Process Innovation, Licensing and Coopetition under Uncertainty and Imperfect Appropriation Regime

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ABSTRACT

We develop a model to examine the behavior of a process innovator that faces an uncertain demand and an imperfect appropriation regime that may allow a rival to license the new technology generated from its innovation effort. The innovator-licensor needs to choose its innovation effort in the initial stage and decide in the second stage whether to licence the technology to the rival and how to structure the licensing agreement (i.e., a fixed fee or a royalty) whereas the uncertain demand is realized only in the third stage. The model analyses how the level of uncertainty and the tightness of the appropriation regime affect the innovator's effort and subsequent coopetition strategy vis-à-vis its rival.

1. Introduction

Whether to license a technology or keep it proprietary for own exploitation is an important issue of relevance to strategy and international business. Endogenizing this choice and understanding the conditions which drive it, such as spillovers, innovation effort and demand conditions, would be a valuable contribution to the literature. Innovators must make ex-ante investment decisions and decide on innovation effort at the risk of spillovers before future demand is known. Under ineffective intellectual property (IP) protection, an innovator keeping the technology proprietary for own use may be confronted with the risk that a competitor might benefit at no cost from spillover effects. Unless it can enforce IP protection, it risks being undermined by a competitor who may quickly respond and benefit from such spillover effects. An interesting question then is how much effort an innovator should make to develop a process innovation under uncertain demand conditions when it risks being undermined by a rival? Of course, the innovator can take costly measures to protect its new technology via patent protection and by raising entry barriers. Patents traditionally provide incentives to pursue innovation by protecting against damaging spillovers. Innovators often protect their IP by securing patents. Still, even with a secure technology the decision facing an innovator to voluntarily license out its patented technology to a competitor for a monetary fee or royalties poses an interesting and subtler issue. Under what conditions should a proprietary technology (process) advantage be shared with a rival? What should be the licensing fee structure to maximize the innovator's value that is also acceptable to the licensee? And what should be the optimal amount of ex-ante innovation effort under uncertainty and an imperfect appropriation regime?

Treating as a choice variable whether to follow an aggressive strategy by pursuing proprietary use of an innovator's superior technology or instead pursue an accommodating stance by sharing the benefits via licensing it to a rival is analogous to choosing whether to compete or collaborate in an innovation context. In the strategy literature, competitive rivalry and cooperation have often been viewed as opposing or mutually exclusive strategy paths (Lado, Boyd, and Hanlon, 1997). However, in practice firms often alternate among competition and cooperation depending on market circumstances. A key strategic choice for an innovator is therefore whether to play "tough" and raise the entry barrier pursuing a proprietary strategy or to accommodate rival entry by collaborating and licensing out its patented technology for monetary benefit. The innovator can adopt different licensing contracts characterized by different fee structures (e.g., fixed fee vs. royalty). In making this choice, the optimal licensing strategy is seen to depend on ex-post demand, on the innovation effort itself, and whether market entry is deterred or accommodated. We further assess the effect of demand uncertainty on these choices. Ex-ante innovation effort, which drives the cost of innovation, influences the degree of the innovation advantage.

We determine conditions for optimal patent licensing strategies, analysing market-entry games in a simple setting. Two firms must decide whether to enter a high-tech market, such as smartphone virtual reality, in view of stochastic demand dynamics and their expectations about the rivals' market-entry decision. They then select the amount (quantity) to produce in the product-market stage. One firm, the *innovator*, pursues an ex-ante technological *process* innovation to establish a cost-based advantage (in the form of reduced future variable production costs) in the product-market stage. The innovator decides ex ante how much (effort) to invest in innovation, which determines the degree of the innovation advantage. The innovator's resulting competitive advantage can hurt the rival ex post as it raises entry barriers and reduces the profit the latter could achieve. In the second (product-market) stage, with the degree of innovation-driven cost advantage given, the innovator decides on the optimal licensing strategy. If the rival's market entry is deterred (which would occur when the rival's marginal cost is above the monopoly price), the innovator would prefer to keep its superior technology proprietary for own exclusive use. When entry is accommodated and the innovator is better off to license out the technology to its rival, it must propose either a fixed-fee or a royalty licensing scheme depending on demand conditions. Once the innovator-licensor sets the terms of the licensing deal, the potential licensee accepts or rejects the deal, hence any terms the licensor proposes must make the licensee at least indifferent between accepting or rejecting the licensing deal. The creation of an innovation process advantage makes the innovator’s payoff more convex in the state of demand. If demand uncertainty is high, the innovator will invest more in process innovation as its payoff is more convex. Although patent licensing policy has been studied extensively in the literature from an industrial organization (IO) and game theory perspectives in a rather deterministic setting (e.g., Kamien and Tauman, 1986; Wang, 1998), the role and impact of imperfect appropriation regime under uncertainty in these choices has not been adequately addressed.

