Managing licensing in a market for technology

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Abstract

Over the last decade, companies have increasingly focused on managing their intellectual assets. We build a model that helps understand how licensing activity should be organized within large corporations, and specifically, we compare decentralization -- where the business unit using the technology makes licensing decisions -- to the situation where a centralized unit is responsible. The business unit has superior information about licensing opportunities but may not have the appropriate incentives because its rewards depend upon product market performance. We find that when business units are in charge of licensing, they forgo valuable licensing opportunities. As non-pecuniary motives of managers become more salient, rewards for licensing are muted and decentralized licensing becomes less efficient. Further, growth of markets for technology favors centralization and is accompanied by an increase in production incentives. Finally, contrary to standard findings, spillovers across business units may actually favor decentralization.

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1. Introduction

There is increasing empirical evidence that markets for technology have become sizable in the last two decades (Arora, Fosfuri, and Gambardella, 2001). Using IRS data, Robins Robbins (2006), estimates that licensing of industrial processes in the United States amounted to $66 billion in 2002. Athreye and Cantwell (2007) show that international technology licensing payments and receipts have accelerated considerably since the 1980s. Arora and Gambardella (2010) estimate that worldwide markets for technology have topped $100 billion in recent years.

The growing market for technology implies that firms have licensing as an important option for fully profiting from their own intellectual property. Some firms earn many millions of dollars in revenues worldwide through licensing activities (The Economist, 2005). IBM alone is currently collecting around 1 billion dollars a year in licensing payments. Several others, including Eastman Kodak, HP, Dow Chemicals, BP, Texas Instruments, Proctor and Gamble, and DuPont have embraced a more open policy of actively licensing their intellectual property to others (see also Davis and Harrison, 2001).

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 Taumann, 2001; Gallini and Wright, 1990). However, little attention has been devoted so far to the analysis of how a firm should organize for managing efficiently its licensing business.

Managing licensing within a large corporation can indeed be complex. A large corporation typically has several divisions or business units, each of which is likely to create
and 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 develop a model that analyzes this decision.

Although there are several potential factors that condition this decision, in this paper we focus on two: 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 organization as a whole. For instance, managers who are rewarded for sales growth or market share will tend to overlook or even resist licensing opportunities, even if they create value for the company overall, as licensing creates potential competition that reduces product market revenues and dissipates rents (Arora and Fosfuri, 2003). Conversely, unless checked, those in charge of licensing may license away the “crown jewels”, mortgaging the firm’s future for current profits.

Simply put, centralizing licensing reduces the danger that licensing decisions will reflect the narrow interests of the division or business unit, rather than of the firm as a whole. On the other hand, the business unit which uses the technology is likely to have much better information about licensing opportunities and prospective partners. In addition to superior information about licensing opportunities, the business units are also better informed about the likely consequences of licensing for their business. Often, the prospective licensee may

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1 For instance, Arora et al. (2001) report the case of a chemical company, based in North America, which produced a basic polymer used for manufacturing plastics. The firm had developed an innovative process for producing the polymer but the market for the raw material in North America was competitive, with many suppliers and expanding production required large investments. The firm found an opportunity to license the technology in East Asia. However, the firm’s plastics division strongly objected to this because they had planned to export to the market using their plant in the Middle East.

2 Interview with Dr. Willy Shih, professor of management practice at Harvard Business School and former Executive Vice-President and co-head of the Technology Group of Thompson.

3 As a licensing executive from Ford Motor Company put it

“We have found that some of our best deals come from referrals via our technical people… 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 …”.

compete directly with them, reducing their market share and profitability, which we term rent-dissipation.

Although we lack systematic data, anecdotal evidence indicates that firms differ in how they organize licensing. 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. This centralization was heralded by a famous email from Lou Gerstner which noted 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).

Conversely, Eastman Kodak, which also has also actively engaged in technology licensing, typically decentralized licensing. For instance, according to Cecil Quillen, former General Counsel of Eastman Kodak, the licensing of chemical technologies (such as cellulose acetate, used for films as well as cigarette filters) was typically left the chemical business.

Similarly, conversations with retired IP managers at a Japanese electronics firm and a Japanese food and bio-products company indicate that not only was licensing effectively decentralized to the business units, the latter also captured most of the licensing revenues. Davis and Harrison (2001) classify Dow and Du Pont decentralized and IBM and Litton as centralized, while other firms, such as Lockheed, have adopted hybrid structures.

Our paper investigates how licensing activity should be organized within large corporations by proposing a simple model in which the management of the firm decides on how to allocate the task of searching for potential licensees and deciding whether to make a

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4 Phelps followed a similar centralized strategy at Microsoft, where was subsequently recruited in 2003 to lead intellectual property and licensing.
5 Personal communication with Cecil Quillen, 26 March, 2010.
deal to the business unit which is in charge of manufacturing and selling the product, or to a licensing unit that is fully dedicated to the licensing of the firm’s technology.  

Interestingly enough, 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 licensing unit. 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.

The type of trade-off we deal with in this paper is a standard one in principal-agent theory where the unit (agent) with information is provided incentives to use its private information appropriately. In our analysis, an important management lever is how revenues

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6 A recent paper by Garicano, Gertner and Dessein (2010) investigates the decision of integrating business units by addressing the tradeoff between coordination and incentives. “The benefit of integration is the ability to identify and realize synergies. The costs of integration arise from the fact that, in addition to cost-reducing effort, the functional manager needs to be motivated to make value-increasing standardization decisions.” Although the broader research question is similar, our paper focuses on the idiosyncrasies of technology licensing. The overlap is greatest when we analyze the case with two business units in section 3.3.

