamble, have embraced a policy of actively licensing their technology to others, earning millions of dollars in licensing revenues (*The Economist* 2005). Surveys indicate that in over half the firms, IP managers report pressures to increase direct income from IP.[1]

The growth of markets for technology notwithstanding (Robbins 2006; Athreye and Cantwell 2007; Arora and Gambardella 2010), there is widespread evidence that a large number of potentially value-enhancing deals are not consummated (Razgaitis 2004; Gambardella et al. 2007). Cockburn and Henderson (2003) report that nearly 75% of the IP managers surveyed believed that they could increase licensing revenues without impairing their competitive advantage. In other words, there is money left on the table in terms of forgone licensing opportunities.

Conflicts inside the firm are often identified as an important cause of this inefficiency (Razgatis 2004).[2] Consistent with this, Cockburn and Henderson (2003) report that 38% of the IP managers in the large firms surveyed stated that their licensing revenues were constrained by the reluctance of business units to license. It suggests that firms must fine-tune the internal organization of their licensing business to fully reap the benefits offered by markets for technology.

A key issue is whether business units, which are likely to use technology, should be left to handle licensing on their own, or whether licensing should be centralized at the corporate level. We lack systematic evidence on this topic, but Davis and Harrison (2001), in their study of IP management practices, classify Dow and Du Pont as decentralized, whereas IBM and Litton are characterized as centralized. Other firms, such as Lockheed, are said to have hybrid licensing structures.[3]

Despite the growing literature on open innovation, little is known on how large, multidivisional firms should organize to participate in the market for technology, and specifically, whether this activity should be centralized, or delegated to divisions (business units). We develop a parsimonious theoretical model to understand this important organizational decision and investigate

[1] See IPO Corporate IP Management Benchmarking Survey (years 2003, 2006, 2009).
[2] There are other important reasons as well, including difficulty in finding licensees and in contracting.
[3] Cockburn and Henderson (2003) report that in 40% of the cases, the licensing decision is controlled by corporate management, whereas business unit managers (including marketing, manufacturing and product managers) control licensing in 10% of the cases, but enjoy a veto over licensing in over 60% of the cases.

how it affects licensing. We focus on two factors: differences in information, and differences in incentives. Decentralization exploits local information not available to headquarters, but decentralized decisions may not be in the best interests of the shareholders. In our model the top management of the firm decides whether to delegate licensing to the business unit that manufactures the product, or to centralize licensing in a specialized licensing unit.

Licensing generates an up-front fee but dissipates production profits in the longer run due to competition from the licensee (*rent dissipation*). The business unit is best able to assess whether a potential deal will enhance overall profits, but it has an interest in protecting the rents accruing from production because both the incentives and private benefits of the unit's managers are anchored to production-based performance.[4] The top management offers incentives by sharing licensing revenues with the business unit, which is costly. Alternatively, licensing can be centralized, albeit at the cost of accepting some loss making deals.

The model produces several interesting results and testable empirical implications. First, when the business unit is in charge of licensing, it forgoes valuable licensing opportunities because the rewards for licensing are (optimally) weaker than those for product market performance. Thus, our model rationalizes under-licensing as a byproduct of decentralized licensing decision, and predicts that when firms centralize licensing the propensity to license increases as does the size of the average consummated deal. This is in line with anecdotal evidence. For instance, Marshall Phelps, who oversaw IBM's licensing division during the 1990s, when its licensing revenues increased from a very modest level to over $1 billion a year, centralized what had hitherto been a de facto decentralized licensing system (Phelps and Kline 2009).[5]

Second, the distortion in the business unit's licensing decisions is stronger when production-based incentives in the company are more powerful, which, in turn, makes centralization of licensing more attractive. In addition, our model suggests that as private benefits become more salient, rewards for licensing are muted and decentralization becomes less efficient.

Third, licensing decisions are delegated to the business unit when the potential downside from licensing is large relative to the revenue. This is, for instance, the case of marginal innovations that are more likely to generate direct competition in the product market.

[4] Incentives inside organizations need not only be monetary. Managers derive private benefits from higher profits and revenue growth in the divisions they manage because of a taste for empire building, because of career concerns, or because they dislike to lay-off workers.

[5] As an IP manager for Boeing, which began to license more aggressively in the last decade, explained "… (H)aving an enterprise wide business unit to manage these (intellectual property) assets … is so important. We're able to make licensing decisions on the basis of the probability of economic benefit to Boeing as a whole" (Kline 2003).

Fourth, traditional wisdom suggests that centralization is more likely in the presence of multiple business units whose decisions affect each other. We extend our model to incorporate multiple business units and spillovers, i.e., licensing by one unit reduces the payoff of another unit. The unexpected finding our model delivers is that when production-based incentives are large, spillovers make decentralization more appealing, not less, as they reduce the costs of incentivizing business units to license.

Finally, though we focus on firms' licensing of in-house technology, the other side of the coin is firms' sourcing technology from outside. Our model extends to the situation in which individual business units (e.g., R&D units) have superior information about the benefits of external technologies. A similar agency conflict within the firm makes decentralization of in-licensing decisions costly and leads to the "not-invented-here" bias against externally developed technology (Katz and Allen 1982). Thus, our model also illuminates some of the tradeoffs a firm faces when it decides to open up to outside ideas and technologies (Chesbrough 2003).

2. Related Literature

A large literature examines various aspects of inter-firm licensing such as the reasons for technology licensing (Arora and Fosfuri 2003; Rockett 1990; Gallini 1984), the factors enhancing or limiting licensing activity (Fosfuri 2006; Arora and Ceccagnoli 2005; Teece 1986; Gans and Stern 2003), and the optimal design of licensing contracts (Kamien and Tauman 2002; Gallini and Wright 1990). We see our paper as linking licensing to the management literature that studies the relationship between organizational structure and firm strategy (Chandler 1962).

A central tenet in business strategy is that organizational structure forms the basis for how strategy is implemented. For instance, scholars have argued that decentralized organizational structures stimulate innovation by exploiting local knowledge and allowing for swift responses to changes in the environment (Burns and Stalker 1961; Slater and Narver 1995), but these advantages may come at the cost of more narrow and incremental R&D (Argyres and Silverman 2004). A more recent literature explores how the internal organization influences a firm's "openness" to the use of external knowledge sources in its innovation process (Cassiman and Valentini 2009; Foss et al. 2011; Leiponen and Helfat 2011). We complement this literature by studying the interplay between the internal organization and the licensing of a firm's technology to external parties.

In addition to the works mentioned in the introduction, a few other papers have empirically related licensing to organizational structure. Pitkethly (2001) argues that Japanese firms actively search for licensees, more so than UK firms, because of greater top management involvement. Consistent with the predictions of our model, Lichtenthaler (2011) concludes that centralization of licensing is associated with higher rates of licensing. Lichtenthaler (2010) finds that licensing revenues are maximal for an intermediate level of centralization of licensing decisions and for an intermediate level of alignment between headquarters' and business units' interests. We find that licensing is maximized for a hybrid structure, where large licensing deals are accepted directly by the top management, and smaller deals are left to business units to decide.

The literature finds that decentralization and delegation of authority enables firms to use the local information available to business units. Team production theory (e.g., Radner and Marschak 1972), which pioneered the formal study of how authority should be delegated in organizations, holds that authority should be delegated to divisions if the information available to them cannot be communicated to headquarters quickly and cheaply. Our model incorporates the importance of local information but also highlights the agency problem implicit in relying upon the unit's information that the organizational economics literature has stressed (for a review, see Mookherji 2006).

Closer to our paper, Dewatripont and Tirole (1999) show that the bundling of tasks with conflicting objectives—such as licensing and production—increases the cost of incentive provision and calls for a separation of tasks. In our context, the cost of incentive provision must be weighed against the efficient use of information, which requires bundling of tasks. Riordan and Sappington (1987) analyze a model where the principal may reduce the agent's informational advantage by doing one of the tasks herself. However, unlike production and licensing, the tasks are independent, which would remove the agency conflict in our framework. The difficulties involved in managing multiple operations inside the firm are also present in the recent literature on organizational economics. For instance, Garicano et al. (2010), analyze a model with two business units that can create negative externalities for each other, leading to centralization. We find conditions such that the opposite result holds because the negative externalities actually lower the cost of incentive provision.