The role of uncertainty in management and strategy has been recognized early on as being fundamental (Wernerfelt and Karnani, 1987; Rumelt et al., 1994). Uncertainty shapes the tension between flexibility and commitment as well as between competition and cooperation. As noted by Folta and O’Brien (2004) and Chevalier-Roignant and Trigeorgis (2011), early movers often acquire IP rights, such as patents and licenses, to protect or appropriate future growth options. Trigeorgis and Reuer (2017) point out that the dilemma between competition and cooperation remains a fundamental research gap in the literature on strategic management. The key issue is when firms are better off cooperating rather than competing in the marketplace in uncertain environments.

Smit and Trigeorgis (2007) propose an option games approach to evaluating technology or other strategic investments in oligopolistic competition by combining real options analysis and game theory. The authors address strategic dilemmas such as when an innovator should take a tough stance to preempt market share (following a proprietary investment strategy that might hurt the competition) or follow an accommodating stance by sharing the investment that might also benefit the rival and avoid retaliation. We extend this work treating as a *choice* variable whether the innovator should take a tough stance (keeping the technology proprietary for own exploitation) or follow a shared/accommodating strategy (licensing one's technology) under cost-based quantity competition, analyzing the conditions when to follow a proprietary or a shared strategy keeping the patent to oneself or licensing it out to a rival.

Specifically, we consider several related issues. One issue is how much (effort or cost) should the innovator invest in the process innovation and how this choice is impacted by demand uncertainty. Second, given the degree of innovation effort, the resulting innovation advantage and the prevailing demand conditions, under what conditions should the innovative firm follow a proprietary or tough strategy keeping the innovation for own exploitation or follow an accommodating stance by agreeing to license its patented technology to its rival? We show how this choice depends on whether rival entry is deterred or accommodated and on the degree of innovation effort – which drives the degree of the innovation advantage – as well as on the degree of spillovers and the level of demand. We show that the royalty rate licensing structure has an advantage over the fixed fee alternative under this setup as it imposes an additional "tax" rate on the rival's effective marginal cost.

2. Model setup

Our setup consists of three stages: (i) the innovation stage at $t = 0$, (ii) the licensing decision stage at time τ, and (iii) the product-market (or commercialization) stage at time $T = \tau + h$. At the outset ("ex ante") the *innovator* (firm i) pursues a technological *process* innovation deciding on its level of innovative effort, noted ε (≥ 0). The cost to exert such an effort is convex increasing, given by

$$C(\varepsilon) = k\varepsilon^2, k > 0.$$

This effort will affect the innovator's unit production cost at time T ("ex post"), but also its rival's (firm j) cost if the latter can free-ride, benefitting from *spillover* effects. Parameter $\gamma \in [0,1]$ captures the effectiveness of the IP protection regime. The spillover parameter, γ, is $\gamma = 0$ if the appropriation regime is perfect; at the other extreme, $\gamma = 1$, the rival fully free rides. High spillovers reduce the innovator's incentive to pursue a cost-reducing process innovation.[1] We assume the innovator is granted a patent for its technology but IP protection is not perfect.

In the intermediate stage (at time τ), the innovator chooses whether to keep the technology proprietary for its own exploitation or license it out to the rival for a commensurate fee. If the two parties close a licensing deal, they get to exploit the same (superior) production technology. Otherwise, because the appropriation regime is imperfect, the rival benefits partly via spillover. In negotiating the terms of the patent licensing agreement, the innovator acts as a "principal," while the rival-imitator is effectively an "agent." In making an offer to its rival (j), the innovator-licensor (firm i) decides on how to structure the licensing agreement (fixed fee vs. royalty rate) with a view to maximize its own expected ex-post profit. The rival will not agree to the terms unless it benefits as well. If the firms agree, the innovator incurs a one-time contractual cost β covering various transaction costs such as lawyer and administrative fees. Under the royalty contract, the innovator will also incur unit monitoring costs, B, to ensure the revenues and earnings figures are objectively reported by the licensee.