7 Glaxo has formed an entirely distinct multi-disciplinary group called Center of Excellence for External Drug Discovery (CEEDD), responsible for identifying external technologies for in-licensing. “This CEDD is about reaching beyond the walls to the world’s laboratory.” Dr. Jean-Pierre Garnier CEO of GlaxoSmithKline (http://www.gsk.com/about/downloads/busdev-brochure.pdf).
from licensing should flow back to the business units. Our focus is on organizational design, and thus we confine ourselves to simple linear contracts, which are common in real life, easy to understand, and robust. Furthermore, contracts between (the managers of) business units and the top management are typically not enforced in courts of law. Rather, they are relational contracts, supported by corporate norms and reputation, which typically precludes the use of complicated contingencies. Further, incentives inside organizations need not only be monetary. Managers may care about profits and revenue growth not just because their bonuses depend on it but also because, for instance, they like being the boss of a larger outfit. Other reasons include avoiding having to layoff workers, greater job safety and better career opportunities.

To preview our main findings, when business units are in charge of licensing, they forgo valuable licensing opportunities because the rewards for licensing are typically weaker than those for product-market profits. As non-pecuniary motives of managers become more salient, rewards for licensing are muted and decentralized licensing becomes less efficient. Further, growth of markets for technology favors centralization and is accompanied by an increase in production incentives. Finally, contrary to standard findings, spillovers across business units may actually favor decentralization.

The rest of the paper is organized as follows. The next section describes the basic ingredients of our model, finds the optimal organizational solution for licensing, and reports the main comparative statics. Section 3 discusses extensions and implications for
understanding empirical findings reported in the literature. Section 4 concludes by summarizing our main findings, directions for future research.

2. A Model of Licensing

Structure of the firm

The firm consists of a management unit (henceforth, HQ), a business unit (henceforth, BU), and possibly a dedicated licensing unit (henceforth, LU). The HQ, the BU and the LU are risk neutral; while the HQ maximizes firm profits, the BU and the LU maximize individual utilities.

Production

The firm has developed a technology that is employed by the BU to generate a gross profit of $\pi$. A fraction $\gamma_1$ of the profit is paid as bonus to the BU. We shall refer to $\gamma_1$ as monetary incentives. Since our primary interest is the internal organization of licensing, production activities are modeled in a reduced form for now, and thus $\gamma_1$ is an exogenous parameter. For instance, it could be that monetary incentives are the result of corporate culture, established norms and rules of thumb, and are not easy to modify by the HQ at least in the short term. In an extension below, we will endogenize monetary incentives and allow product-market profits to depend on the BU’s effort. In addition to the monetary payoff, the BU may also enjoy non-monetary benefits equal to $\gamma_0 \pi$. The key distinction is that whereas monetary benefits reduce overall firm profits (i.e., are a share of the overall profits), non-monetary benefits do not.

Licensing

The technology used by the BU can also be licensed to an independent firm. In our model, one of the key roles of the HQ is to decide who within the firm should be in charge of the two
activities involved in licensing, the BU or a LU. The second role of the HQ is to design the contracts to provide incentives for licensing.

Searching for a potential licensee is costly. We assume that the BU has lower costs of searching for a licensee than a LU due to its knowledge of the industry. For simplicity, the search cost of the BU is set equal to zero whereas the search cost of a LU is $\sigma$, $\sigma > 0$. If a unit searches, it finds a licensing opportunity with probability $q$.

Potential licensees differ along two dimensions: The value they generate from the technology and the extent to which they compete with the BU in the product market. The value the potential licensees obtain from the 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 $w$. The extent of competition with the BU is parameterized by $\tilde{x}$, a random variable uniformly distributed on $[0, c]$. The realized value of $\tilde{x}$ is denoted by $x$. We denote $x$ as the profit dissipation effect from licensing (Arora and Fosfuri, 2003). We also assume that $x$ and $w$ are independently distributed.

We assume that $w$ can be observed both by the BU (or the LU if it is in charge of searching) and it makes a take-it-or-leave offer to the licensee. This allows us to avoid having to analyze bargaining under asymmetric information. It follows that all inefficiencies in the licensing decisions are caused by agency problems inside the firm. However, although the distribution of $\tilde{x}$ is public knowledge, only the BU observes $x$ when a potential licensee is found. 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 (Davis and Harrison, 2001).\footnote{The BU and the LU can suppress information regarding licensing opportunities, i.e., not reveal a potential licensee, but they cannot create artificial licensing opportunities.} Finally, we assume that $c \geq z$,
which implies that on average, rent dissipation exceeds licensing revenues. This assumption is both plausible and also side-steps some uninteresting special cases.

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. Second, we consider the fully centralized solution in which the LU both searches and decides on licensing. Finally, in an extension, we shall analyze a hybrid alternative where the LU is in charge of finding a licensee but submits some potential deals for approval by the BU.

2.1 Decentralization: The BU Searches and Decides on Licensing

To encourage the BU to license, we assume that the HQ pays it a share $\theta$ of the licensing revenue.$^{11}$ Because the BU’s utility depends positively from the level of production profits, the BU suffers when a licensing deal is consummated. In particular, since licensing reduces profits by $x$, the opportunity cost of licensing to the BU is $(\gamma_1 + \gamma_0)x$. Foreseeing that the BU will license only if $\theta w/(\gamma_1 + \gamma_0) \geq x$, the HQ solves the following:

$$\text{Max}_\theta \pi (1 - \gamma_1) + q \int_0^x \int_0^{\gamma_1+\gamma_0} [(1 - 0)w - (1 - \gamma_1)x] \frac{1}{cz} \, dx \, dw.$$  \hspace{1cm} (1)

Let $\gamma = \gamma_1 + \gamma_0$ (i.e. total incentives for production) and $a = 1 - \gamma_1$. Using $w \sim U[0,z]$ and $x \sim U[0,c]$, the HQ’s problem can be rewritten as:

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

The first-order condition $\frac{\partial (z)}{\partial \theta} = 2\gamma - 2\theta (a + 2\gamma) = 0$, implies that $\theta^* = \frac{\gamma}{a + 2\gamma}$. The probability of licensing conditional on a potential licensee being found is $\int_0^x \int_0^\gamma \frac{1}{cz} \, dx \, dw = \frac{x}{2c(a + 2\gamma)}$, and profits (net of payments to the BU) are equal to $\Pi_D = a\pi + q \frac{z^2}{6c(a+2\gamma)}$.

