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ABSTRACT

Managing licensing in a market for technology*

Over the last decade, companies have paid greater attention to the management of 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 are more powerful, making centralization more attractive. Growth of technology markets favors centralization and drives higher licensing rates. Our model conforms to the existing evidence that reports heterogeneity across firms in both licensing propensity and organization of licensing.

JEL Classification: L22 and L24
Keywords: licensing, markets for technology and organization design

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1. Introduction

There is increasing empirical evidence that markets for technology have become sizable in the last two decades (Robbins, 2006; Athreye and Cantwell, 2007; Arora and Gambardella, 2010). These growing markets imply that firms now consider licensing as an important option for fully profiting from their own intellectual property. Indeed, many firms have embraced a more open policy of actively licensing their internal technology to others and earn millions of dollars in revenues worldwide through licensing activities (The Economist, 2005).[1]

Although licensing is growing in importance, there is also widespread evidence that a large number of potentially value-enhancing deals are not consummated (e.g. Razgaitis, 2004; Gambardella, Giuri, and Luzzi, 2007). LES data 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, LES data 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 more likely to experience underlicensing.

Case studies of companies such as IBM, Dow, Being, Motorola, Xerox, and Procter & Gamble, which are acknowledged to be active licensors of internal technology, suggest that how licensing is managed and organized within the firm can explain some of the heterogeneity in terms of unexploited licensing opportunities (Kline, 2003; Phelps and Kline, 2009; Davis and Harrison, 2001; Sterling and Murray, 2007). Three stylized facts emerge from these case studies: 1) In firms that license extensively, licensing is typically handled by a specialized business unit (often treated as an independent business); 2) licensing is incentivized in various ways (licensing revenues are typically shared with operating units); 3) there is often a marked (discrete) jump in licensing revenues when firms remove licensing authority from the business units and manage it centrally.

Inspired by these empirical regularities, this paper develops a parsimonious model to analyze how firms should organize their licensing activities. Our analysis rationalizes underlicensing as a byproduct of decentralized licensing decisions and investigates how licensing propensity can be increased by centralizing licensing authority in a specialized unit. Even though the papers on markets for technology and the so-called "open innovation" paradigm have been flourishing, the relationship between inter-organizational innovation strategy and firms' internal organization has rarely been addressed by previous literature. Managing licensing within a large

[1] For instance, Eastman Kodak has reportedly targeted earning $250-$350 million per year from licensing its digital imaging technology since 2008, and has received $550 million and $400 million from Samsung and LG respectively over the past year (Wall Street Journal, June 24, 2010, online edition).

corporation can indeed be complex as it involves several divisions or business units, each of which is likely to use distinct technology. A key challenge is whether these units should be left to handle licensing on their own, or whether licensing should be centralized at the corporate level. In this paper we focus on two factors that condition this decision: differences in information, and differences in incentives. Decentralization exploits local information not available to centralized decision makers, but decentralized decisions may not be the best interests of the shareholders.

Specifically, in our model the management of the firm decides whether to delegate the task of searching for potential licensees and the authority to execute licensing deals to the business unit in charge of manufacturing the product, or to centralize licensing activity 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 its incentives are anchored to production-based performance. The management of the company addresses this agency problem by installing an incentive scheme that shares with the business unit the associated licensing revenues. The agency cost can be reduced by centralizing licensing activities, whereby the management of the firm acquires information about licensing revenues. The business unit still has superior information about the rent dissipation from licensing, and thus the management of the firm can consult it on a deal-by-deal basis. Consulting the business unit is costly because the unit must be induced to reveal its private information, but consultation can save the firm from value-destroying deals.[2]

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 profits. This distortion is stronger when production-based incentives in the company are more powerful, which, in turn, makes centralization of licensing more attractive. Second, licensing decisions are delegated to the business unit when the potential downside from licensing is large relative to the revenue. Third, growth of markets for technology favors centralization and is accompanied by higher licensing rates.

We then extend our basic model to account for three important aspects: 1) we endogenize production-based incentives; 2) we consider the case of multiple business units; 3) we allow for correlation between revenues and rent dissipation from licensing. We show that when production-

[2] Licensing might sometimes be used for strategic reasons, such as to facilitate collusion, block entry, or establish a technology standard. Although we do not discuss them, licensing will tend to be centralized in these cases.

based incentives are endogenized, they are adjusted downward when most licensing deals are delegated to the business unit. Accounting for negative spillovers from licensing across business units results in the unexpected finding that spillovers may make decentralization more appealing, not less. Finally, correlation between the revenues from licensing and the rent dissipation does not necessarily lead to more centralization. Not surprisingly, if greater correlation implies that the revenues from licensing constitute a more precise signal of the rent dissipation, licensing tends to be more centralized. However, if greater correlation arises from greater covariance between licensing revenues and rent dissipation, the information of the business unit might become more relevant and decentralization will increase.

2. Related Literature

The study of inter-firm licensing has become an important research area, as evidenced by the many articles that examine motivations behind 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). However, little attention has been devoted so far to the analysis of how a firm should organize for efficiently managing its licensing business.

There is a large literature in economics and corporate finance on the delegation of authority in organizations, which we will briefly review here. Mookherjee (2006) provides a comprehensive review. Team production theory (e.g., Radner and Marschak, 1972), which pioneered the formal study of how authority should be delegated in organizations, ignored incentive problems, focusing instead on the differences in information available to divisions and headquarters. Team production theory holds that authority should be delegated to divisions if the information available to them cannot be communicated to headquarters quickly and cheaply.

However, it was readily recognized that superior information also provided power, and that the incentives of divisions might diverge from those of the firm itself. Our work falls within the literature that considers the question of delegation of authority in contexts where there are information differences and divergence of incentives.

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 this paper, we explore the implications of this general insight in a context where bundling is efficient because the business unit can search more effectively and because it has superior information about the payoff from a given deal.

Riordan and Sappington (1987) analyze a model where the principal may reduce the agent's informational advantage by doing one of the tasks in the firm herself. However, unlike production and licensing, the tasks are independent, and organizational structure only matters if there is correlation between the (hidden) costs of performing the tasks. This results in adifferent organizational problem compared to our model where the management needs to consult the business unit in order to manage licensing optimally.

When we extend our basic model to two business units, it becomes closer to a recent paper by Garicano, Gertner, and Dessein (2010), who analyze a model with two business units that can create negative externalities for each other. The externalities increase the cost of incentive provision and call for centralized decision-making in their model, whereas we find the opposite result. We compare our results to those of Garicano et al. (2010) more carefully in Section 5.

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 generates an expected gross profit of π, absent licensing. We abstract from the R&D process that has generated such technology but discuss this issue in subsection 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. 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 relax the latter assumption in Section 5. Note that *c* parameterizes the extent of rent dissipation as greater *c* implies higher expected costs from licensing.

We assume that $c \geq z$, which implies that for any *w,* there are deals that destroy value. This assumption sidesteps some uninteresting special cases, but our results hold even if it is relaxed.

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. We assume that 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 σ, $\sigma > 0$.

Information structure

We assume that *w* can be observed both by the BU (always) and the HQ (only when the licensing is centralized).[3] However, although the distribution of $\tilde{x}$ is public 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. 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. Further, we assume that the licensee receives 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 subsection 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 of the production profits is paid as bonus to the BU, for instance, to alleviate an (additional) agency problem at the production stage. In addition, 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.

A different interpretation is that γ is the share of production profits that the BU managers appropriate in the form of perks such as expensive meals or air travel in corporate jets (Jensen and Meckling, 1976; Fama, 1980). Also, 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

[3] It is plausible that by dealing with the licensee the HQ can infer its willingness to pay for the technology.

workers off. If γ is interpreted as a non-monetary benefit, it is assumed that it comes at the same cost to the firm that a monetary benefit would.