3. A Model of Licensing: Assumptions and Notations

The firm. The firm consists of a risk-neutral management unit (henceforth, HQ) and a risk-neutral and wealth and credit-constrained business unit (henceforth, BU). There are two main activities to be performed: production, which the BU is in charge of, and licensing, which can be decentralized to the BU or centralized in a specialized licensing unit in the HQ (see below). We model production as reduced form since our primary interest is the internal organization of licensing. The firm has a technology that is currently employed by the BU to produce and that generates an expected gross profit of π, absent licensing. We ignore for now the R&D process that has generated such technology but discuss this issue in **§**4.3.2.

Licensing. The technology used by the BU can also be licensed to other firms. We assume that there is a probability *q* of finding a potential licensee where *q* parameterizes the size of the market for technology. Each deal differs along two dimensions: the value that it generates for the licensee and the extent to which it destroys profits in the product market for the licensor. The value the potential licensee obtains from the licensed technology is $\tilde{w}$ where $\tilde{w}$ is a random variable uniformly distributed on $[0, z]$. The realized value of $\tilde{w}$ is denoted by *w*. Without loss of generality we normalize z=1, so that all costs and benefits must be interpreted relatively to the revenues from licensing. This formulation is consistent with the notion that the technology developed by the firm has many applications, and its value depends on the potential licensee. Rent dissipation is parameterized by $\tilde{x}$, a random variable whose realized value is denoted by *x*. Rent dissipation arises primarily because licensing increases the competition the licensor faces in the product market (Arora and Fosfuri 2003), i.e., after licensing production profits are $\pi - x$. We assume that $\tilde{x}$ is uniform on $[0, c]$ and that $\tilde{w}$ and $\tilde{x}$ are independently distributed. We shall discuss this assumption in **§**4.3.2. Note that *c* parameterizes the extent of rent dissipation as greater *c* implies higher expected costs from licensing.

We assume that *w* can be observed both by the BU and the HQ. However, although the distribution of $\tilde{x}$ is common knowledge, only the BU observes x. As discussed earlier, the BU is directly involved with the manufacturing and commercialization of the final product, and so is better equipped to evaluate the degree of competition from the licensee.[6] The key is that it is not possible to contract upon *x* because, for instance, rent dissipation materializes over time and cannot be distinguished from other factors influencing profits, such as changing market conditions.

We assume that searching for potential licensing deals is costly. The technology must be marketed, and employees need to scan and monitor the external environment. The BU can search for licensees at a lower cost than the HQ due to its better knowledge of the technology and the market. For the sake of simplicity, the search cost of the BU is set equal to zero whereas the search cost of the HQ is $\sigma > 0$.

[6] As a licensing executive from Ford Motor Company put it

> … Our engineers may be working with a supplier (*who is*) going to make parts … based on Ford intellectual property. The supplier and the engineer may realize "*This could be good technology to make parts or something for other companies, both inside and outside the automotive industry*. *But … the supplier needs a license* …". Harry Fradkin, Ford Motor Company, quoted in Davis and Harrison (2001, page 76; emphasis added).

Finally, the licensee is assumed to receive a take-it-or-leave offer. This takes bargaining out of the equation. It follows that all inefficiencies in the licensing decisions are caused by agency problems inside the firm. In §4.3.2 we discuss how the introduction of bargaining would affect our findings.

Payoff structure. We analyze linear contracts, which are simple, robust, and optimal inside our framework. A fraction γ_1 of the production profits is paid as bonus to the BU. We will refer to γ_1 as "monetary benefits".[7] In addition, the BU may enjoy "private benefits" as well. For instance, managers might like being the boss of a larger outfit because of greater job safety and better career opportunities, or they might simply dislike having to lay workers off. We model private benefits as a fraction γ_0 of profits from production. The key distinction is that whereas monetary benefits directly reduce overall firm profits (i.e., they are transfer from the HQ to the BU), private benefits do not. Finally, the HQ assigns a fraction θ of the licensing revenue to the BU when the latter has licensing authority. All payments from the HQ to the BU must be non-negative, which rules out the option of "selling the firm" to the BU manager.

Let $\gamma = \gamma_1 + \gamma_0$ (i.e., total benefits to the BU for production) and $a = 1 - \gamma_1$. Notice that for any given γ, an increase in a reflects a decrease in the importance of monetary benefits relative to private benefits. In the baseline model we treat γ as exogenous. The endogenous production bonus is addressed in the extensions §.

The BU maximizes the sum of the payoff from production and licensing, net of the cost of licensing. Notice that the opportunity cost of licensing to the BU is γx because licensing reduces production profits. We assume that the participation constraint of the BU does not bind.[8] The HQ maximizes the profit from production plus the net revenue from licensing, minus the monetary payments to the BU. Results would remain qualitatively unchanged if the HQ were to maximize the revenue (sales) rather than the profit from production plus the net revenue from licensing, minus the monetary payments to the BU. They would disappear if, in addition, the HQ were to maximize the gross rather than the net revenue from licensing.

Organization of licensing. In our setting w and x are measured at the deal level, while all other variables are at the firm or technology level. Therefore, w and x determine whether a particular deal goes through or not, whereas the other parameters jointly determine how licensing is organized.

[7] A different interpretation is that γ_1 is the share of production profits that the BU managers appropriate in the form of perquisites such as expensive meals or air travel in corporate jets (Jensen and Meckling 1976; Fama 1980). The crucial distinction is that γ_1 has a direct cost to the firm, unlike γ_0.

[8] If the participation constraint of the BU were to bind, the HQ would internalize the payoff of the BU fully. The HQ would therefore maximize total profits (profits from production plus licensing) and the agency problem would disappear. Assuming that the participation constraint binds in some but not all states of the world would give rise to more case distinctions, but it would not change results qualitatively.

We solve the model under two different organizational solutions for the licensing activity. First, we analyze the fully decentralized solution in which the BU both searches and decides on licensing. This case provides intuition that carries over in the rest of the paper. In particular, it shows the reason for the chronic under-licensing. Second, we consider the solution in which the HQ takes over the licensing activity, centralizes the search for potential licensees, and decides on all deals.

The timing of the game. At $t = 0$, R&D efforts result in a new technology and the monetary benefits γ_1 and private benefits γ_0 are established (either exogenously or endogenously). At $t = 1$, the HQ chooses the organizational form for the licensing activity and the licensing bonus θ to the BU. At $t = 2$, production and licensing take place. At $t = 3$, rent dissipation from licensing unfolds. We focus primarily on stages $t = 1$ to $t = 3$ in the analysis below and discuss stage $t = 0$ in §4.3.2 (R&D stage) and §5.2 (endogenous γ). The game is solved backward in order to find the subgame perfect Nash equilibrium.

4. Solving the Model

In the analysis, we make the following assumption:

Assumption 1: $\frac{c}{a+2\gamma} \geq 1 \geq \frac{ca}{2}$.

The first part of the inequality implies that for any w, there are deals that destroy value. The second part implies that at least some licensing deals are attractive to the HQ in the sense that the maximal value of licensing revenues $z=1$ is greater than the expected share of profit dissipation. This assumption sidesteps some uninteresting special cases, but our results hold even if it is relaxed.

4.1. Decentralization: The BU searches and decides on licensing

When licensing is decentralized the HQ chooses the share θ of the licensing revenue given to the BU. Foreseeing that the BU will license only if $\theta w/\gamma \geq x$, the HQ solves the following problem:

$$\mathrm{Max}_{\theta}\ a\pi + q\int_0^1\int_0^{\frac{\theta w}{\gamma}}[(1-\theta)\mathrm{w} - \mathrm{ax}]\frac{1}{\mathrm{c}}\mathrm{dx\,dw}. \tag{1}$$

Using $\widetilde{w} \sim U[0,1]$ and $\tilde{x} \sim U[0,c]$, the HQ's problem can be rewritten as:

$$\mathrm{Max}_{\theta}\ a\pi + \frac{q\theta}{6\gamma^2 c}[2\gamma - \theta(a + 2\gamma)]. \tag{2}$$

Maximizing profits with respect to θ yields $\theta^* = \frac{\gamma}{a+2\gamma}$.[9] HQ profits are equal to:

$$\Pi_{\mathrm{D}} = a\pi + q\frac{1}{6c(a+2\gamma)}. \tag{3}$$

[9] It is easy to show that this is also the optimal licensing bonus if the bonus could be made contingent on w. This implies that the linear bonus scheme derived above is fully optimal.