$^{11}$ An alternative, namely contingent bonuses, is discussed in the appendix.
Proposition 1. (i) Incentives to license are less powerful than production incentives, i.e. \( \theta^* < \gamma \). (ii) Licensing incentives are greater when the BU enjoy high production incentives, and, if the share of monetary incentives is high i.e., \( \frac{\partial \theta^*}{\partial y} > 0 \) and \( \frac{\partial \theta^*}{\partial a} < 0 \).

Proof: Follows directly by noting that \( \theta^* = \frac{\gamma}{a + 2\gamma} \).

2.1.1 Discussion

Note first that result holds under more general conditions. For instance, it does not depend on the specific distribution chosen for \( x \) and \( w \) (see Appendix for proof) and also holds when we endogenize monetary production incentives (see Extension I below).

Proposition 1 is an important finding because it shows the problems firms face in opening to the market for technology. It suggests that licensing revenues are effectively treated as less valuable to the firm than product market revenues. It also points out to the widespread complain of business units that licensing revenues remain in the corporate coffer and do not flow back sufficiently at the business unit level.

Empirically, it implies that conditional on licensing being decentralized to the business units, the probability of licensing \( = \frac{z}{2c(a + 2\gamma)} \) will fall as the share of non-monetary incentives for production increases i.e., as \( a \) increases given \( \gamma \). Anecdotal evidence indicates that licensing is decentralized in Japanese and European firms. If Japanese firms are more likely to favor non-monetary incentives relative to European firms, then the proposition implies that Japanese firms would license less (conditional on being open, i.e., being willing to license). This prediction is broadly consistent with the some recently available evidence from inventor surveys. Based on survey of European inventors who had obtained EPO patents, Gambardella, Giuri and Luzzi (2007) report that of the patents the patent holder was willing to license, about 66% of the patents were actually licensed. Nagaoka and Walsh
(2009) report that for patents that Japanese patent holders were willing to license, about 54% were licensed. A similar pattern is reported by Zuniga and Guellec (2009) in their survey of patenting firms in Europe and Japan. They find that nearly 50% of the European firms that licensed to unaffiliated firms report that they licensed more than 80% of their patent portfolio, while of Japanese firms that report some licensing to unaffiliated parties, only 40% claim to have licensed more than 80% of their portfolio. Once again, this is consistent with a higher $\theta/\gamma$ in Europe than Japan, which in turn is consistent with a higher share of non-monetary incentives in Japan. Obviously, a more careful empirical test would have to control for how the firms are distributed across size categories and industries; the point is the potential of our simple model to illuminate these patterns.

2.2 Centralization: The LU Searches and Licenses

By searching the LU finds potential licensees and gets informed about $w$. We assume that the HQ makes a lump sum payment that is equal to the search costs. We assume that the LU freely reveals the information about $w$ to the HQ (and BU) or alternatively, it simply does what it is best for the HQ (there is no advantage of behaving differently in our setting). The HQ uses this additional information by making licensing deals contingent on $w$. That is, licensing deals with revenues greater than $\tilde{w}$ are authorized, the others are rejected. Thus, the program the HQ maximizes is the following:

$$\max_{\tilde{w}} a\pi + q \int_{\tilde{w}}^{z} f_c[w - ax] \, dx \, dw - \sigma.$$  

After substituting for $f_{\tilde{w}}(w)$, $f_c(w)$ and $f_{\tilde{w}}(w)$ we have:

$$\max_{\tilde{w}} a\pi + \frac{q}{2z} (z - \tilde{w})(z + \tilde{w} - ca) - \sigma. \quad (3)$$
The first order conditions with respect to $\hat{w}$, \( \frac{\partial (3)}{\partial \hat{w}} = 0 \rightarrow \hat{w}^* = \frac{ca}{2} \) if $\frac{ca}{2} \leq z$, otherwise the best option is to stay close, i.e. no licensing. Replacing $\hat{w}$ in (3), one obtains the profit in the centralized case: $\Pi_C = a\pi + q \left( \frac{(2z-ac)^2}{8z} \right) - \sigma$, provided that $\frac{ca}{2} \leq z$ and $\sigma$ is small.

2.3 The Choice between Centralization and Decentralization

The centralized solution is preferred to the decentralized one if $\left( \frac{(2z-ac)^2}{8z} \right) - \frac{z^2}{6c(a+2\gamma)} \geq \frac{\sigma}{q}$.

**Proposition 2:** *The parameter space under which the centralized solution dominates the decentralized one expands as $\frac{\sigma}{q}$ decreases, $\gamma_0$ increases, a decreases given $\gamma$, c decreases and $z$ increases.*

**Sketch of the Proof.** The comparative statics with respect to $\frac{\sigma}{q}$ is obtained by simply inspecting the profit expressions under centralization and decentralization. The comparative statics with respect to $\gamma_0$ comes directly from the fact that profits under centralization do not depend on the non-monetary incentives, thus while profits under decentralization do depend negatively on $\gamma_0$. The comparative statics with respect to $a$ (given $\gamma$), c and $z$ are less straightforward. Let $S$ represent the difference in profits (payoff of the HQ) under centralization and decentralization. Then $S = \left( \frac{(2z-ac)^2}{8z} \right) - \frac{z^2}{6c(a+2\gamma)}$. Then $S = 0$ is cubic in $a$, $c$ and $z$ but with only one real valued root. Using that root, one can show the results.