In the baseline model we treat γ as exogenous. The endogenous production bonus is addressed in the extensions section.

The HQ and the BU are risk neutral. The BU maximizes the sum of the payoff from production, $\gamma\pi$, and licensing, θw, net of the cost of licensing, γx. Notice that the opportunity cost of licensing to the BU is γx because licensing reduces production profits. We assume that the BU earns rents from its activities, and these exceed the outside option. In other words, the participation constraint of the BU does not bind. The HQ maximizes the residual part of the profit from production, $(1 - \gamma)\pi$, plus the net revenue from licensing, $(1 - \theta)w$, minus the cost of licensing, $(1 - \gamma)x$.[4]

Organization of licensing

In our setting *w* and *x* are measured at the deal level, while all other variables, such as *c* and *z*, 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.

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 underlicensing. Second, we consider the solution in which the HQ takes over the licensing activity and centralizes the search for potential licensees. As the BU has better information about the rent dissipation effect from licensing, the HQ submits some deals for approval to the BU.

Later in our discussion, we shall refer to the case of large firms with multiple BUs and technologies. Provided that each licensing deal only affects one BU, our findings below can be straightforwardly extended to such companies. The organization of licensing when the profit dissipation is experienced by more than one BU is analyzed in Section 5.

The timing of the game

At $t = 0$, R&D efforts result in a new technology and the production incentives γ are established. At $t = 1$, the HQ chooses the organizational form for the licensing activity and the

[4] 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. The HQ may also put greater weight on production revenues than on licensing revenues, e.g., to keep the current workforce or to increase managerial entrenchment. This would exacerbate the distortions that we find in the organization of licensing, but again it would not change our results qualitatively.

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 subsections 4.3.2 (R&D efforts) and 5.1 (endogenous γ). The game is solved backward in order to find the subgame perfect Nash equilibrium.

4. Solving the Model

4.1. Decentralization: The BU searches and decides on licensing

The licensing activity is fully decentralized and the HQ only chooses the share θ of the licensing revenue that is assigned to the BU in case a deal is consummated. Foreseeing that the BU will license only if $\theta w/\gamma \geq x$, the HQ solves the following problem:

$$\mathrm{Max}_{\theta}\ \pi(1-\gamma) + q\int_0^z \int_0^{\frac{\theta w}{\gamma}} [(1-\theta)w - (1-\gamma)x]\frac{1}{cz}\,dx\,dw. \quad (1)$$

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

$$\mathrm{Max}_{\theta}\ \pi(1-\gamma) + \frac{q\theta z^2}{6\gamma^2 c}[2\gamma - \theta(1+\gamma)]. \quad (2)$$

Maximizing profits with respect to θ yields $\theta^* = \frac{\gamma}{1+\gamma}$.[5] HQ profits are equal to $\Pi_D = (1-\gamma)\pi + q\frac{z^2}{6c(1+\gamma)}$. The probability of licensing conditional on a potential licensee being found is $\int_0^z \int_0^{\frac{\theta^* w}{\gamma}} \frac{1}{zc}dxdw = \frac{z}{2c(1+\gamma)}$. This leads to the following proposition:

Proposition 1. *When the BU is in charge of licensing: (i) Licensing incentives are lower than production incentives, i.e.* $\theta^* < \gamma$*; (ii) The gap between production and licensing incentives increases with the level of production incentives, i.e.,* $\frac{\partial\left(\frac{\gamma}{\theta^*}\right)}{\partial\gamma} > 0$*; (iii) The probability of licensing conditional on a potential licensee being found decreases with the level of production incentives, i.e.,* $\frac{\partial\left(\frac{z}{2c(1+\gamma)}\right)}{\partial\gamma} < 0$.

4.1.1. Discussion

Note first that 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 production incentives are endogenous (see subsection 5.1). The intuition for the result is that HQ acts like a monopsonist, who restricts the quantity of licenses by setting too low a licensing bonus. Choosing $\theta = \gamma$ would maximize total value; however, the HQ can obtain a larger

[5] 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.

fraction of rents from licensing by reducing θ. Some marginal deals are lost in exchange for a reduction in the payment to the BU across the consummated infra-marginal deals.[6]

Part (i) of Proposition 1 is important because it shows the problems firms face in opening to the market for technology. The widespread complaints of business units that licensing revenues do not flow fully back to the business-unit are consistent with this result. Part (i) also suggests why licensing revenues earned by units are treated as lower quality earnings. It is sometimes argued that licensing revenues are treated as "poor quality" because they can disguise poor product market performance. Instead, our analysis suggests that discounting licensing revenues is optimal because it increases the amount of profit that remains in the corporate coffers.

Part (ii) suggests that the distortion of licensing incentives is more pronounced if production incentives are high-powered. The intuition is that stronger production incentives necessitate stronger licensing incentives, thereby increasing the infra-marginal gain from distorting the licensing bonus downward. Hoskisson, Hitt, and Hill (1993) report that large diversified firms tend to use financial controls to manage their business-units rather than strategic metrics. Thus, insofar as large, diversified industrial companies are more likely to use high-powered incentives, we expect the complaints about insufficient rewards for licensing to show up more often for these firms.

4.2. Hybrid solution

This solution can be thought of as a situation in which the HQ takes over the licensing activity by creating a specialized licensing unit.. For instance, Glaxo has created a specialized licensing unit, while Microsoft handles licensing at the company's headquarters. Similarly, Du Pont has created a licensing unit that coordinates with the relevant BU in executing deals (Sterling and Murray, 2007). Once the HQ observed a potential deal, it can decide to go forward with licensing or can choose to delegate the decision to the BU about that particular deal. The BU is offered a share, θ, of the licensing revenues for the deals that are sent for its approval (notice that with $\theta = 0$ the BU vetoes all deals). There is no revenue sharing for the BU if licensing deals are not submitted for approval. The HQ exploits the additional information about licensing revenues from licensing by making the BU participation in the decision contingent on w. Let $\overline{w}$ be the value of the revenues from licensing such that any deal for which $w \geq \overline{w}$ the HQ does not seek the approval of the BU. Instead all deals such that $w < \overline{w}$ must be approved by the BU. The HQ maximizes the following:

$$\text{Max}_{\theta,\overline{w}}\, \pi(1-\gamma) + q\int_{\overline{w}}^{z}\int_{0}^{c}[w-(1-\gamma)x]\frac{1}{cz}\mathrm{d}x\mathrm{d}w +$$

$$+\, q\int_{0}^{\overline{w}}\int_{0}^{\frac{\theta w}{\gamma}}[(1-\theta)w-(1-\gamma)x]\frac{1}{cz}\mathrm{d}x\mathrm{d}w - \sigma. \qquad (3)$$

[6] We thank an anonymous reviewer for suggesting this intuition.