The probability of licensing conditional on a potential licensee being found is:

$$\int_0^1 \int_0^{\frac{\theta^* w}{\gamma}} \frac{1}{c} dx dw = \frac{1}{2c(a+2\gamma)}. \quad (4)$$

This leads to the following proposition:

Proposition 1. *When the BU is in charge of licensing: (i) Licensing incentives are lower than total production benefits, i.e.* $\theta^* < \gamma$*; (ii) Higher total production benefits reduce licensing by increasing the gap between total production benefits and licensing incentives i.e.,* $\frac{\partial\left(\frac{\gamma}{\theta^*}\right)}{\partial \gamma} > 0$*; (iii) For a given level of total production benefits, an increase in the relative importance of private benefits also reduces licensing by increasing the gap between total production benefits and licensing incentives, i.e.,* $\frac{\partial\left(\frac{\gamma}{\theta^*}\right)}{\partial a} > 0$ *(iv) Licensing profits are decreasing in the monetary and the private benefits.*

4.1.1. Discussion

Result (i) in Proposition 1 holds under more general conditions. For instance, it does not depend on the specific distribution chosen for $\tilde{w}$ and $\tilde{x}$ (see Appendix A1) and also holds when monetary benefits, γ_1, are endogenous (see §5.1). Moreover, it does not depend on the presence of private benefits as $\theta^* < \gamma_1$ for $\gamma_0 = 0$. The intuition for the result is that the HQ acts like a monopsonist, who restricts the quantity of licenses by setting too low a licensing bonus. In so doing, the HQ trades off losing the surplus from the marginal deals in exchange for reducing the payment to the BU for the infra-marginal deals. For $\gamma_0 = 0$, choosing $\theta = \gamma$ would maximize total value; however, the HQ can obtain a larger fraction of rents from licensing by reducing θ. For $\gamma_0 > 0$, choosing $\theta = \gamma$ would imply that the value from the marginal deal is negative, thus the HQ has incentives to lower θ such that the value from the marginal deal is equal to zero (i.e. $\theta = \frac{\gamma}{a+\gamma}$). However, the HQ prefers to lower θ even further to pay less on inframarginal deals at the cost of losing marginal deals of positive value.

Part (i) of Proposition 1 highlights the problems firms face in opening to the market for technology. Interviews with BU managers confirm that they are typically judged using profits and sales targets, and, in some cases, cash flow as well. These interviews also indicated that licensing revenues are reported separately to the HQ under the category of “other income”. When asked, the managers confirmed that though licensing revenues could help them reach a profit target, they could not help with sales targets. In other words, there is a disincentive to license, consistent with our model.

Part (ii) suggests that the licensing disincentive is more pronounced if production benefits are high-powered. The intuition is that stronger production benefits necessitate stronger licensing incentives, thereby increasing the infra-marginal gain from distorting the licensing bonus downward. Hoskisson et al. (1993) report that large diversified firms tend to use financial controls (i.e. evaluating division managers based on financial performance) to manage their BUs rather than strategic metrics (i.e., evaluating division managers based on operational understanding of strategies proposed, such as improvements in customer satisfaction or growth in new products). Thus, we expect more under-licensing in large, diversified industrial companies, insofar as they are more likely to use high-powered incentives (a larger γ in our model).

Part (iii) points out that the distortionary effect of production benefits is accentuated when production benefits are tilted towards private benefits. Like monetary benefits, private benefits require additional offsetting incentives for licensing, but unlike monetary benefits, there is no offsetting reduction in the HQ's share of rent dissipation. Consequently, higher private benefits reduce licensing. Part (iv) shows that high-powered production benefits tend to crowd-out licensing as it is costlier for the HQ to incentivize the BU to license. Obviously we cannot conclude that the firm should try to reduce production benefits or shift them from private to monetary (also, they are assumed to be exogenous here) without taking into account their role in encouraging effort by the BU managers. Nevertheless, Proposition 1 iii and iv suggest that firms should pay attention to the negative effect of production benefits - especially private benefits - on licensing when this activity is left to the BU.

4.2. Centralization: the HQ searches and licenses

This solution can be thought of as a situation in which the HQ takes over the licensing activity. For instance, Glaxo has created a central licensing unit, while Microsoft handles licensing at the company's headquarters. Similarly, Du Pont has created a licensing unit that executes licensing deals (Sterling and Murray 2007).

Once the HQ observes w associated with a potential deal, it can decide to license or reject the deal. Naturally, the HQ's decision is contingent on w. Let $\widehat{w}$ be the licensing revenues threshold such that any deal for which $w \geq \widehat{w}$ the HQ licenses. Instead all deals such that $w < \widehat{w}$ are rejected. The HQ maximizes the following:

$$\max_{\widehat{w}} a\pi + q \int_{\widehat{w}}^{1} \int_{0}^{c} [w - ax] \frac{1}{c} \mathrm{d}x \mathrm{d}w - \sigma.$$

Using $\widetilde{w} \sim U[0,1]$ and $\tilde{x} \sim U[0,c]$ we obtain:

$$\max_{\widehat{w}} a\pi + \frac{q}{2}(1 - \widehat{w})(1 + \widehat{w} - ca) - \sigma. \tag{5}$$

Using Assumption 1, the first-order conditions with respect to $\hat{w}$ yields $\hat{w}^* = \frac{ca}{2}$. Replacing $\hat{w}^*$ in (5), one obtains the profit in the centralized case and the probability of licensing:

$$\Pi_C = a\pi + q\frac{(2-ac)^2}{8} - \sigma, \qquad (6)$$

provided that σ is sufficiently small to make it profitable to search for a licensee.

The probability of licensing conditional on a potential licensee being found is: $1 - \frac{ca}{2}$.

Proposition 2. *When licensing is centralized, the probability of licensing conditional on a potential licensee being found is independent of private benefits and increases with monetary benefits.*

The HQ does not need to pay a share θ of the revenues from licensing to incentivize licensing. However, the share of the rent dissipation from licensing borne by the HQ is decreasing in γ_1. Hence, the HQ is more willing to license for high monetary benefits to the BU. Notice that private benefits, γ_0, are ignored by the HQ in its licensing decision because they affect neither the revenues nor the rent dissipation experienced by the HQ. Notice also that under centralization, only "big" deals, i.e., where the revenue is greater than a threshold level, are executed.

4.3. The choice of the organizational mode for licensing

We now move the analysis from the deal to the technology (firm) level; i.e., should the HQ leave the licensing activity entirely to the BU or should it centralize it?[10]

Let $\Pi_C - \Pi_D = q\Delta(c,\gamma,a) - \sigma$, where

$\Delta(c,\gamma,a) = \left[\frac{(2-ac)^2}{8} - \frac{1}{6c(a+2\gamma)}\right]$. If $\Delta(c,\gamma,a) \geq \frac{\sigma}{q}$, then centralization is preferred to decentralization.

Proposition 3: *A necessary condition for centralization to dominate decentralization is* $\gamma > \frac{(4\sqrt{3}-5)}{23}(1+\gamma_0)$. *Other things equal, the parameter space under which centralized licensing dominates decentralized licensing expands as* $\frac{\sigma}{q}$ *decreases,* γ_0 *or* γ_1 *increase, and* a *increases given* γ. *If* $\gamma < \frac{(1+2\sqrt{3})}{11}(1+\gamma_0)$, *then the parameter space for which centralization dominates decentralization expands as c decreases.*

Proof: See Appendix A2.

The centralized solution is only observed if the agency conflict resulting from decentralized licensing as measured by total production benefits γ is sufficiently strong. In this case, decentralization arises in equilibrium even if there are no asymmetries in search costs. Thus, the

[10] Firm level and technology level are interchangeable here.

choice between centralization and decentralization is not only driven by search costs but also by the tradeoff between the cost of the agency conflict and that of less informed decisions. The centralized solution is less likely to be observed if q is small and/or search costs are large, production benefits are relatively weak, especially those that are private, and c is large.