Let us start with $a$. By definition $a \in [0,1]$. It is easy to show that $\Pi_C|_{a=0} > \Pi_D|_{a=0}$. If $\Pi_C|_{a=1} < \Pi_D|_{a=1}$, then there exists an $\hat{a} \in [0,1]$ such that for $a<\hat{a}$ $\Pi_C > \Pi_D$, while for $a>\hat{a}$ $\Pi_C < \Pi_D$. If $\Pi_C|_{a=1} > \Pi_D|_{a=1}$ then centralization is always chosen.
Now consider $c$. By assumption $c \in [z, \infty]$. Let $c \geq \frac{2z}{a}$. In this range $\Pi_C = 0 < \Pi_D$. Consider now the case in which $c = z$. Let $\Pi_C|_{c=z} = \frac{z(2-a)^2}{8}$ and $\Pi_D|_{c=z} = \frac{z}{6(a+2y)}$. If $(a + 2y)(2 - a)^2 > \frac{4}{3}$, then there exists a $\hat{a} \in \left[\frac{2z}{a}, z\right]$ such that for $c < \hat{a}$, $\Pi_C > \Pi_D$, while for $c > \hat{a}$, $\Pi_C < \Pi_D$. Otherwise, decentralization is always chosen. The proof for $z$ follows similarly.

2.3.1 Discussion

Proposition 2 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 centralization becomes more widespread when markets for technology develop. Notice this follows directly from the assumption that the BU can search at a lower cost. Indeed, if we extend the model slightly to include a fixed cost of licensing for the BU as well, then the implication is that as $q$ increases, firms are more likely to become open to licensing. As $q$ increases further, they will switch from decentralized to centralized.

Second, given $\gamma$, an increase in $a$ is equivalent to a situation where the BU’s incentives for production shift from monetary to non-monetary. Proposition 2 implies that centralization is relatively more attractive when the BU’s production incentives are largely non-monetary (i.e., when firms make little use of explicit monetary incentives for product-market performance of the BU). An increase in non-monetary incentives, $\gamma_0$, similarly favors centralization. These predictions can also be empirically tested if one can develop measures of the incentive of managers. However, insofar as monetary incentives are relatively more salient for American managers compared to Japanese managers (relative to non-monetary incentives), the prediction is consistent with the anecdotal evidence that US firms are more
likely to centralize licensing relative to Japan even though licensing opportunities (i.e., $q$) are comparable in both markets.

Empirical testing will require measuring $q$, which is not straightforward. However, there are some hints of how $q$ varies across countries and over time. A BTG study, cited in Arora, Fosfuri and Gambardella (2001) finds that expenditures on external technology as a % of R&D amounted to 12% in the US, 10% in Japan and only 5% in Europe. A recent OECD survey confirms both that established firms have increased their propensity to license-in and to license-out new technologies (Sheehan et al., 2004). The survey, which was administered in 2003, covered 105 firms in the US, Europe and Asia-Pacific, most with greater than 1000 employees. Almost 60% of the firms interviewed reported increased inward and outward licensing during the previous decade. If so, our theory predicts that all else equal, we should see a trend towards centralization of licensing over time.

Our model can also help illuminate some cross-country patterns in licensing. The inventor surveys indicate that even if we exclude cross-licensing, Japanese firms are more open to licensing than American or European firms: US firms were willing to license 31% of their patents, whereas the corresponding shares are 42% for Japanese firms and only 21% for European firms. Second, as already noted, conditional on being willing to license, the share of patents licensed were 66% for European firms, 54% for Japanese firms, and only 43% for American firms. Third, our sense, based on informal conversations with firms and industry experts, is that relative to Japanese and European firms, American firms are more likely to centralize licensing. Once again, ignoring potential differences in the size and industry distribution, our model points to three key parameters, namely $q$, $\gamma$ and $a$.\(^{12}\) These patterns are consistent if Japan has high $q$ and $a$ but low $\gamma$, Europe has low $q$ and high $a$ and perhaps also

\(^{12}\) In addition, obviously, parameters that measure the value and generality of the technology, $c$, and the potential for rent dissipation, $z$, are also important. However, these will vary within and across firms and industries and we ignore them for now.
low $\gamma$, whereas US has high $q$ and $\gamma$ and low $a$. This would result in greater openness in the US and Japan relative to Europe, and greater centralization in the US relative to Japan and Europe.\footnote{It is also not inconsistent with the overall licensing shares. Note that our model does not predict that overall licensing rates would move monotonically with the key parameters, because firms could change from decentralized to centralized, which could increase or decrease licensing rates.}

Finally, let us interpret $c$ as the generality of the technology. More general technologies are less likely to generate direct competition to the licensor, thus generality is associated with the profit dissipation effect. A more specific technology with narrow applications is more likely to generate greater profit dissipation effect. Thus, Proposition 2 would suggest that the more specific is the technology, the less likely the firm sets up a dedicated unit to search for licensing.

3 EXTENSIONS

3.1 Hybrid solution

This solution can be thought of as a situation in which the LU can approve deals but can choose to have some subset of deals subject to approval by the BU (i.e., the BU has veto power over those licensing deals). To induce licensing the BU is offered a share, $\theta$, of the licensing revenues for the deals that are sent for its approval. As above the HQ can exploit the additional information about the revenues from licensing by making the approval of the BU contingent on $w$. Let $\bar{w}$ be the value of the revenues from licensing such that any deal for which $w \geq \bar{w}$ the LU does not have to seek the approval of the BU. Instead all deals such that $w < \bar{w}$ must be approved by the BU. The HQ maximizes the following:

$$\max_{\theta, \bar{w}} \pi a + q \int_{\bar{w}}^{\infty} \int_{0}^{\infty} [(w - ax) \frac{1}{cz} \, dx \, dw + q \int_{0}^{\bar{w}} \int_{0}^{\infty} [(1 - \theta)w - ax] \frac{1}{cz} \, dx \, dw - \sigma.]$$