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

$$\max_{\theta,\bar{w}} \pi(1-\gamma) + q\frac{(z-\bar{w})(\bar{w}+z-(1-\gamma)c)}{2z} + q\frac{\theta\bar{w}^3[2\gamma-\theta(1+\gamma)]}{6c\gamma^2 z} - \sigma. \quad (4)$$

Notice that $\frac{\partial(4)}{\partial\theta} = 0$ implies that $\theta^* = \frac{\gamma}{1+\gamma}$. In other words, the optimal level of licensing incentives, θ^*, is exactly the same we had above in the fully decentralized case. Thus, again, licensing incentives to the BU are set at a suboptimal level by the HQ. Replacing θ^* in (4) and maximizing profits with respect to $\bar{w}$, we find the following solution in the relevant range ($\bar{w}^* \leq$ z):

$$\bar{w}^* = \left(1 - \sqrt{\frac{2\gamma}{1+\gamma}}\right) c(1+\gamma) > 0. \quad (5)$$

Notice that $\bar{w}^*$can be interpreted as the extent of decentralization of licensing authority within the firm. The larger $\bar{w}^*$ is, the greater the number of deals that are handled by the BU. As $\bar{w}^*$ approaches *z*, the hybrid model approaches the decentralized solution. Notice that $\frac{\partial\bar{w}^*}{\partial\gamma} < 0$ and $\frac{\partial\bar{w}^*}{\partial c} > 0$. HQ profits are equal to $\Pi_\mathrm{H} = (1-\gamma)\pi + q\frac{(z-\bar{w}^*)(\bar{w}^*+z-(1-\gamma)c)}{2z} + q\frac{\bar{w}^{*3}}{6cz(1+\gamma)} - \sigma$. We can state the following:

Proposition 2. *Other things equal, a larger share of deals is delegated to the BU in the hybrid model when: a) production incentives are weak (γ is low); b) rent dissipation is large (c is large); c) revenues from licensing are small (z is small).*

The intuition for this proposition is rather straightforward. Delegating authority to the BU is costly because the HQ has to pay a share θ of the revenues from licensing. First, this share increases with production incentives, which increases the cost of consulting the BU. Second, 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. The probability that rent dissipation is larger than the revenue from licensing increases with *c* and falls with *z*. Hence, it becomes relatively more important to use the BU's private information about *x* for high values of *c* and low values of *z*.

Corollary 1. *The hybrid solution delivers greater rates of licensing than the decentralized solution.*

Notice for $w < \bar{w}^*$ there is the same amount of licensing in the hybrid solution and the decentralized solution, but for $w \geq \bar{w}^*$ the hybrid solution results in unambiguously more licensing. This is consistent with the observation that firms that aggressively license their intellectual property create a licensing unit that reports to the headquarters. Indeed, 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.[7]

4.3. The choice of the organizational mode for licensing

In the previous section we investigated the factors that explain which licensing deals are submitted for approval to the BU within the hybrid model. 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 not?[8]

Although we lack systematic data, anecdotal evidence indicates that firms differ in how they organize licensing. 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.

Notice that the hybrid model can replicate the full decentralization of licensing activity by setting $\bar{w}^* = \mathrm{z}$. However, because the BU has a lower cost of searching for licensees, we cannot conclude that the hybrid solution dominates the decentralized model.

Let $\Pi_H - \Pi_D = q\Delta(c, z, \gamma) - \sigma$, where $\Delta(c, z, \gamma) = \frac{1}{6}\left[3z - 3c(1-\gamma) + \frac{4c^2\gamma\sqrt{2\gamma(1+\gamma)}}{z} + \frac{c^2(1+\gamma)(1-5\gamma)}{z} + \frac{z^2}{c(1+\gamma)}\right]$. If $\Delta(c, z, \gamma) \geq \frac{\sigma}{q}$, then the hybrid solution is preferred to full decentralization.

Proposition 3*: Other things equal, the parameter space under which the hybrid solution dominates the decentralized one expands as:* $\frac{\sigma}{q}$ *decreases,* γ *increase, z increases, and c decreases for* γ *small enough.*

Proof: See Appendix A2.

The hybrid solution is less likely to be observed if q is small and/or search costs are large, production incentives are relatively weak, *z* is small, and *c* is large. While the comparative statics with respect to $\frac{\sigma}{q}$ is straightforward, the others can be intuitively understood (see Appendix A2 for the formal proof) by noting that the hybrid solution is relatively less profitable, the smaller is $\bar{w}^*$ (or

[7] This was heralded by a famous email from the newly installed CEO, Lou Gerstner, who declared that "Intellectual property assets such as patents belong to IBM, not to the individual units … Negotiations concerning intellectual property with companies outside IBM are the responsibility of the Intellectual Property and Licensing staff" (Phelps and Kline, 2009, page 31).

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

the greater is the set of deals that are submitted for approval), and that $\frac{\partial \bar{w}^*}{\partial \gamma} < 0$, $\frac{\partial \bar{w}^*}{\partial z} = 0$, and $\frac{\partial \bar{w}^*}{\partial c} > 0$.[9]

4.3.1. Discussion

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, if q parameterizes the development of the market for technology (it is easier to find partners in thicker and more efficient markets), our findings suggest that the hybrid model becomes more widespread when markets for technology develop. This directly follows the assumption that the BU can search at a lower cost. Indeed, if we extend the model slightly to include a fixed cost of searching for the BU as well (but lower than the cost for the HQ), then the implication is that as q increases, firms become more open to licensing, i.e., they invest resources in the search for potential licensees, but licensing remains decentralized. As q increases further, the firm will switch from decentralized to hybrid. As greater centralization implies higher probability of licensing, a related implication is that changes in how licensing is organized within firms feed back into the market for technology and contribute to its further development.

Empirical testing will require measuring q, which is not straightforward. However, there are some hints of how q varies across industries, countries and over time. Markets for technology are more developed in the chemical industry, biotechnology, software and semiconductor industry (Arora, Fosfuri and Gambardella, 2001), in the U.S. versus Europe, and have increased over time (Arora and Gambardella, 2010). If so, our theory predicts that we should see a trend toward centralization of licensing over time in these industries, especially in the U.S.

Second, as noted earlier, if large industrial companies are more likely to use financial measures to manage their business units (Hoskisson et al., 1993), we should expect a greater centralization of licensing in these firms, accompanied by an increase in licensing. Measuring the extent of production-based incentives is difficult. However, insofar as firms in the U.S. and Europe increase their reliance upon such incentives over time, they should also centralize licensing, which is consistent with the anecdotal evidence from firms such as IBM, Du Pont, and Procter & Gamble.

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[9] Starting from very large values of γ and small values of c, an increase in c can expand the parameter space where the hybrid solution dominates. Decentralized licensing leads to a severe agency problem for such parameter values, because the BU experiences most of the rent dissipation. Hence, an increase in c increases the HQ's cost of inducing the BU to license in the decentralized solution more than it increases the cost of taking uninformed decisions (regarding x) in the hybrid solution. However, for c large enough the cost of uninformed decisions dominates, leading to non-monotonicity in c for large values of γ. See Appendix A2.

Putting together these arguments, our model suggests that large firms heavily underlicense when markets for technology are underdeveloped. However, as markets for technology become more efficient, they end up centralizing their licensing activities, which in turn further boosts technology transactions.

Third, we should observe decentralization of licensing when licensing deals are more likely to generate rent dissipation. This is, for instance, the case when the potential licensee competes in the same product market of the licensor. One can argue that general-purpose technologies are characterized by less rent dissipation. "A more general technology allows a larger degree of transferability of skills across the different sectors of the economy" (Aghion, Howitt, and Violante, 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, 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.

Fourth, we should observe that decentralization is associated with lower licensing rates. This result is supported by a recent empirical paper by Arora, Belenzon, and Rios (2011) who study the organization of R&D in American corporations. They find that narrow and incremental patents are more likely to be given to business units to manage. Interestingly, they also report that firms that decentralize the management of their patent portfolio experience faster sales growth. Since licensing cannibalizes sales in the product market, this finding is consistent with lower licensing propensity under decentralization. This is supported by direct survey evidence as well. 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. Because Arora et al. (2011) find that patents from R&D units are more likely to be controlled by HQ rather than the BU, these findings indicate that patents controlled by BU are less likely to be licensed.