While the comparative statics with respect to $\frac{\sigma}{q}$ is straightforward, the others can be intuitively understood by noticing that decentralization is costly because the HQ has to pay a share θ of the revenues from licensing. Since production benefits make the BU more reluctant to license the technology, licensing profits for the HQ decrease with production benefits, especially private benefits. Instead, the cost of centralizing licensing arises from the signing of value-destroying deals, i.e., those deals for which the rent dissipation may (with some probability) exceed the revenue. Since the expected rent dissipation is greater under centralization, the HQ tends to prefer centralization for high monetary benefits as the rent dissipation is shared to a greater extent with the BU. It is easy to see that the latter effect is independent of the distributions of w and x. However, the fact that licensing profits under decentralization decrease with monetary benefits depends on the chosen distributions. For any distribution, one can show that centralization is more likely to arise in equilibrium when monetary benefits increase if monetary benefits are not too small and the distribution of x is not too unfavorable compared to the distribution of w. The probability that the rent dissipation is larger than the revenue from licensing increases with c. Hence, except for very high values of γ, the value of the BU's private information about x increases as c increases.[11]

Proposition 4: *For parameters such that centralized licensing is preferred to decentralized licensing, the probability of licensing is higher under centralization than under decentralization.*

Proposition 4 shows that the agency problem under decentralization results in a lower propensity to patent compared to centralization, which is a potentially testable implication of the analysis.

Proof: See Appendix A3.

4.3.1. Discussion

[11] If production benefits are very large and the licensing opportunities are very rich (i.e. c is small enough), a modest increase in c may make centralization even more attractive relative to decentralization, in some range. Centralization performs better than decentralization when the rent dissipation is borne by the BU to a large extent. An increase in c may reduce profits less under centralization (due to more unprofitable licensing deals being accepted) than under decentralization (due to more profitable licensing deals being rejected). Under this parameter configuration, which is not economically very relevant, there can be a non-monotonic relationship between the choice of the organizational form for licensing and c.

Proposition 3 identifies the conditions under which licensing activity is fully decentralized. In the case of a multi-technologies company, this proposition refers to the technology level; that is, which technologies are decentralized and which ones are assigned to the corporate level. This proposition produces several testable implications.

First and foremost, our model explains under-licensing under decentralization. Anecdotal accounts, supported by survey evidence, suggest that firms systematically forgo licensing opportunities. Surveys of licensing executives reveal that even when a potential licensee has been identified, only for a third of the cases are negotiations started, and fewer than half of those negotiations are completed (Razgaitis 2004). In addition to the usual problems of incomplete contracts, these surveys indicate that agency problems—internal conflicts among stakeholders—are an important reason for the failure of valuable deals to go forward. Consistent with this, Gambardella et al. (2007) report that large firms, which arguably suffer more from agency problems, are also more likely to experience under-licensing.

There is other evidence supporting our prediction that decentralization is associated with lower licensing rates. A recent survey of US patent holders by Jung and Walsh (2010) finds that patents where the inventor is from the manufacturing unit (rather than central R&D) are less likely to be licensed. Patents from R&D units are more likely to be controlled by the HQ rather than the BU (Arora et al. 2011). Taken together, these findings indicate that patents controlled by the BU are less likely to be licensed.

Second, our model shows that the move from decentralization to centralization of licensing will be accompanied by an increase in the frequency and average size of licensing deals. Recall that under centralization, only deals with revenue above $\hat{w}^*$ are accepted. Further, Proposition 4 shows that centralization also involves a greater overall probability of licensing. IBM's centralization of licensing was marked by a dramatic increase in the frequency and size of licensing deals. Similarly, Kodak's well publicized recent emphasis on licensing its technology has been accompanied by a centralization of its licensing activities. Consistent with this, Lichthenthaler (2011) reports that in the 25 large firms he studies, centralization (and the presence of a specialized licensing unit) is associated with higher licensing.

Third, our model also predicts that firms will centralize licensing when the technology is more general. That is, we should observe decentralization of licensing when licensing deals are more likely to generate rent dissipation compared to their revenue potential, i.e., a higher *c*. This is, for instance, the case when the potential licensee competes in the same product market of the licensor and thus licensing destroys profits of both the licensor and the licensee. One can argue that general-purpose technologies are characterized by less direct competition between licensor and licensee. “A more general technology allows a larger degree of transferability of skills across the different sectors of the economy” (Aghion et al. 2002). Thus, Proposition 3 implies that the more specific is the technology, the more likely it is that a firm will confer the licensing authority to the BU. Consistent with this, Arora et al. (2011) find that patents assigned to business units tend to be narrower and more incremental as compared to centrally-assigned patents. Palomeras (2007) finds that firms are more likely to license patents with greater generality through an online market for technology, yet2.com. Using an online market to sell technology is akin to removing the authority over licensing decisions from the BU, because such patents are typically offered to any bidder willing to pay the required licensee fees.

4.3.2. Additional implications and ramifications of the model

Hybrid organization: For the sake of exposition, we have characterized the choice between centralization and decentralization as dichotomous; firms either delegate all licensing authority to the BU or they centralize the decision and do not rely on local information. In reality, firms organize licensing in hybrid forms in which although search for potential deals, contract design and final authority to license is kept at the corporate level, the BU is consulted about the suitability of different deals. In a working paper, we extend our simple model to uncover hybrid organizational forms for licensing. Interesting enough, Propositions 3 and 4 above apply *mutatis mutandis*. The fraction of deals that are delegated to the BU is greater when production benefits are weak, especially private production benefits, and c is large. Hybrid organizational forms also imply higher probability to license.

Correlation: For simplicity, we have also assumed that w and x are independently distributed. However, it is plausible that the revenue from licensing and the rent dissipation are correlated. Greater correlation can stem from greater precision, that is, observation of the revenue from licensing provides a more precise signal of the rent dissipation. In this case, the information of the BU becomes less relevant because, under centralization, the HQ observes the revenue from licensing and, thus, can infer the rent dissipation with greater accuracy. This favors centralization.

However, greater correlation can also stem from greater covariance between w and x. For instance, deals that bring more value to the licensee, because the licensee is a more efficient firm, also increase the competitive pressure that the licensor faces (positive covariance). On the other hand, a greater distance in the product (or geographical) space between the licensee and the licensor would reduce product market competition, and thus would create greater returns to both the licensee and the licensor (negative covariance). In the case in which correlation is due to greater covariance, the information of the BU becomes relatively more important as higher revenue deals are associated with higher expected rent dissipation, thus favoring decentralization of licensing.

R&D: We have ignored the technology generation stage of the model. However, including an R&D stage would not substantially change our main findings. Assume that the expected value of a technology depends positively on the effort exerted by the BU. The consideration of a technology generation stage might affect the allocation of licensing authority. Indeed, as Aghion and Tirole (1997) point out, allocating the formal decision right to an agent increases her incentive to invest in the relationship. Decentralization of authority implies greater rewards for the BU and thus ex ante more incentives to expend effort in the development of the technology. In other words, we expect that decentralization of licensing should be associated with a decentralization of R&D to BUs. Extending this reasoning a step further, Proposition 3 would suggest that one should observe that BUs tend to develop more focused, narrower technologies, while general-purpose technologies are developed centrally, which is indeed what Argyres and Silverman (2004) find.

Bargaining: Finally, in the analysis above, we have assumed that both the BU and the HQ are able to fully extract the licensee's willingness to pay w. Consider a variant of the model where bargaining leads to a split of the gains from trade among the parties involved (formal calculations are available from the authors upon request). In particular, the licensor (either the BU or the HQ) obtains a share λ of the bargaining surplus and the licensee obtains a share $1 - \lambda$. Suppose also that while the BU and the licensee observe x due to their direct knowledge of the industry, the HQ does not. Notice that this slightly more general setup nests the base model for $\lambda = 1$.

Assume first a decentralized solution where the BU searches for and negotiates with a potential licensee. Denote the licensing fee L. The minimum fee that the BU is willing to accept is $L_{Min} = \gamma x/\theta$ and the maximum fee that the licensee is willing to pay is $L_{Max} = w$. Hence, as above, there is licensing if and only if $w \geq \gamma x/\theta$. However, the licensing fee is now $L^* = \frac{\lambda w+(1-\lambda)\gamma x}{\theta+\lambda(1-\theta)}$, which is increasing in λ and decreasing in θ. For $\lambda < 1$, the HQ has thus an additional incentive to distort θ (further) downward in order to induce the BU to drive a tougher bargain with potential licensees.