Using $w \sim U[0, z]$ and $x \sim U[0, c]$ we obtain:
\[
\max_{\theta, \overline{w}} \Pi \alpha + q \frac{(z-\overline{w})(\overline{w}+z-a\gamma)}{2z} + q \frac{\theta \overline{w}^2(2\gamma-\theta(a+2\gamma))}{6cyz} - \sigma
\]  

(4)

Notice that \(\frac{\partial(4)}{\partial \theta} = 0 \to \theta^* = \frac{\gamma}{a+2\gamma}\). In other words, the optimal level of licensing incentives, \(\theta^*\), is exactly the same we had above in the decentralized case. Replacing \(\theta^*\) in (4) and simplifying we get:

\[
\frac{\partial(4)}{\partial \overline{w}} = -\frac{\overline{w}}{z} + \frac{ac}{2z} + \frac{1}{(a+2\gamma)2cz} \overline{w}^2 = 0.
\]

(5)

Solving (5) in the relevant range of values of \(\overline{w}\) we have that

\[
\overline{w}^* = \left(1 - \frac{2\gamma}{\sqrt{(a + 2\gamma)c}}\right) (a + 2\gamma)c > 0.
\]

(6)

Notice, that by totally differentiating (4) we get \(\frac{\partial \overline{w}}{\partial \gamma} < 0, \frac{\partial \overline{w}}{\partial \alpha} > 0\), and \(\frac{\partial \overline{w}}{\partial c} > 0\). Also as \(\overline{w}^*\) approaches \(z\), the LU increasingly submits the deals to the veto of the BU. Thus, the larger is \(\overline{w}^*\), the less profitable is to have an independent LU searching for licensees because the HQ has to pay for search costs, \(\sigma\), of the LU. By comparing the first order conditions one can also show that \(\overline{w}^* < \overline{w}^*\).

**Proposition 3.** *The hybrid solution always dominates the centralized case, i.e. \(\Pi_H \geq \Pi_C\).*

**Proof.** In the hybrid solution, the HQ could have chosen \(\overline{w}^* = \overline{w}^* = \frac{ca}{2}\) and \(\theta^* = 0\), which would result in profits of \(\Pi_C\). Since \(\overline{w}^* \neq \overline{w}^*\) and \(\theta^* \neq 0\), it follows from a revealed preference argument that \(\Pi_H \geq \Pi_C\).

Since the BU is assumed to be more efficient at searching for licensing, we cannot conclude that the hybrid case also dominates the decentralized outcome. There are two forces pushing in opposite directions. When the BU is in charge of licensing, search costs are lower. On the other hand, in the hybrid case the HQ is better informed, that is, it has information about the realization of \(w\). This reduces information rents it has to provide the BU. It turns out that the comparison between the hybrid solution and the decentralized model is similar to that we discussed above between centralized and decentralized solution (the hybrid being an
improved version of the centralized solution). Thus all implications apply *mutatis mutandis*, i.e. the hybrid solution less likely to be observed if \( q \) is small, search costs are large, production incentives are relatively weak, especially the monetary ones, and \( c \) is larger with respect to \( z \). (Proofs in Appendix.)

3.2 *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 production incentives in relations 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 monetary production incentives are designed. However, in the long run it is less likely that such incentives remain unchanged. Below we analyze what are 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 directly monitored by the HQ, and thus, the BU is provided a share of profits, \( \gamma \). For simplicity, we shall assume here that non-monetary incentives are equal to zero. 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 efforts expended by the BU, and hence the production profits, continue to be \( \pi(\gamma) \). In the appendix, we develop model that rationalizes this assumption and also derives the licensing revenue and rent dissipation in a more direct fashion. 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 $\gamma$.\footnote{Specifically, $\frac{\partial \pi(y)}{\partial y} > 0$, $(1 - \gamma) \pi(y)$ is concave in $\gamma$, and $(1 - \gamma) \pi(y)$ is maximized for some $\gamma \in (0,1)$ that we denote $\gamma^*$. We will also assume that $\frac{\partial((1 - \gamma) \pi(y))}{\partial y} \bigg|_{y=0} > 0$ and sufficiently large to ensure that $\gamma > 0$ is chosen by the HQ. A simple case where these assumptions are satisfied is where gross profit is linear in BU’s effort, and the cost (to the BU) is quadratic in effort.} For ease of exposition, we also normalize $z=1$, thus $c\geq 1$. The net utility of the BU from the production activity is $U(\gamma)$ where $\frac{\partial U(\gamma)}{\partial y} > 0$.

3.2.1 **Endogenous monetary incentives to the BU: No market for technology**

As a benchmark, we shall start with the case in which there is no market for technology. Licensing is thus not an option. The HQ maximizes profit from production, that is:

$$\max_{\gamma} \pi(\gamma)(1 - \gamma).$$

Let $\gamma_{no_mft}$ be the share of profits from production assigned to the BU that maximizes the profits from production when the firm is closed. The corresponding first order condition is

$$\pi_{\gamma}(1 - \gamma) - \pi(\gamma) = 0 \quad (7)$$

3.2.2 **Endogenous monetary incentives to the BU: Decentralized**

Considering first the decentralized solution, the HQ solves the following program:

$$\max_{\gamma, \theta} \pi(\gamma)(1 - \gamma) + q \int_0^1 \int_0^\gamma [(1 - \theta)w - (1 - \gamma)x] c \, dx \, dw$$

**Proposition 4:** The solution to the HQ’s problem when the BU searches and decides on licensing and production incentives are endogenous is given by $\theta^* = \frac{\gamma_{dc}}{1 + \gamma^*}$ and $\gamma_{dc}$ as the solution to $\pi_{\gamma}(1 - \gamma) - \pi(\gamma) - \frac{q}{6c(1 + \gamma)^2} = 0. \quad (8)$

**Proof:** See appendix.

Proposition 4 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 production incentives, i.e. $\gamma_{no,mft} \geq \gamma_{dc}$. Furthermore, incentives to license are less powerful than production incentives, i.e. $\theta < \gamma_{dc}$.