4.3.2. Additional implications and ramifications of the model

Our model can also be reinterpreted as one in which the management of the firm has to decide how to allocate the responsibility for bringing in external technology between two units: an R&D unit that is normally in charge of developing technology internally, and a central unit specialized in licensing in external technology. The R&D units may be best placed to identify and evaluate external technology, but may exhibit the Not-Invented-Here syndrome (Allen and Katz, 1982). The Not-Invented-Here syndrome, where firms are said to be guilty of ignoring promising external technology in favor of internal development, is believed to be pervasive. Thus, if R&D units were in charge of locating and acquiring external technologies, external technology acquisitions may be rare. For instance, a typical licensing arrangement between a pharmaceutical company and a biotech firm will involve the pharmaceutical firm paying for the biotech firm's development costs. In turn, this will be charged against the R&D manager's budget, requiring the R&D manager to cut one or more internal projects. The R&D division, not surprisingly, may view the deal less favorably than the sales and marketing division. Mindful of this, companies shift the in-licensing authority away from the R&D unit to a downstream division. For instance, Eli Lilly does not restrict itself to drugs developed in-house but instead allows its products divisions to source them externally. In other words, the R&D units in Eli Lilly do not have the authority to veto in-licensing by the product division.[10] Similarly, Glaxo has formed a central group for in-licensing.[11] Thus, with some small adjustments our model can also inform the important question of how to balance incentives between the internal development of technology and the monitoring and acquisition of extra-mural R&D, an issue that has recently become hot within the open innovation literature.

We have ignored the technology generation stage of the model. However, including an R&D stage would not substantially change our main findings. For instance, 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. A symmetric argument would apply if the relevant effort is that of the HQ. Extending this reasoning a step further, one should observe that business units tend to develop more focused, narrower technologies, while general-purpose technologies are developed centrally. Indeed, an implication of Proposition 3 is that more incremental, narrow technologies are typically decentralized, and thus the BU will have more incentives to exert effort in their development.

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

[10] Interview with Peter Johnson, VP, Eli Lilly, (17 May, 2011).
[11] See http://www.gsk.com/about/downloads/busdev-brochure.pdf.

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 $\lambda = 1$.

Consider first the 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.

Consider instead the hybrid solution. 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 position of the licensor (i.e., the lower is λ), the greater the benefit from delegating the negotiations to the BU. The extent of delegation is therefore decreasing in λ ($\frac{\partial \bar{w}}{\partial \lambda} < 0$), implying that we should 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 production incentives are exogenous; 2) we have assumed that the firm has only one BU; 3) we have treated $\tilde{w}$ and $\tilde{x}$ as independently distributed. We shall relax these assumptions below. These three extensions are key for pursuing the main goal of this paper; that is, to understand how licensing is managed in large companies. The first extension captures changes that might occur in a company across time, when the whole incentive system ends up adapting to functioning markets for technology. The second extension is important because large companies are very likely to have several divisions and business units. The third extension focuses on the potential implications that correlation between revenues from licensing and rent dissipation might have for the allocation of licensing authority within the firm. We focus on the hybrid case only, and to simplify the algebra, but without any loss of generality, we set $q=1$ and $\sigma=0$.

[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.

5.1. Endogenous monetary incentives to the BU

Thus far we have assumed that production incentives 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, production incentives do not immediately reflect this. However, in the longer run incentives may adapt to the changed circumstances. Below we analyze the main implications of allowing production incentives to be a choice variable.

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 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.[13]

5.2.1. Endogenous monetary incentives to the BU: No market for technology

As a benchmark, we start with the case in which licensing is not an option. The HQ maximizes profits from production, that is: $\max_\gamma \pi(\gamma)(1-\gamma)$. Let γ_{no_mft} be the share of profits from production assigned to the BU that maximizes the profits from production when the firm is does not consider licensing or there are no licensing opportunities. The corresponding first-order condition is

$$\pi_\gamma(1-\gamma)-\pi(\gamma)=0. \tag{6}$$

5.2.2. Endogenous monetary incentives to the BU: Hybrid model

The HQ solves the following program:

$$\max_{\gamma,\theta,\bar{w}} \pi(\gamma)(1-\gamma)+\int_{\bar{w}}^{z}\int_0^{c}[w-(1-\gamma)x]\frac{1}{cz}dx\,dw+\int_0^{\bar{w}}\int_0^{\frac{\theta w}{\gamma}}[(1-\theta)w-(1-\gamma)x]\frac{1}{cz}dx\,dw.$$

Proposition 4: *The solution to the HQ's problem when production incentives are endogenous is given by* $\theta^*=\frac{\gamma^*}{1+\gamma^*}$, $\bar{w}^*=\left(1-\sqrt{\frac{2\gamma^*}{(1+\gamma^*)}}\right)c(1+\gamma^*)$ *for* $\bar{w}^*\le z$*, and* γ^* *is the solution to*

$$\pi_\gamma(1-\gamma)-\pi(\gamma)+\frac{\left(z-\min\{\left(1-\sqrt{\frac{2\gamma}{(1+\gamma)}}\right)c(1+\gamma),z\}\right)c}{2z}-\frac{(\min\{\left(1-\sqrt{\frac{2\gamma}{(1+\gamma)}}\right)c(1+\gamma),z\})^3}{6(1+\gamma)^2c}=0\,. \tag{7}$$

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[13] Specifically, $\frac{\partial\pi(\gamma)}{\partial\gamma}>0$, $(1-\gamma)\pi(\gamma)$ is concave in γ, and $(1-\gamma)\pi(\gamma)$ is maximized for some $\gamma\in(0,1)$. We will also assume that $\left.\frac{\partial((1-\gamma)\pi(\gamma))}{\partial\gamma}\right|_{\gamma=0}>0$ and sufficiently large to ensure that $\gamma>0$ is chosen by the HQ. A simple case where these assumptions are satisfied is where the gross profit is linear in the BU's effort, and the cost (to the BU) is quadratic in effort.

Proof: See Appendix A3.

Proposition 4 has several interesting implications, which are summarized in the following corollary.

Corollary 2: *With a functioning market for technology, the HQ adjusts production incentives according to the extent of decentralization of licensing authority. If licensing authority is highly decentralized for $\gamma = \gamma_{no\_mft}$ ($\overline{w}^*$ is close to z), then production incentives are set below the production incentives absent a market for technology, i.e., $\gamma_{no\_mft} \geq \gamma^*$. If licensing authority is highly centralized for $\gamma = \gamma_{no\_mft}$ ($\overline{w}^*$ is close to 0), then production incentives are set above the production incentives absent a market for technology, i.e., $\gamma_{no\_mft} \leq \gamma^*$. Furthermore, licensing incentives are always less powerful than production incentives, i.e., $\theta^* < \gamma^*$.*

Proof: See Appendix A3.

The second part of Corollary 2 confirms our previous finding that licensing incentives are less powerful than production incentives even when both are chosen by the HQ. The first part of the corollary adds some interesting insights. It shows that when licensing authority is mostly decentralized at the business unit level, production incentives are distorted downward in the presence of an active market for technology. The intuition for this result is that production incentives make it more expensive for the HQ to incentivize the BU to license. A small reduction in γ away from γ_{no_mft} has no first-order effect on production profits, but increases the licensing payoff by allowing the HQ to decrease θ. Thus, production incentives are optimally muted when the BU has authority over most licensing deals.