Instead, if the HQ negotiates with the licensee, there will be licensing if and only if $w \geq E(x) = c/2$, and the resulting licensing fee is $L^* = \lambda w + (1-\lambda)(1-\gamma)\frac{c}{2}$.[12] By centralizing the licensing decision, the HQ saves licensing bonus but 1) it makes less informed decisions and 2) it loses the ability to leverage the BU's bargaining power through a reduction in θ. The weaker the bargaining

[12] The licensee observes x, but unlike, for example, the bargaining game of Farrell and Gibbons (1989), this piece of information can never be transmitted to the HQ as "cheap talk" because the two parties have opposing interests: The licensee would always claim x to be whatever results in the lowest possible licensing fee. For this reason, the licensee's information about x cannot influence the bargaining outcome.

position of the licensor (i.e., the lower is λ), the greater the benefit from delegating the negotiations to the BU. We should thus observe more decentralization and lower licensing bonuses in situations where the licensor is in a weak bargaining position.

5. Extensions

There are three aspects of our model that we have simplified to make it tractable and obtain useful insights: 1) we have assumed that the firm has only one BU; 2) we have assumed that monetary benefits are exogenous; 3) we have looked at out-licensing only. We shall relax these assumptions below. The first extension is important because large companies have several BUs. The second extension captures changes that might occur in a company across time, when the whole incentive system ends up adapting to markets for technology. The third extension focuses on the potential implications that agency problems inside large firms may have in acquiring technologies from outside.

5.1 Two BUs

Large companies have several BUs. If these units are independent, our model applies with little change. However, if licensing by a BU has spillovers for other units in the firm, the organization of licensing raises new issues.[13] One might suspect that with multiple BUs, centralization would be more profitable if licensing by one BU imposes rent dissipation on another. However, this intuition is only partially correct, and in some cases, misleading.

Consider a variation of the basic model where there are two BUs, BU_A and BU_B. It is helpful to imagine one single BU being split into two, identical in all ways except in how they experience rent dissipation. To maintain focus, we ignore search costs.[14] The two BUs produce total production profits of π. As before, the revenue from a deal is w. The total rent dissipation is x, but it does not affect the two units equally. With 50% probability, BU_A experiences a loss of $\phi_L x$ and BU_B experiences a loss of $\phi_H x$ where $\phi_L < ½$ and $\phi_L + \phi_H = 1$. Symmetrically, with 50% probability BU_B experiences a loss of $\phi_L x$ and BU_A experiences $\phi_H x$. Both units observe their rent dissipation when a potential deal materializes.

[13] For instance, Kodak's chemical BU, Eastman Chemicals, had a proprietary polyester technology that was used by its polyester division to serve the final market. However, when the company licensed the polyester technology to Huls, the photography business objected because Huls was owned by AGFA, which competed in photographic films (personal interview with Cecil Quillen, ex-General Counsel, Eastman Kodak, 4/1/2010).

[14] Decentralization with two BUs may imply higher search costs. Our focus here is to show that the standard coordination argument for centralization does not necessarily prevail.

Since total rent dissipation remains the same, profits under centralization are the same as with one BU. Under decentralization, we assume that each BU gets a share θ of the licensing revenue, independently of whether it is the BU initiating the licensing deal or not.[15] If unit j discovers a potential licensee, it licenses the technology if $\frac{x}{w} \leq \frac{\theta}{\gamma\phi_j}$. The expected profit of the firm with two BUs (net of the payment to the units) is thus:

$$\Pi \quad = a\pi + \sum_{j=L,H}\left(\frac{1}{2}\int_0^1\int_0^{\frac{\theta w}{\phi_j\gamma}}[(1-2\theta)w - ax]\frac{1}{c}dx\,dw\right).$$

Proposition 5: *For* $\phi_L < \frac{1}{2}$, *both the probability to license and profits under decentralization are strictly greater with two BUs than with one BU if and only if* $3\gamma_1 + 2\gamma_0 > 1$.

Proof: See Appendix A4.

Before discussing the intuition, it is worth stressing the implications of this result. The presence of spillovers across divisions is usually seen as a justification for centralized decision making. However, by proposition 5, as long as $3\gamma_1 + 2\gamma_0 > 1$, a firm with two BUs has higher profits when it decentralizes. This contrasts, for example, with Garicano et al. (2010), where intra-organizational externalities increase incentive costs, because the surplus-maximizing HQ optimally induces the BUs to internalize the externalities.

To understand the intuition behind proposition 5, note that spillovers across units create a new type of inefficiency (bad decisions made) but also mitigates an inefficiency present in the single BU case (too few good decisions made). If $\phi_j = \phi_L$, the BU receives half of the total licensing bonus, but experiences less than half of the total rent dissipation. It accepts deals that a single BU would not have accepted. Similarly, if $\phi_j = \phi_H$, the BU rejects deals that a single BU would have accepted. Thus, with two BUs, there is a tradeoff. On the one hand, there are profitable deals made that a single BU would have rejected ("good decisions") because of the problem of under-licensing we discussed above. On the other hand, there are "bad decisions" where either unprofitable deals are accepted that a single BU would have rejected (if $\phi_j = \phi_L$ for the BU in charge), or profitable deals are rejected that a single BU would have accepted (if $\phi_j = \phi_H$).

However, as production benefits increase, under-licensing becomes a more severe problem: the additional loss from bad decisions in the two BU case relative to the single BU case is smaller than the gain from making more good decisions. In other words, the higher the production benefits,

[15] Focusing on symmetric licensing bonuses is without loss of generality because the BUs are ex-ante symmetric. Assuming that both BUs receive a licensing bonus will imply that the one BU case and two BUs case yield identical outcomes with symmetric rent dissipation (i.e., ϕ_L = ½), providing us with a nice benchmark. Dropping this assumption strengthens our finding as explained later.

the greater the gain from increasing licensing and the smaller is the inefficiency due to uncoordinated licensing decisions across BUs.[16] Consequently, for high production benefits, spillovers in licensing across BUs may favor decentralization rather than centralization.

Spillovers across business units favor decentralization even more if the firm can adopt the hybrid solution discussed above. While the HQ centralizes the search for licensing deals, it consults the BUs upon the suitability of selected deals. With spillovers across BUs, the HQ can extract information more cheaply thus will decentralize more licensing.

5.2. Endogenous monetary benefits to the BU

Thus far we have assumed that production benefits are exogenous, dictated by norms and routines inside the firm. It is plausible that changing incentives in relational contracts is a slow process, with considerable inertia. Thus, in the short run even if there are licensing opportunities out there in the market, they are not taken into account when production benefits are designed. However, in the longer run incentives may adapt to the changed circumstances. We show below that monetary benefits are muted (compared to the level in the absence of a market for technology) when licensing is decentralized, and they are enhanced when licensing is centralized.

For simplicity, we shall assume here that private benefits are equal to zero, thus $\gamma = \gamma_1$. Assume that production profits depend upon the effort exerted by the BU. We assume that this effort cannot be monitored by the HQ, and thus, the BU is provided a share of profits, γ. A simple way of capturing this is to represent the gross profits from production as $\pi(\gamma)$, so that the profits available to the HQ (net of the share given to the BU) are $(1-\gamma)\pi(\gamma)$. We assume that even when licensing is introduced, the effort expended by the BU depends on the gross profit from production, $\pi(\gamma)$.We assume that the gross profit from production increases as the BU gets a higher share of it, but the firm's net profit is maximized for some intermediate value of γ, denoted $\hat{\gamma}$, which is the level chosen when there is no market for technology.

5.2.1 Endogenous monetary benefits to the BU: Decentralized

The HQ solves the following program:

$$\max_{\gamma,\theta} \pi(\gamma)(1-\gamma) + q\int_0^1 \int_0^{\overline{\frac{\theta w}{\gamma}}} [(1-\theta)w - (1-\gamma)x]\frac{1}{c}\mathrm{d}x\, \mathrm{d}w. \quad (7)$$

Maximizing the program above with respect to θ and γ yields the following result:

[16] If the HQ were to reward only the unit that finds the licensee, the profitability under decentralization increases, because licensing revenues shared with the BU are halved and the profits are consequently greater.

Proposition 6: *The solution to the HQ's problem when the BU searches and decides on licensing and monetary benefits are endogenous is given by* $\theta^* = \frac{\gamma_{dc}}{1+\gamma_{dc}}$ *and* γ_{dc} *is the* γ *that solves*

$$\pi_\gamma(1-\gamma) - \pi(\gamma) - \frac{q}{6c(1+\gamma)^2} = 0. \tag{8}$$

Proof: See Appendix A5.

Proposition 6 has several interesting implications, which are summarized in the following corollary.