Proof: See appendix.

The second part of Corollary 1 confirms our previous finding that licensing incentives are less powerful than production incentives even when both types of incentives are chosen by the firm. The first part of the corollary adds some new interesting insights. It shows that when licensing activity is decentralized at the business unit level, production incentives are distorted downwards 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 $\gamma$ has no first order effect on production, but increases the licensing payoff by allowing HQ to decrease $\theta$. Thus, production incentives are optimally muted when the business unit is in charge of licensing.

3.2.3 Endogenous monetary incentives to the BU: Centralized

The program the HQ maximizes is the following:

$$\max_{\gamma, \hat{w}} \pi(\gamma) (1 - \gamma) + q \int_0^1 \int_0^c [w - (1 - \gamma)x] \, dx \, dw - \sigma.$$  

After substituting for $\gamma$ and $\hat{w}$, we have:

$$\max_{\gamma, \hat{w}} \pi(\gamma) (1 - \gamma) + \frac{q}{2} (1 - \hat{w})(1 + \hat{w} - c(1 - \gamma)) - \sigma. \quad (9)$$

By taking the first order conditions with respect to $\hat{w}$ one obtains:

$$\frac{\partial (9)}{\partial \hat{w}} = 0 \rightarrow \hat{w}^* = \frac{c(1 - \gamma)}{2}. \quad (10)$$

Replacing $\hat{w}$ in (9):

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

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Differentiating (10) w.r.t. $\gamma$ and setting equal to zero we get the first order condition for the optimal monetary incentive under centralization, $\gamma_c$
\[
\frac{\partial (10)}{\partial \gamma} = \pi_\gamma (1 - \gamma) - \pi(\gamma) + q \left(1 - \frac{c(1-\gamma)}{2}\right) \frac{c}{2} = 0.
\] (11)

Comparing (11) with (7), it follows that that $\gamma_c \geq \gamma_{no.mft}$. In other words, $\gamma$ is now set at level even higher than that when the firm is closed, i.e., where there is no market for technology. Combining with Corollary 1, we get the result that $\gamma_c \geq \gamma_{no.mft} \geq \gamma_{dc}$

**Proposition 5:** *With a functioning market for technology, if the licensing is centralized, the HQ optimally increases the power of production incentives above the production incentives absent a market for technology.*

**Discussion:** This intuition behind this result is that under centralized licensing, the higher the production incentives, the greater is the share of the rent dissipation shared by the BU. Consequently, when licensing is centralized HQ increases production incentives beyond level optimal in a closed firm. Combined with earlier results, the testable empirical prediction is that whereas production incentives are muted (compared to the level absent a market for technology) when licensing is decentralized, they are enhanced when licensing is centralized. In so far as increases in $q$ should first lead to decentralized licensing and then to centralization (by proposition 2), this proposition implies that we should see production incentives first decrease and then increase as markets for technology grow.

### 3.3 Two BUs

It seems prima facie sensible that when there are multiple business units, centralization would be more profitable. For instance, if licensing by one BU imposes rent dissipation on another, one might imagine this would call for centralization. However, this intuition is misleading. Consider a model with two business units, $BU_A$ and $BU_B$. It may be helpful to imagine one
single business unit being split into two, identical in all ways except in how they experience
rent dissipation.

The two BUs produce total gross profits of $\pi$ if there is no licensing. When licensing
opportunities are introduced, with probably $q$ one of the units observes a licensing
opportunity of value $w$. The total profit 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 $\phi_L < \frac{1}{2}$ and $\phi_L + \phi_H = 1$ and with 50% probability, the symmetric outcome obtains.
Let BU_i get a share $\theta_i$ of the licensing revenue. We assume that both units are paid a share of
the licensing revenue when the technology is licensed^15 and $w$ and $x$ are distributed as in the
baseline model.

Consider the behavior of the unit $i$ that discovers a potential licensee. It licenses the
technology if and only if

$$\frac{x}{w} \leq \frac{\theta_i}{\gamma \phi_i}$$

where $\phi_i \in \{\phi_L, \phi_H\}$. We continue to assume that $\frac{\theta_i}{\gamma \phi_i} < c$ in the
relevant range. Letting $\theta = \theta_A + \theta_B$ the expected profit of the firm with two units (net of
the payment to the units) is thus given as:

$$E = \pi (1 - \gamma_A) + \frac{1}{2} \sum_{i=1,2} \sum_{j=L,H} \left( \frac{\theta_i w}{\phi_j} \right) \left( \frac{1}{2} \int_0^x \int_0^w [(1 - \theta)w - (1 - \gamma_i)x] \frac{1}{c^2} dx dw \right)$$

To ensure that the problem is concave in $\theta_A$ and $\theta_B$, we assume the following:

**Assumption 1:**

$$1 - \gamma_1 (1 - 2\phi_L)^2 - 2(1-\gamma_0) \phi_L \phi_H > 0$$

If Assumption 1 does not hold, the solution is either never to license or to license for any
value of $x$, and the profits with one unit is then always greater than with two units.

Maximizing profits with respect to $\theta_1$ and $\theta_2$ yields

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^15 This assumption can be justified on the grounds of fairness. Doing away with this assumption will only
strengthen our finding. Furthermore, it provides a nice benchmark for the comparison as the profit is the same
with one and two business units and symmetric rent dissipation, $\phi_L = \frac{1}{2}$. 

Using this solution, we can directly compare the profits with one and two units.

**Proposition 6:** For $\phi_L < \frac{1}{2}$, the profits with two units are strictly greater than the profits with only one unit if and only if $3\gamma_1 + 2\gamma_0 > 1$.