Instead, when licensing authority is mostly centralized at the corporate level, production incentives are distorted upward in the presence of an active market for technology. The intuition behind this result is that for deals such that $w \geq \overline{w}^*$, the share of the rent dissipation borne by the BU is increasing in γ. By increasing production incentives there is a marginal decrease in (net) production profits and in licensing profits for $w < \overline{w}^*$, but these are compensated by a reduction in the rent dissipation experienced by HQ for $w \geq \overline{w}^*$

Since $\frac{\partial \overline{w}^*}{\partial \gamma} < 0$, the testable prediction is that we should observe a negative relationship between the extent of decentralization of licensing authority and the power of production incentives.

5.2. Two BUs

Large companies are likely to have several divisions or business units. Our model above would apply *mutatis mutandis* to a multidivisional company whose business units are independent from each other. However, when licensing by a BU affects the profits of other divisions, the organization of licensing raises new issues. The information relevant for licensing is now distributed across the organization, and more BUs have to be involved in the decision-making process. The BUs are unlikely to agree on every licensing deal, and the HQ has to decide how to translate the information and opinions received from the BUs into decisions.[14]

Consider a model with 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. The two BUs produce total gross profits of π if there is no licensing. If there is licensing, the value of 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 $\phi_H x$. Let BU_i get a share θ_i of the licensing revenue, $i \in \{A, B\}$. Since the BUs are symmetric, without loss of generality, we focus here on symmetric bonuses, $\theta_A = \theta_B \equiv \frac{\theta}{2}$.

The HQ approves directly all deals for which $w \geq \overline{w}$, while it consults the BUs for $w < \overline{w}$. We consider a simple procedure whereby the BUs are asked simultaneously whether they approve licensing or not. In Appendices A4 and A5 we show that it is a weakly dominant strategy for BU_i, which would experience profit dissipation $\phi_j x$ from licensing, to approve a deal if and only if $\frac{x}{w} \leq \frac{\theta}{2\gamma\phi_j}$, $i \in \{A, B\}$ and $j \in \{H, L\}$. Moreover, as long as $\frac{z\theta}{2\gamma\phi_L} < c$, so that a positive fraction of deals are rejected by the BUs in equilibrium, the optimal rule is one where both BUs must veto a deal for the deal to be rejected (*unanimity rejection*). The intuition is that in view of the insufficient licensing under decentralization, it is optimal to leave the licensing decision to the BU most willing to license.

Proposition 5: *Under the unanimity rejection rule, profits with two BUs are strictly greater than profits with only one BU. Further, the HQ sets a lower licensing bonus θ^* and sets a higher $\overline{w}^*$ when there are two BUs instead of one. Also, the probability of licensing remains unchanged.*
Proof: See Appendix A6.

Decentralization results in underlicensing. With two BUs the HQ can effectively decentralize the licensing decision to the more willing BU, thereby lowering the (incentive) cost of licensing. Indeed, if the rent dissipation were symmetric across the BUs, the profits with one BU and two BUs would coincide. This proposition is a simple application of the Theory of Second

[14] For instance, 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).

Best—the distortion of licensing incentives under decentralization is partially offset by the distortion due to negative spillovers. The HQ exploits the fact that the BU experiencing low rent dissipation does not consider the other BU when approving a licensing deal. Hence, the negative spillover on the other unit reduces the incentive cost of inducing licensing. 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.

The analysis has the interesting implication that the HQ relies more on the private information distributed across the organization when there are multiple BUs, which can be interpreted as increased decentralization. However, this does not make a centralized licensing unit less valuable to the HQ. Indeed, unlike the one BU case, the HQ may prefer to centralize search even if $\bar{w}^*(\phi_L) = z$, because a BU searching for licensees would have an incentive to suppress deals that were unfavorable to it but eventually would be approved by the other BU.[15]

5.3. Correlation between *w* and *x*

So far we have assumed that *w* and *x* are independently distributed (abusing the notation, we drop the tildes in this subsection). However, it is plausible that the revenue from licensing and the rent dissipation are correlated. One might suspect that correlation between *w* and *x* favors centralization of licensing authority as the HQ is able to observe *w* and thus learn about *x*. This intuition is only partially correct. The effect of correlation on the allocation of licensing authority depends on the underlying reason for correlation between licensing revenue and rent dissipation.

Theoretically, correlation between *w* and *x* could go either way. The two may be positively correlated because 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. That is, differences in productivity across potential licensees might be a source of positive covariance between *w* and *x*. On the other hand, differences in the product (or geographical) location of the potential licensee might generate a negative covariance between *w* and *x.* 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. To model this correlation in a tractable way, we assume that $x = \alpha\left(w - \frac{z}{2}\right) + \frac{c}{2} + b\varepsilon$, where ε is uniformly

[15] "One business unit may feel it's fine to license a technology, but another may disagree and believe its success depends on keeping that technology exclusive, … That's why … we established a separate intellectual-property holding company. " (Gene Partlow, vice president of Boeing's intellectual property business, quoted in Kline, 2003)

distributed between –c and c, with density 1/(2c).[16] This formulation nests the base model analyzed thus far in which $\alpha = 0$ and $b=1/2$. Notice that α and *b* do not affect the unconditional mean of *x*. In this formulation, α is the covariance between *w* and *x* and $var(x|w) = \frac{b^2c^2}{3}$, so that a decrease in *b* increases the precision of the signal regarding *x* that the HQ receives from observing *w*.

A useful observation before proceeding is that higher correlation might imply either a higher α or a lower b.[17] Intuitively, when greater correlation stems from a higher α we expect that the information of the BU becomes relatively more important as higher revenue deals are associated with higher expected rent dissipation. Instead, when greater correlation implies greater precision we expect that the information of the BU becomes less relevant. We explore this intuition more formally below. Analytical proofs for the general case are not feasible, but we analyze the limit case of $\alpha \to 0$ and $b \to \frac{1}{2}$ where the model approaches the baseline model.

Proposition 6: *For the limit case of $\alpha \to 0$ and $b \to \frac{1}{2}$ and $\overline{w}^* < z$:*

i) *The extent of decentralization increases with b* $\left(\text{i. e.}, \frac{\partial \overline{\mathrm{w}}^*}{\partial \mathrm{b}} > 0\right)$.

ii) *For $\gamma \leq \frac{1}{2}(\sqrt{2} - 1)$ an increase in α increases the extent of decentralization* $\left(\text{i. e.}, \frac{\partial \overline{\mathrm{w}}^*}{\partial \alpha} > 0\right)$. *For $\gamma > \frac{1}{2}(\sqrt{2} - 1)$ an increase in α increases the extent of decentralization if and only if $\frac{z}{c} \leq \overline{\left(\frac{z}{c}\right)}$, where $\overline{\left(\frac{z}{c}\right)}$ is decreasing in γ.*

Proof: See Appendix A7.

Starting from our baseline case of no correlation, Proposition 6 shows that increasing levels of correlation between *w* and *x* do not necessarily result in more centralization of licensing authority. Indeed, when monetary incentives are sufficiently modest, a larger α (increased correlation) leads to more, not less, decentralization. A higher α means that licensing deals imply higher average rent dissipation, so that the information from the BU becomes more relevant. When the cost of extracting this information is small (i.e., γ is small), a larger fraction of deals are decentralized. Instead, as expected, a reduction in *b*, i.e., an increase in the precision, makes centralization more appealing. Although profits for those deals whose authority is centralized do not change (as the mean of *x* is independent of *b*), profits for those deals that are sent to the BU tend to shrink. Thus, greater precision makes the information of the BU less relevant and licensing is more

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[16] Notice that *x* can take negative values. This can be interpreted as cases in which licensing increases the value of the firm's own profits from production, for instance, by facilitating the development of complementary products or the establishment of the firm's technology as an industry standard.