Corollary 1: *With a functioning market for technology, if the BU is in charge of licensing, the HQ (weakly) reduces the power of monetary benefits, i.e.* $\hat{\gamma} > \gamma_{dc}$ *Furthermore, licensing incentives are less powerful than monetary benefits, i.e.* $\theta < \gamma_{dc}$.

Proof: See Appendix A5.

The second part of Corollary 1 confirms our previous finding that licensing incentives are less powerful than monetary benefits even when both types of incentives are chosen by the HQ. The first part of the corollary adds some new interesting insights. It shows that when licensing activity is decentralized at the BU level, monetary benefits are distorted downwards in the presence of an active market for technology. The intuition for this result is that monetary benefits make it more expensive for the HQ to incentivize the BU to license. A small reduction in γ away from $\hat{\gamma}$ has no first-order effect on production, but increases the licensing payoff by allowing the HQ to decrease θ. Thus, monetary benefits are optimally muted when the BU is in charge of licensing.

5.2.2. Endogenous monetary benefits to the BU: Centralized

The program the HQ maximizes is the following:

$$\max_{\gamma,\hat{w}} \pi(\gamma)(1-\gamma) + q\int_{\hat{w}}^{1}\int_{0}^{c}[\mathrm{w} - (1-\gamma)\mathrm{x}]\frac{1}{\mathrm{c}}\mathrm{dxdw} - \sigma.$$

The first-order condition for $\hat{w}$ yields: $\frac{\partial(9)}{\partial\hat{w}} = 0 \rightarrow \hat{w}^* = \frac{\mathrm{c}(1-\gamma)}{2}$. Replacing $\hat{w}$ yields:

$$\max_{\gamma} \pi(\gamma)(1-\gamma) + \frac{q}{2}\left(1 - \frac{c(1-\gamma)}{2}\right)^2 - \sigma. \tag{9}$$

Differentiating (9) *w.r.t.* γ and setting equal to zero we get the first order condition for the optimal monetary incentive under centralization, γ_c,

$$\frac{\partial(9)}{\partial\gamma} = \pi_\gamma(1-\gamma) - \pi(\gamma) + q\left(1 - \frac{c(1-\gamma)}{2}\right)\frac{\mathrm{c}}{2} = 0. \tag{10}$$

Proposition 7: *With a functioning market for technology, if the licensing is centralized, the HQ optimally increases the power of monetary benefits above the level absent a market for technology.*

Proof. See Appendix A6.

In other words, γ is now set at level even higher than that when there is no market for technology. The intuition behind this result is that under centralized licensing, the higher the monetary benefits, the greater is the share of the rent dissipation borne by the BU. Consequently, when licensing is centralized the HQ increases monetary benefits beyond the optimal level absent a market for technology. By combining Corollary 1 and Proposition 7, it follows:

Corollary 2: $\gamma_c \geq \hat{\gamma} \geq \gamma_{dc}$.

Proof. See Appendix A6.

5.3. 'Not-Invented-Here' Syndrome

Open innovation or markets for technology involve the movement of technology both in and out of the firm. Traditionally, large firms have been marked by their resistance to both types of movements. Internal technology has been protected as "crown jewels" while external technology has been disdained as "Not Invented Here" (Katz and Allen 1982). Hitherto in this paper, we have focused on how a firm organizes the licensing of its technology. In this subsection, we sketch out how the framework we have developed can also be used to illuminate how the firm acquires external technology.

In acquiring external technology, the cost of acquisition is readily observable, but it is hard for the top management of the firm to assess the value of the external technology as non-experts (Cohen and Levinthal 1989; Arora and Gambardella 1994). Thus the HQ would rely upon experts, in this case, its R&D unit, to select suitable technologies. However, buying external technology may be against the self-interest of the R&D unit. Their budgets might be diverted to finance the acquisition of external technology, requiring layoffs. More subtle biases may be at work as well. For instance, spending on external technology may reduce the funds available for internal research, upsetting in-house R&D staff members who get private benefits from conducting research (Stern 2004). A simple way to model this is that the R&D unit derives a value λ per unit of its R&D budget.

In order to align the interests of R&D unit with those of the HQ, the R&D unit must share both the costs and the benefits of acquiring an external technology. This can be done by letting the R&D unit finance a share γ of the cost of the technology x out its budget in return for a share θ of the profits w from the technology. As before we assume that w is distributed over the interval $[0, 1]$, and x is distributed over the interval $[0, c]$. However, now x is public knowledge, whereas only the R&D unit observes w.

Assuming that the R&D unit's share of the profit from a deal flows back into its budget, the net payoff to the R&D unit from accepting a deal is $\lambda(\theta w - \gamma x)$. An external technology is therefore acquired if only if $\theta w/\gamma \geq x$. The net payoff to the firm from the external technology is $(1-\theta)w - (1-$

$\gamma)x$.[17] In the simplest case, θ is exogenously set as the reward to the R&D unit, and the key decision variable is the extent of cost-sharing.[18] This is formally identical to the basic model analyzed in §4 for $\gamma_0 = 0$, and it follows that the firm will optimally set γ such that $\gamma > \theta$. Thus, the R&D unit will reject a fraction of the good external technologies offered, and the firm will display a "Not Invented Here" syndrome.

In sum, agency conflicts within large firms can result in the firm becoming more insular from the external market for technology. In large firms, individual BUs (divisions, R&D units) have specialized information about the costs and benefits of external opportunities. Eliciting this information is costly. Therefore, when firms rely upon the local information of their BUs, they must trade-off the cost of eliciting information against the benefits. The result is a bias against external opportunities. The "Not Invented Here" bias against externally developed technology and viewing internally generated technology as "crown jewels" are manifestations of this bias.

6. Conclusion

The diffusion of the open innovation paradigm and the development of markets for technology have created new strategic options for firms. As firms try to reap the benefits of markets for technology, we need a better understanding of how they should organize internally for licensing. This is particularly true for large firms, which typically contain many individual BUs.

One key choice in terms of organizing for the market for technology is where the decision-making power should be vested. A BU is typically closer to the market, can identify potential licensees more easily, and can assess the likely rent dissipation from licensing more accurately. However, managers of BUs often have incentives to protect product market profits, and will typically have little reason to license technology to potential competitors, even if there are gains from trade. Thus, firms that wish to participate in the market for technology must either provide these managers with suitable incentives or hand the licensing decision to a specialized unit that has no vested interest in production profits. We develop a parsimonious model that addresses this important organizational choice.

The model generates several findings consistent with existing empirical evidence on licensing. For instance, it rationalizes the commonly held belief and stylized fact that firms frequently fail to consummate licensing deals even when both parties could benefit. Our model

[17] If the R&D budget is chosen optimally, a small reduction in the budget will have no first order effect on the firm's profit. Thus, the net payoff of a deal is $(1-\theta)w - (1-\gamma)x$.

[18] However, we can also allow the firm to choose θ, without changing the qualitative results; see §5.2.

shows that when licensing is decentralized to BUs, it is not optimal to provide them with the value-maximizing level of incentives to license. This results in incentives to license being weaker than incentives for production, so that the BU will turn down potentially profitable deals. Centralization creates a different type of inefficiency because, unable to assess the rent dissipation potential of a deal, the central unit may commit both types of errors: enter into unprofitable deals as well as refuse potentially profitable deals.

The model implies that firms with stronger production-based incentives are more likely to under-license if licensing is delegated to BUs, especially when the managers of BUs enjoy private benefits for increasing profits from production, for instance because they like being the boss of a bigger outfit. Centralization is more likely under such conditions. Centralization of licensing is also associated with greater licensing and with bigger deals.

Moreover, the standard argument that spillovers across business units favor centralization does not necessarily apply in our context. Under decentralization, the BU is reluctant to use its private information regarding licensing opportunities in order to preserve production rents. If there are two units, the units are more willing to license the technology, because a share of the rent dissipation is borne by the other unit. This lack of internalization of the externality actually may benefit the firm, because it makes it less costly to induce the unit(s) to act upon their private information.