**Sketch of proof:** It can be verified that total profits with one business unit, $\Pi_1$, and with two business units, $\Pi_2$, are equal for $\phi_L = \frac{1}{2}$. For $\phi_L = \frac{1}{2}$, the two business units also experience the same rent dissipation in each and every case. Furthermore, $\Pi_1$ is independent of $\phi_L$ whereas $\Pi_2$ is decreasing in $\phi_L$ if and only if $3\gamma_1 + 2\gamma_0 > 1$, and the result follows.

**Discussion**

Before discussing the intuition, it is worth stressing the implications of this result. Simply put, this result implies that if licensing creates rent dissipation for other BUs, this can actually make decentralization more attractive to the firm, not less. To see this note that multiple BUs has no effect on centralized profits. Next consider two situations. In both there are two BUs. However, in the first case, there are no spillovers. Each BU’s licensing decisions create rent dissipation only for itself. This is identical to the situation where there is only one BU, only twice as big. However, when there are spillovers as described earlier, by proposition 6, as long as $3\gamma_1 + 2\gamma_0 > 1$, the firm has higher profits under spillovers. It follows then that spillovers may actually increase the benefits from decentralizing licensing.

To understand the intuition behind proposition 6, note that effect of spillovers across units involves two opposing effects. On the one hand, with spillovers, licensing becomes less efficient because when deciding to license, a BU ignores the spillovers on the other BU. This is the standard intuition behind expecting benefits from centralization. However, with the spillover, it also becomes cheaper for the HQ to induce a BU to license. Recall that under
decentralization, there is insufficient licensing. Thus getting the BU to license more readily increases efficiency and profits. This tradeoff is mediated by the level of production incentives. The higher the production incentives, the greater the benefit to increasing licensing and the smaller is the inefficiency due to inefficient licensing.

To get more insight into these effects, it is useful consider the effect of the asymmetric profit dissipation across the BUs on i) the profits for a constant probability of licensing, and ii) on the probability of licensing for a constant monetary incentive to license.

Notice that the asymmetric profit dissipation translates into stochastic licensing decisions for the firm for given \( x \) and \( w \). In particular, for \( \frac{\theta_i}{\phi_H(y_1 + \gamma_0)} < \frac{x}{w} \leq \frac{\theta_i}{\phi_L(y_1 + \gamma_0)} \), there is licensing if and only if the unit that discovers the potential licensee draws the \( \phi_L \). For a given probability of licensing, this is not the optimal: It is optimal to accept all deals for which \( \frac{x}{w} \) is below a certain threshold and reject all others. We denote this effect “the stochastic licensing effect”, and this inefficiency, which is specific to the two-unit situation, reduces licensing profits when there are two units. Notice that in the symmetric case, when \( \phi_L = \phi_H \), this inefficient range disappears. More generally, the greater the asymmetry, the greater is the inefficiency in the two BU case due to stochastic licensing. However, the larger are \( \gamma_0 \) and \( \gamma_1 \), the smaller is the marginal effect of increasing asymmetry.

The probability of licensing = \( \frac{1}{2} \int_0^Z \int_0^{\theta_i w} \frac{1}{cz} dx dw + \frac{1}{2} \int_0^Z \int_0^{\theta_i w} \frac{1}{cz} dx dw \),

Using \( \phi_H = 1 - \phi_L \), it is then easy to show that the probability of licensing is decreasing in \( \phi_L \). That is, if the two business units experience more asymmetric loses from licensing, it increases the probability of licensing for given monetary licensing incentives. Therefore, if \( \phi_L \) decreases, the HQ can reduce the licensing bonus and still maintain the same licensing
activity in terms of the number of deals consummated. This effect is denoted the “propensity to license effect”, and it tends to increase the profits from licensing when there are two units. With high incentives for production, licensing is costly to induce, and the firm benefits more from the propensity to license effect than it loses from the stochastic licensing effect. If the HQ were to reward only the unit that finds the licensee, the licensing revenues shared with the BU are halved and the profits are consequently greater. Obviously, this implies that profits under the spillover case would be higher still, reinforcing the result.

3.4 Correlation between $w$ and $x$

We have assumed, thus far, that $w$ and $x$ are independent. It is likely that the two are in fact positively correlated. Those who value the technology the most are also likely to be a close competitor. To understand the implications for our model, recall that in addition to having lower costs, the other advantage of decentralization is that only the BU observed $x$. That greater the correlation between $x$ and $w$, the smaller this advantage because we have assumed that HQ are also able to observe $w$. Thus, greater correlation is likely to increase centralization. Insofar as the firms chooses to keep licensing decentralized, correlation should not affect profits.

4 Discussion and Implications

Markets for technology have created new strategic options for firms, especially for innovating firms. As many companies are trying to reap the benefits of well-functioning markets for technology, there is little understanding of how they should organize internally for licensing. This is especially 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 also can assess the likely rent dissipation
from licensing more accurately. However, managers of business units will typically have
incentives to increase sales revenue and profits from the business, 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 and market share. We proposed a simple model that
addresses this important strategic decision.

The model generates several findings consistent with existing empirical evidence on
licensing. For instance, it rationalizes the commonly held belief that firms frequently fail to
consummate licensing deals even when both parties could benefit. Even when the decisions
are given to the business units, which have all the relevant information, it proves too costly to
provide them with the appropriate incentives to licensing. 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 unsuitable deals as well as refuse potentially
valuable deals. Further, centralized licensing units are likely to incur greater costs in
searching for potential licensees.

The model also predicts that when the managers of business units have non-pecuniary
motives for increasing profits from production, for instance because it reduces the likelihood
of layoff or because they like being the boss of a bigger outfit, that leaving them in charge of
licensing will create more inefficiency than if managers only cared about the monetary
bonuses. Thus, managers with non-pecuniary motives will license less and are more likely to forego potentially useful deals. This may explain why conditional on being open, European firms are more likely to license than Japanese firms, even though there is more licensing activity in Japan.

If, however, non-pecuniary motives are less salient but the demand for technology is high, implying a high payoff to searching for potential licensees, firms will optimally choose to centralize licensing, even with the inefficiencies implicit in centralization. Consistent with this, American firms are more likely than others to have centralized licensing activity.