[17] The (Pearsson) correlation between *w* and *x* is $\rho_{w,x} = \frac{\alpha z}{\sqrt{4b^2c^2+\alpha^2z^2}} > 0$, which is increasing in $\alpha \in (0,1)$ and decreasing in $b \in \left(\frac{1}{2}, 1\right)$.

centralized. While Proposition 6 is a local result, simulations (available upon request) confirm that $\frac{\partial \bar{w}^*}{\partial b} > 0$ for any admissible values of α and γ.

Allowing for correlation between *w* and *x* has an ambiguous effect on the probability of licensing. The probability of licensing is driven by two forces: the extent of decentralization (more decentralization implies relatively less licensing) and the overall size of the market for technology (larger technology market implies more licensing). As *b* falls below the baseline level of $b = ½$, the increase in precision increases centralization. This pushes towards more licensing. However, a decrease in *b* also decreases the volume of value enhancing deals—the market for technology shrinks – and the latter effect dominates, under the specification we have chosen. Similarly, an increase in covariance will reduce the market for technology, which tends to reduce the licensing probability. Still, this can be offset by the increase in centralization ($\frac{\partial \bar{w}^*}{\partial \alpha} < 0$), which occurs for high values of *z/c* and γ; see Proposition 6. Appendix A8 demonstrates this conjecture more rigorously.

6. Conclusion

Markets for technology have created new strategic options for firms, especially innovating 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 business units.

One key choice in terms of organizing for the market for technology is where the decision-making power should be vested. A business unit 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 business units 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 proposed 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 shows that when the decisions are given to the business units, which have all the relevant information, it is not optimal to provide them with the appropriate incentives to license. This results in incentives to license always being weaker than incentives for production, so that the business unit will turn down potentially valuable deals. Centralizing licensing decisions 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 valuable deals. Further, centralized licensing units are likely to incur greater costs in searching for potential licensees. The firm can do better by centralizing the search for licensing deals and then selectively delegate the authority over licensing to the business units.

The model predicts that as markets for technology become more efficient firms will increasingly establish specialized licensing units, which in turn will boost their propensity to license out intellectual property. Second, firms with stronger production-based incentives are more likely to underlicense and are more likely to centralize licensing authority when technology markets expand. Finally, the model shows that general-purpose technologies that are broadly applicable display a higher licensing probability and are more likely to be managed centrally.

The model also predicts that the higher the degree of decentralization of licensing authority, the weaker production incentives should be if the firm can adjust them. Moreover, our analysis shows that the standard argument that intra-firm externalities calls for centralization does not necessarily apply in our context. Under decentralization the business unit 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. Finally, we show that correlation between the revenues from licensing and the rent dissipation does not necessarily lead to more centralization. If greater correlation implies that the revenues from licensing constitute a more precise signal of the rent dissipation, then, as expected, the information of the business unit becomes less relevant. Instead, when greater correlation arises from greater covariance between licensing revenues and rent dissipation, the information of the business unit might become more relevant and decentralization increases.

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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:

$$\text{Max}_{\theta}\ \pi(1-\gamma) + q\int_0^{\infty}\int_0^{\frac{\theta w}{\gamma}} [(1-\theta)w - (1-\gamma)x] f(x) g(w)\, dxdw. \qquad \text{(A1)}$$

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

$$\frac{\partial(A1)}{\partial\theta} = q\int_0^{\infty}\int_0^{\frac{\theta w}{\gamma}} (-w) f(x) g(w)\, dxdw + q\int_0^{\infty} w\left[(1-\theta) - (1-\gamma)\frac{\theta}{\gamma}\right]\frac{w}{\gamma} f\left(\frac{\theta w}{\gamma}\right) g(w) dw = 0.$$

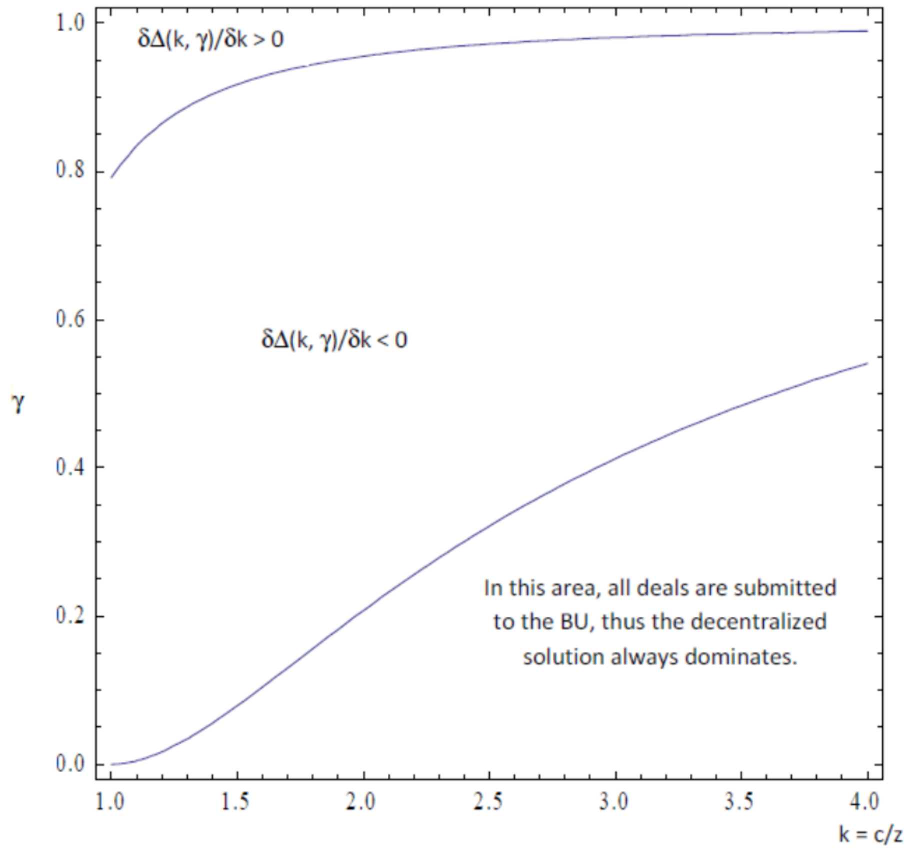
Since the first term is negative, the second term must be positive. Therefore, $(1-\theta) - (1-\gamma)\frac{\theta}{\gamma} > 0$, which implies that $\theta^* < \gamma$, i.e., licensing incentives are less powerful than production incentives.