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APPENDIX

A1: Proof of Proposition 1.i under general distribution forms for $\tilde{w}$ and $\tilde{x}$

Foreseeing that the BU will license only if $\theta w/\gamma \geq x$, the HQ solves the following:

$$Max_\theta\, \pi(1-\gamma_1) + q\int_0^z \int_0^{\frac{\theta w}{\gamma}} [(1-\theta)w - (1-\gamma_1)x] f(x)g(w)\, dxdw.$$

Assuming the second order condition for a maximum is satisfied, the first-order condition is

$$q\int_0^z \int_0^{\frac{\theta w}{\gamma}} (-w) f(x)g(w)\, dxdw + q\int_0^z w\left[(1-\theta) - (1-\gamma_1)\frac{\theta}{\gamma}\right]\frac{w}{\gamma} f(\frac{\theta w}{\gamma})g(w)dw = 0.$$

Since the first term is negative, the second term must be positive. Therefore, $(1-\theta) - (1-\gamma_1)\frac{\theta}{\gamma} > 0$, which implies that $\theta^* < \frac{\gamma}{1+\gamma_0}$, i.e., licensing incentives are less powerful than production incentives.

A2: Proof of Proposition 3

i) The comparative statics with respect to $\frac{\sigma}{q}$ is obtained by simply noting that decentralization occurs if and only if $\Delta(c,\gamma,a) \geq \frac{\sigma}{q}$.

ii) The comparative statics with respect to γ_0 follows directly from the fact that the first term in $\Delta(c,\gamma,a)$ is independent of γ_0, while the second term decreases with γ_0. Similarly, notice that the first term in $\Delta(c,\gamma,a)$ increases with γ_1, while the second term decreases with γ_1.

iii) A necessary condition for centralization to dominate decentralization is that $\Delta(c,\gamma,a) > 0$. Now, $\frac{\partial\Delta(c,\gamma,a)}{\partial a} \geq 0 \Leftrightarrow \frac{2-ca}{4} \leq \frac{1}{6c^2(a+2\gamma)^2}$. As $c > 1$ and $a + 2\gamma > 1$, it follows that $\frac{(2-ca)^2}{8} < \frac{2-ca}{4} \leq \frac{1}{6c^2(a+2\gamma)^2} < \frac{1}{6c(a+2\gamma)}$. Hence, $\frac{\partial\Delta(c,\gamma,a)}{\partial a} \geq 0 \Rightarrow \Delta(c,\gamma,a) \leq 0$. Therefore, $\Delta(c,\gamma,a) > 0 \Rightarrow \frac{\partial\Delta(c,\gamma,a)}{\partial a} < 0$, which implies that the parameter space under which the centralized solution can dominate expands when *a* decreases.

iv) Consider the comparative statics with respect to *c*. The proof is divided into two steps.

<u>Step 1:</u> *If* $\gamma > \frac{a(\sqrt{3}-1)}{8}$, *there exists* $\bar{c} \epsilon \left]\frac{1}{(a+2\gamma)}, \frac{2}{a}\right[$ *such that* $\Delta(c,\gamma,a) > 0$ *for* $c \in \left[\frac{1}{(a+2\gamma)}, \bar{c}\right[$ *and* $\Delta(c,\gamma,a) \leq 0$ *for* $c \in \left[\bar{c}, \frac{2}{a}\right]$. *Otherwise,* $\Delta(c,\gamma,a) \leq 0$ *for all* $c \in \left[\frac{1}{(a+2\gamma)}, \frac{2}{a}\right]$.

In order to prove this claim, notice first that $\frac{\partial^2\Delta(c,\gamma,a)}{\partial c^2} = \frac{a^2}{4} - \frac{1}{3c^3(a+2\gamma)}$, which is increasing in c. Furthermore, $\left.\frac{\partial^2\Delta(c,\gamma,a)}{\partial c^2}\right|_{c=\frac{1}{a+2\gamma}} < 0$ and $\left.\frac{\partial^2\Delta(c,\gamma,a)}{\partial c^2}\right|_{c=\frac{2}{a}} > 0$. Hence, $\Delta(c,\gamma,a)$ switches from being concave to being convex as c increases. Notice also that for $c = \frac{2}{a}$ we have that $\Delta(c,\gamma,a) < 0$ and

$\frac{\partial\Delta(c,\gamma,a)}{\partial c}\Big|_{c=\frac{2}{a}} > 0$. Together with continuity of $\Delta(c,\gamma,a)$, these properties imply that $\Delta(c,\gamma,a)$ has a local minimum for some $c_B \in \left]\frac{1}{(a+2\gamma)},\frac{2}{a}\right[$ and that $\Delta(c,\gamma,a) < 0$ for all $c \in \left[c_B,\frac{2}{a}\right]$. Furthermore, if $\frac{\partial\Delta(c,\gamma,a)}{\partial c}\Big|_{c=\frac{1}{a+2\gamma}} > 0$, there is a local maximum for some $c_A \in \left]\frac{1}{(a+2\gamma)},c_B\right[$. There cannot exist other interior extrema in the range considered. Now, $\Delta\left(\frac{1}{(a+2\gamma)},\gamma,a\right) > 0 \Leftrightarrow \gamma > \frac{a(\sqrt{3}-1)}{8}$ and $\frac{\partial\Delta(c,\gamma,a)}{\partial c}\Big|_{c=\frac{1}{a+2\gamma}} > 0 \Leftrightarrow \gamma > \frac{a(\sqrt{3}+1)}{4}$. As the latter condition is more restrictive, $\frac{\partial\Delta(c,\gamma,a)}{\partial c}\Big|_{c=\frac{1}{a+2\gamma}} > 0 \Rightarrow \Delta\left(\frac{1}{(a+2\gamma)},\gamma,a\right) > 0$. Hence, there are three possible cases. First, if $\gamma > \frac{a(\sqrt{3}+1)}{4}$, $\Delta(c,\gamma,a) > 0$ for all $c \in \left]\frac{1}{(a+2\gamma)},c_A\right[$, and $\Delta(c,\gamma,a)$ is strictly decreasing in *c* for $c \in [c_A,c_B]$. Notice that $\gamma > \frac{a(\sqrt{3}+1)}{4}$ implies that $\gamma_1 > \frac{1+\sqrt{3}-4\gamma_0}{5+\sqrt{3}}$. Hence, it must be that $\gamma > \gamma_0 + \frac{1+\sqrt{3}-4\gamma_0}{5+\sqrt{3}} = \frac{1}{11}\left(1+2\sqrt{3}\right)\left(1+\gamma_0\right)$. Second, if $\frac{a(\sqrt{3}+1)}{4} \geq \gamma > \frac{a(\sqrt{3}-1)}{8}$, it follows that $\Delta\left(\frac{1}{(a+2\gamma)},\gamma,a\right) > 0$ and that $\Delta(c,\gamma,a)$ is decreasing in *c* for $c \in \left[\frac{1}{(a+2\gamma)},c_B\right]$. Hence, if $\gamma > \frac{a(\sqrt{3}-1)}{8}$, there exists some $\bar{c}\epsilon \left]\frac{1}{(a+2\gamma)},\frac{2}{a}\right[$ such that $\Delta(c,\gamma,a) > 0$ for $c < \bar{c}$ and $\Delta(c,\gamma,a) \leq 0$ for $c \geq \bar{c}$. As the third and final case, consider $\frac{a(\sqrt{3}-1)}{8} \geq \gamma$. The above arguments imply that $\Delta\left(\frac{1}{(a+2\gamma)},\gamma,a\right) \leq 0$, $\Delta(c,\gamma,a)$ is decreasing in *c* for $c \in \left[\frac{1}{(a+2\gamma)},c_B\right]$, and thus $\Delta\left(\frac{1}{(a+2\gamma)},\gamma,a\right) \leq 0$ for all permissible values of *c*.

<u>Step 2:</u> *If* $\frac{a(\sqrt{3}+1)}{4} \geq \gamma > \frac{a(\sqrt{3}-1)}{8}$, *then* $\frac{\partial\Delta(c,\gamma,a)}{\partial c} \leq 0$ *for all values of c such that* $\Delta(c,\gamma,a) \geq 0$.

Since $\gamma > \frac{a(\sqrt{3}-1)}{8}$, it follows from step 1 that $\Delta(c,\gamma,a) \geq 0$ if and only if $c \in \left[\frac{1}{(a+2\gamma)},\bar{c}\right]$. Furthermore, since $\frac{a(\sqrt{3}+1)}{4} \geq \gamma$, it follows from the proof of step 1 that $\frac{\partial\Delta(c,\gamma,a)}{\partial c} \leq 0$ for all $c \in \left[\frac{1}{(a+2\gamma)},\bar{c}\right]$.