The model also predicts that firms that fully decentralize licensing to the business unit should have weaker production incentives than firms where licensing is centralized. More generally, the higher is the degree of decentralization of the licensing activity, the weaker should be the production incentives and the smaller the participation of the business unit to the licensing revenues.

Finally, our analysis shows that the standard argument that intra-firm externalities calls for centralization does not necessarily apply in our context. Under decentralization the HQ faces the problem that 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 profit dissipation is carried by the other unit. This lack of internalization of the externality actually may benefit the HQ, because it alleviates the moral hazard problem and makes it less costly to induce the unit(s) to act upon their private information.

Clearly, our simple model can be extended and refined in many ways, many of which have been noted in our discussion. Our paper is the first step in trying to understand how a firm has to reorganize internally in order to open up to the market for technology outside.
Apparends

A1. A reinterpretation of the model

Our objective here is to derive the licensing revenue and rent dissipation in a model where we explicitly allow for managerial effort to affect production profits. We assume that the BU observes the licensing fee and the rent dissipation before a licensing deal is made. However, after a licensing deal is made, the HQ also observes rent dissipation. Under conditions derived below, the BU always receives a fraction $\gamma$ of the production surplus. In other words, the BU receives $\gamma \pi$ from its production activities if there is no licensing and $\gamma(\pi - x)$ if there is licensing. The HQ therefore maximizes:

$$
Max_{\theta} \left\{ \int_0^Z \left( \int_0^\theta \left( (1 - \gamma)(\pi - x) + (1 - \theta)w \right) f(x)dx + \int_{\theta}^\pi (1 - \gamma)\pi f(x)dx \right) g(w)dw \right\}
$$

(A.1)

Endogenizing the payoff structure

Suppose that the technology has a measure 1 of applications to the firm, the potential licensor. The technology can also be used by a potential licensee that has a competitive advantage in the development of a measure 1 of applications. If the technology is licensed, the licensee develops $m$ applications that the licensor could do itself - although not as fast - and $1 - m$ applications that the licensor could not do. Hence, $m$ represents the number of applications that the licensor loses because the licensee is able to occupies these market segments first. We assume that $m$ is distributed on $[0, 1]$ according to the density function $f(m)$.

Each application developed by the firm has value $\pi$ and each application developed by the licensee has value $\lambda \pi$. Let $\lambda$ vary by licensee as well, and assume it to be distributed on $[0, \frac{\pi}{2}]$. However, we assume that although $\lambda$ is stochastic, its realization is observed by all. We assume that only the BU observes $m$. This is in line the idea that the BU is better informed about its own and a potential licensee’s technical capabilities than the rest of the firm.

Then, we assume that the BU makes a take-it-or-leave it offer to the licensee. Clearly, the most it can extract is $\lambda \pi$. This is equal to the realized value of $w$, and we assume that $w$ is distributed on $[0, z]$ according to $g(z)$. The rent dissipation is $m \pi$. This is the realized value of $x$.

In the centralized solution, the HQ makes a “take-it-or-leave-it” offer to the license. This offer is $\lambda \pi$. The rent dissipation are $m \pi$. If the deal takes place, the BU develops $(1-m)$ applications. For each of those applications, it invests effort $e_m$ and receives a reward $\gamma \pi$. It follows that it invests the same amount of effort in the development of each of the applications so $e_m = e^*$, and thus, its total effort is $(1-m)e^*$ and its reward is $(1-m)\gamma \pi$.

The last element of the model is the constant share of profits, $\gamma$. To illustrate how this could arise, assume an application requires an unobservable effort $e$ by the BU. The effort results in gross profits of $\frac{8\beta \pi}{3}$ with probability $e$ and in 0 with probability $1 - e$. The cost of effort for the BU is $c(e) = \frac{\beta}{2} e^2$.

We have that $e^* = \gamma \sqrt{\frac{8\pi}{3\beta}}$ where $\gamma$ is the share of the profits offered to the BU.

The HQ maximizes $(1 - \gamma)\gamma \sqrt{\frac{8\pi}{3\beta}} \sqrt{\frac{8\beta \pi}{3}}$, which results in $\gamma^* = \frac{1}{2}$. Hence, the expected payoff to the HQ is $\frac{2\pi}{3}$ and the expected payoff to the BU is $\frac{\pi}{3}$. That is, $\gamma = \frac{1}{3}$ in this particular example. Therefore, the payoff to the HQ under licensing is $(1 - \gamma)(\pi - x)$ where $\gamma = \frac{1}{3}$ and $x = m \pi$. Thus, under the decentralized solution, the HQ solves a problem equivalent to (A.1).
A2: Contingent bonuses to reward licensing

We show here that it is never optimal to use a bonus contingent on consummated deal to reward the BU. Let $T$ be the contingent bonus. The program can be written as follows:

$$\max_{\theta,T} \pi a + q \int_0^Z \int_0^T [(1 - \theta)w - T - ax]\frac{1}{xz} \, dw$$

Using $w \sim U[0,z]$ and $x \sim U[0,c]$, and taking the derivatives with respect to $\theta$ and $T$, we have:

$$\frac{\partial(B_1)}{\partial \theta} = 2z(\gamma - a\theta - 2\gamma \theta) - 3T(a + 2\gamma) \geq 0$$

$$\frac{\partial(B_1)}{\partial T} = z(\gamma - a\theta - 2\gamma \theta) - 2T(a + 2\gamma) \geq 0.$$  

It is easy to see that the only values of $\theta$ and $T$ that satisfy the first order conditions with equality are $T^* = 0$ and $\theta^* = \frac{\gamma}{a+2\gamma}$. Thus it is not optimal for the HQ to use contingent bonus to reward the PU.

**Proofs of propositions**

Microfoundation and discussion of correlation between $x$ and $w$

Results with general distribution forms