A2: Proof of Proposition 3

It is sufficient to prove that $\frac{\partial\Delta(c,z,\gamma)}{\partial\gamma} > 0$, $\frac{\partial\Delta(c,z,\gamma)}{\partial z} > 0$, $\frac{\partial\Delta(c,z,\gamma)}{\partial c} < 0$. First, using the envelop theorem one can show that $\frac{\partial\Delta(c,z,\gamma)}{\partial\gamma} = \frac{(z-\bar{w}^*)(\bar{w}^{*2}+\bar{w}^* z+z^2+3c^2(1+\gamma)^2}{6cz(1+\gamma)^2} > 0$. Second, notice that $\frac{\partial\Delta(c,z,\gamma)}{\partial z} = \frac{1}{6}\left[3 - \frac{c^2\left[4\gamma\sqrt{2\gamma(1+\gamma)}-(1+\gamma)(1-5\gamma)\right]}{z^2} - \frac{2z}{c(1+\gamma)}\right]$. It is easy to see that $\frac{2z}{c(1+\gamma)} < 2$ and by using the fact that $\bar{w}^* \leq$ z one can show that $\frac{c^2\left[4\gamma\sqrt{2\gamma(1+\gamma)}-(1+\gamma)(1-5\gamma)\right]}{z^2} < 1$. Hence, $\frac{\partial\Delta(c,z,\gamma)}{\partial z} > 0$. Finally, $\frac{\partial\Delta(c,z,\gamma)}{\partial c} = \frac{1}{6}\left[-3(1-\gamma) + \frac{z^2}{c^2(1+\gamma)} + \frac{2c\left[4\gamma\sqrt{2\gamma(1+\gamma)}-(1+\gamma)(1-5\gamma)\right]}{z}\right]$. Using the same arguments as above, the last two terms are strictly less than 1 and 2, respectively. Thus for γ small enough, the first term dominates and $\frac{\partial\Delta(c,z,\gamma)}{\partial c} < 0$. Let $k = \frac{c}{z}$, then $\frac{\partial\Delta(k,\gamma)}{\partial k} = \frac{1}{6}\left[-3(1-\gamma) + \frac{1}{k^2(1+\gamma)} + 2k\left[4\gamma\sqrt{2\gamma(1+\gamma)} - (1+\gamma)(1-5\gamma)\right]\right]$. Figure A.1 shows the curve $\frac{\partial\Delta(k,\gamma)}{\partial k} = 0$ in the space (k, γ). Above the curve, $\frac{\partial\Delta(k,\gamma)}{\partial k} > 0$; below the curve, $\frac{\partial\Delta(k,\gamma)}{\partial k} < 0$. Interesting enough, for sufficiently large values of γ, at small values of *c* relative to *z*, an increment of *c* makes the hybrid solution more likely (i.e. the parameter space under which it occurs in equilibrium expands); however, for *c* sufficiently large, any increment in *c* makes the decentralized solution more likely. Notice, however, that for less extreme values of γ (for instance, monetary incentive less than 75% of production profits), greater *c* always implies more decentralization.

Figure A.1

Difference between hybrid and decentralized payoff to HQ, Δ, as function of γ and *k*



Note: $\Pi_H - \Pi_D = q\Delta(c, z, \gamma) - \sigma$, thus the hybrid solution is preferred to full decentralization if $\Delta(c, z, \gamma) \geq \frac{\sigma}{q}$. Thus, $\frac{\partial\Delta(k,\gamma)}{\partial k} < 0$ implies that as *c* becomes larger relative to *z*, the set of $\frac{\sigma}{q}$-values for which the hybrid solution is preferred shrinks.

A3: Proof of Proposition 4 and Corollary 2

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

$\max_{\gamma,\theta,\overline{w}} \pi(\gamma)(1-\gamma) + \frac{(z-\overline{w})(\overline{w}+z-(1-\gamma)c)}{2z} + \frac{\theta\overline{w}^3[2\gamma-\theta(1+\gamma)]}{6c\gamma^2 z}$ where $\overline{w} \in [0, z]$.

Notice that $\frac{\partial\Pi}{\partial\theta} = 0$ implies that $\theta^* = \frac{\gamma}{1+\gamma}$. After substituting θ^* into the profit function we obtain $\pi(\gamma)(1-\gamma) + \frac{(z-\overline{w})(\overline{w}+z-(1-\gamma)c)}{2z} + \frac{\overline{w}^3}{6(1+\gamma)c}$. Maximizing with respect to $\overline{w}$ and equating to zero we get $\overline{w}^* = \min\{\left(1 - \sqrt{\frac{2\gamma}{(1+\gamma)}}\right)c(1+\gamma), z\} > 0$. Finally, maximizing with respect to γ and equating to zero we obtain $\pi_\gamma(1-\gamma) - \pi(\gamma) + \frac{(z-\overline{w})c}{2z} - \frac{\overline{w}^3}{6(1+\gamma)^2 c} = 0$ where $\overline{w} = \overline{w}^*$, which completes the proof of Proposition 4. Finally, by evaluating (7) setting $\overline{w}^*(\gamma_{no\_mft})$ close to z and 0, it is easy to see that the optimal γ is lower and higher than γ_{no_mft}, respectively.

A4: Lemma 1: *Under both the unanimity rejection rule (both BUs have to reject a deal for a deal to be rejected) and the unanimity acceptance rule (each BU has veto power), it is a Bayesian Nash equilibrium in weakly dominant strategies for BU_i to approve a licensing deal if and only* $\frac{x}{w} \leq \frac{\theta}{2\gamma\phi_j}$ *where* $\phi_j \in \{\phi_L, \phi_H\}$ *and i = A, B.*

Proof. Consider the decision of BU_i under the unanimity rejection rule. If BU_h approves a given deal, the decision of BU_i does not matter for the outcome, *h,i* $\in$ *{A, B}* and *h* $\neq$ *i*. It is thus (weakly) optimal to approve the deal if and only if $\frac{x}{w} \leq \frac{\theta}{2\gamma\phi_j}$ where $\phi_j x$ is the profit dissipation experienced by BU_i. Suppose instead that BU_j does not approve the deal. Then, it is (strictly) optimal for BU_i to approve the deal if and only if $\frac{x}{w} \leq \frac{\theta}{\gamma\phi_j}$. The proof for the unanimity acceptance rule is analogous.

A5: Lemma 2: *The unanimity rejection rule strictly dominates the unanimity acceptance rule.*

Proof. The expected profits of the firm with two BUs are given by

$$\Pi = \pi(1-\gamma) + \int_{\overline{w}}^{z}\int_{0}^{c}[w-(1-\gamma)x]\frac{1}{cz}\mathrm{d}x\mathrm{d}w + \int_{0}^{\overline{w}}\int_{0}^{\frac{\theta w}{2\phi_j\gamma}}[(1-\theta)w-(1-\gamma)x]\frac{1}{cz}dx\,dw.$$

Here, $\phi_j = \phi_L$ under the unanimity rejection rule, and $\phi_j = \phi_H$ under the unanimity acceptance rule. Maximizing profits with respect to θ and $\overline{w}$ yields:

$$\theta^*(\phi_j) = \frac{2\gamma\phi_j}{1-\gamma+4\gamma\phi_j} \text{ and } \overline{w}^*(\phi_j) = Min\left\{c\left(1-\gamma+4\gamma\phi_j - 2\sqrt{\gamma\phi_j(1-\gamma+4\gamma\phi_j)}\right), z\right\}$$

Substituting $\theta^*(\phi_j)$ in Π, for a given $\overline{w}$, the expected profit of the firm can be written as $\Pi(\overline{w}, \phi_j) = \pi(1-\gamma) + \int_{\overline{w}}^{z}\int_{0}^{c}[w-(1-\gamma)x]\frac{1}{cz}\mathrm{d}x\mathrm{d}w + \frac{\overline{w}^3}{6c(1-\gamma+4\gamma\phi_j)}$, which is decreasing in ϕ_j. Therefore, we have that $\Pi(\overline{w}^*(\phi_H), \phi_H) \leq \Pi(\overline{w}^*(\phi_H), \phi_L) \leq \Pi(\overline{w}^*(\phi_L), \phi_L)$. Since $\Pi(\overline{w}^*(\phi_H), \phi_H)$ is the firm's profit under the unanimity acceptance rule and $\Pi(\overline{w}^*(\phi_L), \phi_L)$ is the profit under the unanimity rejection rule, the proof follows.