Finally, notice that it follows from step 1 of part iv) that a necessary condition for $\Delta(c,\gamma,a) > 0$ is $\gamma > \frac{a(\sqrt{3}-1)}{8} \Leftrightarrow \gamma > \frac{(4\sqrt{3}-5)}{23}(1+\gamma_0)$.

A3: Proof of Proposition 4

It is convenient to use γ_0 and γ_1 as variables rather than *a* and γ in this proof. The probabilities of licensing are $\frac{1}{2c(1+\gamma_1+2\gamma_0)}$ and $\int_{\widehat{w}^*}^{1} dw = 1 - \frac{(1-\gamma_1)}{2}$ under decentralization and under centralization, respectively. Hence, there is a higher probability of licensing under centralization if and only if $\tilde{\Delta}(c,\gamma_0,\gamma_1) = 1 - \frac{c(1-\gamma_1)}{2} - \frac{1}{2c(1+\gamma_1+2\gamma_0)} \geq 0$. We have that $\tilde{\Delta}(c,\gamma_0,\gamma_1) = 0$ for

$\bar{\bar{c}} = \frac{1}{1+2\gamma_0+\gamma_1-\sqrt{2}\sqrt{(\gamma_0+\gamma_1)(1+2\gamma_0+\gamma_1)}}$ where $\bar{\bar{c}} \in \left]\frac{1}{1+\gamma_1+2\gamma_0}, \frac{2}{1-\gamma_1}\right[$. Furthermore, $\tilde{\Delta}(c, \gamma_0, \gamma_1) > 0$ for $c \,\epsilon \left[\frac{1}{1+\gamma_1+2\gamma_0}, \bar{\bar{c}}\right[$ and $\tilde{\Delta}(c, \gamma_0, \gamma_1) \leq 0$ for $c \,\epsilon \left[\bar{\bar{c}}, \frac{2}{1-\gamma_1}\right]$.

Now, $\Delta(\bar{\bar{c}}, \gamma_0 + \gamma_1, 1 - \gamma_1) = \frac{-1+4\gamma_0+5\gamma_1-2\sqrt{2}\sqrt{(\gamma_0+\gamma_1)(1+2\gamma_0+\gamma_1)}}{24(1+2\gamma_0+\gamma_1)}$. Analysis of this function shows that $\Delta(\bar{\bar{c}}, \gamma_0 + \gamma_1, 1 - \gamma_1) < 0$ for all $\gamma_0 \geq 0$ and $\gamma_1 < 1$. Hence, $\bar{\bar{c}} > \bar{c}$ where $\bar{c}$ is defined in step 1of part iv) in appendix A2. This, in turn, implies that for any c such that centralization is preferred to decentralization it must hold that $c \leq \bar{c} < \bar{\bar{c}}$, which implies that $\tilde{\Delta}(c, \gamma_0, \gamma_1) > 0$. Proof follows.

A4: Proof of Proposition 5 and further details

Start by proving Proposition 5. The expected profit of the firm with two BUs (net of the payment to the BUs) is:

$$\Pi^{2BU} = \pi(1-\gamma_1) + \frac{1}{2}\sum_{j=L,H}\left(\int_0^{z1}\int_0^{\frac{\theta w}{\phi_j \gamma}}[(1-2\theta)w - (1-\gamma_1)x]\frac{1}{c}dx\, dw\right).$$

It is easy to check that the problem is concave in θ, thus maximizing profits with respect to θ yields: $\theta^* = \frac{(\gamma_1+\gamma_0)\phi_L\phi_H}{1-2(1-2\gamma_0)\phi_L\phi_H-(1-6\phi_L\phi_H)\gamma_1}$. Using this solution, we can compute the equilibrium profits:

$$\Pi^{2BU} = \frac{z^2}{12c\left(1-2(1-2\gamma_0)\phi_L\phi_H-(1-6\phi_L\phi_H)\gamma_1\right)}.$$

The total profits with one BU, Π^{1BU}, and with two BUs, Π^{2BU}, are equal for symmetric rent dissipation, $\phi_L = \phi_H = \frac{1}{2}$. Now, Π^{1BU} is independent of ϕ_L whereas Π^{2BU} is decreasing in ϕ_L if and only if $3\gamma_1 + 2\gamma_0 > 1$. Hence, $\Pi^{2BU} > \Pi^{1BU}$ for $\phi_L < \frac{1}{2}$ if and only if $3\gamma_1 + 2\gamma_0 > 1$.

The probability of licensing with two Bus is:

$$Prob^{2BU} = \frac{1}{2}\int_0^1\int_0^{\frac{\theta^* w}{\phi_L(\gamma_1+\gamma_0)}}\frac{1}{c}dx\, dw + \frac{1}{2}\int_0^1\int_0^{\frac{\theta^* w}{\phi_H(\gamma_1+\gamma_0)}}\frac{1}{c}dx\, dw = \frac{\theta^*}{4c(\gamma_0+\gamma_1)\phi_L(1-\phi_L)}.$$

The probability of licensing with one BU, $Prob^{1BU}$, and with two BUs, $Prob^{2BU}$, are equal for $\phi_L = \phi_H = \frac{1}{2}$. Furthermore, $Prob^{2BU}$ is decreasing in ϕ_L if and only if $3\gamma_1 + 2\gamma_0 > 1$. Since $Prob^{1BU}$ is independent of ϕ_L, $Prob^{2BU} > Prob^{1BU}$ for $\phi_L < \frac{1}{2}$ if and only if $3\gamma_1 + 2\gamma_0 > 1$.

Let us provide some additional details regarding the effects at play. It is easy to show that for given γ and θ the probability of licensing is decreasing in ϕ_L. The key is that since $\frac{\theta}{\phi\gamma}$ is convex in ϕ, it follows from Jensen's Inequality that $\frac{\theta}{\gamma\left(\frac{1}{2}\phi_L+\frac{1}{2}\phi_H\right)} = \frac{\theta}{\phi\gamma} < \frac{1}{2}\frac{\theta}{\gamma\phi_L} + \frac{1}{2}\frac{\theta}{\gamma\phi_H}$. That is, when the two BUs experience more asymmetric losses from licensing, the increases the probability of licensing for given monetary benefits. Hence, if ϕ_L decreases, the HQ can reduce the licensing bonus and still maintain the same licensing activity.

There is, however, also inefficiency created by the two BUs uncoordinated decisions: For $\frac{\theta}{\phi_H(\gamma_1+\gamma_0)} < \frac{x}{w} \leq \frac{\theta}{\phi_L(\gamma_1+\gamma_0)}$, there is licensing if and only if the unit that discovers the potential licensee draws ϕ_L. This is inefficient because – for a given level of licensing activity – it is optimal to accept all deals for which $\frac{x}{w}$ is below a certain threshold and reject all others. This inefficiency, which is specific to the setup with two BUs, reduces licensing profits.

These two contending effects are conditioned by production incentives. With high incentives for production, licensing is costly to induce, and the firm benefits more from the increased licensing than the loss due to an inefficient mix of licensing deals.

A5: Proofs of Proposition 6 and Corollary 1

Using $w \sim U[0,1]$ and $x \sim U[0,c]$, the objective function becomes:

$\text{Max}_{\gamma,\theta}\left\{\pi(\gamma)(1-\gamma)+\frac{q\theta}{6\gamma^2 c}[2\gamma-\theta(1+\gamma)]\right\}$.

The associated first-order condition is: $\frac{\partial \Pi}{\partial \theta}=\frac{q}{6\gamma^2 c}[2\gamma-2\theta(1+\gamma)]=0$, which implies that $\theta^*=\frac{\gamma}{1+\gamma}$. After substituting θ^*, the profit function becomes $\pi(\gamma)(1-\gamma)+\frac{q}{6(1+\gamma)c}$. Maximizing with respect to γ and equating to zero yield $\pi_\gamma(1-\gamma)-\pi(\gamma)-\frac{q}{6c(1+\gamma)^2}=0$, which completes the proof of Proposition 6. Corollary 1 follows directly from comparing first-order conditions absent a market for technology ($\pi_\gamma(1-\gamma)-\pi(\gamma)=0$) and (8) and from $\gamma_{dc}>0$

A6: Proofs of Proposition 7 and Corollary 2

Comparing (10) with the first-order conditions absent a market for technology ($\pi_\gamma(1-\gamma)-\pi(\gamma)=0$), it follows that that $\gamma_c \geq \gamma_{no\_mft}$, which proves Proposition 7. Corollary 2 follows from combining Corollary 1 and Proposition 7.