A6: Proof of Proposition 5

For a given $\overline{w}$, expected profits with two BUs ($\Pi^2(\overline{w}, \phi_L) \equiv \pi(1-\gamma) + \int_{\overline{w}}^{z}\int_{0}^{c}[w-(1-\gamma)x]\frac{1}{cz}\mathrm{d}x\mathrm{d}w + \frac{\overline{w}^3}{6c(1-\gamma+4\gamma\phi_L)}$) are greater than profits with only one BU ($\Pi^1(\overline{w}) \equiv \pi(1-\gamma) +$

$\int_{\bar{w}}^{z}\int_{0}^{c}[w-(1-\gamma)x]\frac{1}{cz}\mathrm{d}x\mathrm{d}w+\frac{\bar{w}^{3}}{6c(1+\gamma)}$), because $\phi_L \leq \frac{1}{2}$. If $\bar{w}$ can be adjusted further, then profits with two BUs can only increase. Therefore, we have that

$\Pi^1(\bar{w}^*) \leq \Pi^2(\bar{w}^*, \phi_L) \leq \Pi^2(\bar{w}^*(\phi_L), \phi_L)$ where $\bar{w}^*$ and $\bar{w}^*(\phi_L)$ are the optimal thresholds with one and two BUs, respectively, and the proof follows.

The probability of licensing with two BUs under the unanimity rejection rule is:

$\int_{\bar{w}^*(\phi_L)}^{z}\int_{0}^{c}\frac{1}{\mathrm{cz}}dx\,dw+\int_{0}^{\bar{w}^*(\phi_L)}\int_{0}^{\frac{\theta^*(\phi_L)}{2\gamma\phi_L}}\frac{1}{\mathrm{cz}}dx\,dw$ where $\theta^*(\phi_L)$ and $\bar{w}^*(\phi_L)$ are defined in Appendix A5. This reduces to $\frac{z}{2c(1+\gamma)}$, which is the same probability of licensing as with one BU.

A7: Proof of Proposition 6

The HQ solves the following program:

$$\underset{\theta,\bar{w}}{\mathrm{Max}}\left\{\pi(1-\gamma)+\int_{\bar{w}}^{z}\int_{-c}^{c}\left(w-(1-\gamma)\left(\alpha\left(w-\frac{z}{2}\right)+\frac{c}{2}+b\,\varepsilon\right)\right)\frac{1}{2cz}d\varepsilon\,dw\right.$$
$$\left.+\int_{0}^{\bar{w}}\int_{-c}^{\frac{\theta w/\gamma-\alpha(w-z/2)-c/2}{b}}\left((1-\theta)w-(1-\gamma)\left(\alpha\left(w-\frac{z}{2}\right)+\frac{c}{2}+b\,\varepsilon\right)\right)\frac{1}{2cz}d\varepsilon\,dw\right\}$$

Maximizing profits with respect to θ and $\bar{w}$ yields:

$\theta^*(\bar{w})=\frac{\gamma(3(c-2bc-\alpha z)\gamma+4\bar{w}(1+\alpha\gamma))}{4\bar{w}(1+\gamma)}$ and $\bar{w}^*=\frac{2(1-\alpha)(c+2bc-\alpha z)+8bc\gamma(1+\alpha\gamma)-\mathrm{A}}{4(1-\alpha)^2}$ for $\bar{w}^* \leq z$ where

$A \equiv \sqrt{\gamma((1-\alpha)^2(c-\alpha z)^2\gamma+4bc(1-\alpha)(c-\alpha z)(8+(7+\alpha)\gamma)+4b^2c^2(16+17\gamma-\alpha(16-\gamma(14+32\gamma-\alpha(15-16\gamma^2)))))}.$

Part (i) of the proposition follows directly from differentiating $\bar{w}^*$ with respect to *b* and taking the limits. Consider now part (ii) of the proposition. Differentiating $\bar{w}^*$ with respect to α and taking the limits yields: $\frac{\partial\bar{\mathrm{w}}^*}{\partial\alpha}=\frac{-2\frac{z}{c}\sqrt{\gamma(1+\gamma)}-2\sqrt{2}\gamma(3+4\gamma+\gamma^2)+(1+\gamma)(\sqrt{2}\gamma\frac{z}{c}+4(1+\gamma)\sqrt{\gamma(1+\gamma)})}{4\sqrt{\gamma(1+\gamma)}}$. Hence, $\frac{\partial\bar{\mathrm{w}}^*}{\partial\alpha}\geq 0 \Leftrightarrow \frac{\mathrm{z}}{\mathrm{c}}\leq$ $\frac{2(3\sqrt{2}\gamma+4\sqrt{2}\gamma^2+\sqrt{2}\gamma^3-2\sqrt{\gamma(1+\gamma)}-4\gamma\sqrt{\gamma(1+\gamma)}-2\gamma^2\sqrt{\gamma(1+\gamma)}))}{\sqrt{2}\gamma+\sqrt{2}\gamma^2-2\sqrt{\gamma(1+\gamma)}}\equiv\overline{\left(\frac{z}{c}\right)}(\gamma)$ where $\overline{\left(\frac{z}{c}\right)}'(\gamma)<0$. Finally, as $\frac{\mathrm{z}}{\mathrm{c}}\leq 1$ by assumption, $\frac{\mathrm{z}}{\mathrm{c}}\leq\overline{\left(\frac{z}{c}\right)}(\gamma)$ for $\gamma\leq\frac{1}{2}(\sqrt{2}-1)$.

A8: Proposition 7: *For the limit case of* $\alpha \to 0$ *and* $b \to \frac{1}{2}$*:*

i) The probability of licensing increases with b.

ii) *There exists a decreasing function* $\widehat{\left(\frac{z}{c}\right)}(\gamma)$ *such that an increase in* α *decreases the probability of licensing if and only if* $\frac{z}{c} \leq \widehat{\left(\frac{z}{c}\right)}(\gamma)$.

Proof. The probability of licensing is ProbLic =

$$\int_{\bar{w}^*}^{z}\int_{-c}^{c}\frac{1}{2cz}d\varepsilon\, dw + \int_{0}^{\bar{w}^*}\int_{-c}^{\frac{\theta^* w/\gamma-\alpha(w-z/2)-c/2}{b}}\frac{1}{2cz}d\varepsilon\, dw$$

. Part (i) of the proposition follows directly from differentiating the probability of licensing with respect to b and taking the limits. Consider now part (ii) of the proposition. Differentiating the probability of licensing with respect to α and taking the limits yields: $\frac{\partial \text{ProbLic}}{\partial \alpha} = -\frac{\sqrt{2}\gamma\sqrt{\gamma(1+\gamma)}-4\frac{c}{z}(1-2\gamma-5\gamma^2-2\gamma^3)+(1+\gamma)(8\sqrt{2}\frac{c}{z}\gamma\sqrt{\gamma(1+\gamma)}-(4-3\gamma))}{8(1+\gamma)}$.

Hence, $\frac{\partial \text{ProbLic}}{\partial \alpha} \leq 0 \Leftrightarrow \frac{z}{c} \leq \frac{4(1+\gamma)(1-3\gamma-2\gamma^2+2\sqrt{2}\gamma\sqrt{\gamma(1+\gamma)})}{4+\gamma-3\gamma^2-\sqrt{2}\gamma\sqrt{\gamma(1+\gamma)}} \equiv \widehat{\left(\frac{z}{c}\right)}(\gamma)$. Finally notice that $\widehat{\left(\frac{z}{c}\right)}'(\gamma) < 0$, $\widehat{\left(\frac{z}{c}\right)}(0) = 1$, and $\widehat{\left(\frac{z}{c}\right)}(1) = 0$, which implies that there exist permissible values of $\frac{z}{c}$ both greater than and less than $\widehat{\left(\frac{z}{c}\right)}(\gamma)$ for $0 < \gamma < 1$.