[1] Patents are granted by governments to enhance the incentives for private firms to pursue innovations by providing them with the exclusive right to use the patented technology. Innovators are encouraged to pursue innovation as they are protected from spillover effects when IP rights are effectively enforceable by law.

Ex post, in the product-market stage (at time τ), the innovative firm i can reap the benefits of its ex-ante costly innovation effort ε, with reduced unit production cost given by $c_i(\varepsilon) = ce^{-\varepsilon}$.[2] If the two firms cannot reach a deal (at time τ), the rival (firm j) can benefit to some extent from the innovator's efforts owing to *spillovers*, with its unit cost reduced to $c_j(\varepsilon, \gamma) = ce^{-\gamma\varepsilon}$, with γ being the degree of spillover The rival firm will choose to operate under the old, more costly technology ($c_j(\varepsilon, 0) = c$) if IP rights are effectively enforced ($\gamma = 0$). Closing an agreement (at time τ) leads to a situation where the rival has the same production cost as the innovator (effectively $\gamma = 1$). The two firms then compete in the product market over output (in the ex post stage), facing linear demand of the form:

$$p(x, Q) = x - bQ, \qquad (1)$$

where x is the state of demand, Q the total output supplied in the industry by both firms and b (> 0) is the slope of the inverse demand function. This linear demand function describes a situation where the price adjusts quickly to ensure that demand matches firms' supply. At each stage, the innovator forms expectations about the distribution of future demand. Ex post demand at time T, X_T, is unknown at the outset ($t = 0$) as well as at time τ, but it is known to be lognormally distributed with possibility to update expectations.[3] We proceed backwards to determine the optimal licensing deal.

3. Licensing and deterred vs. accommodated entry

Patented innovations are often viewed as a strategic device to establish barriers to entry. Under demand uncertainty, the rival's entry decision will depend on the state of ex-post demand x,

[2] If the innovator made no effort ($\varepsilon = 0$), its ex-post unit cost is $c_i(0) = c$, which is the cost under the old production technology. Making a greater innovator effort helps reduces the ex-post unit cost, but the unit contribution gradually decreases ($c_i'(\varepsilon) < 0$ and $c_i''(\varepsilon) > 0$) such that reducing the unit cost to nil could only be achieved with an incredible amount of effort ($c_i(\infty) = 0$).

[3] The drift term per unit of time is μ, while variance per unit of time is σ^2.

which is unknown at the outset. Thus, the innovator cannot know for sure whether the rival will enter or not. In other words, the innovator cannot ensure whether benefiting from a process innovation helps it deter (or accommodate) rival entry. Entry will be deterred ex post if the innovator can set a monopoly price (p_M) below its rival's unit production cost, and will be accommodated otherwise. The innovator will not operate (and hence will earn zero profit) ex post if the state of demand x is not sufficient to cover its unit cost $c_i(\varepsilon)$. If the innovator is a monopolist, it will set a unit price $p_M(x,\varepsilon) = [x + c_i(\varepsilon)]/2$ and earn a monopoly profit given by[4]

$$\pi_M(x,\varepsilon) = \frac{\left(x - c_i(\varepsilon)\right)^2}{4b}. \tag{2}$$

Rival entry will be deterred if $p_M(x,\varepsilon) \le c_j(\varepsilon,\gamma)$, which occurs if $x \le \bar{x}(\varepsilon,\gamma)$ with

$$\bar{x}(\varepsilon,\gamma) \equiv ce^{-\varepsilon}\left[2e^{(1-\gamma)\varepsilon} - 1\right]. \tag{3}$$

We refer to the critical demand threshold $\bar{x}(\varepsilon,\gamma)$ as the *entry barrier*.

When entry is accommodated ($x > \bar{x}(\varepsilon,\gamma)$), the two producing firms compete à la Cournot.[5] The rival/imitator (firm *j*) can only make a profit if the state of demand x exceeds the above entry barrier $\bar{x}(\varepsilon,\gamma)$, with the rival's profit function then given by

$$\pi_j(x,\varepsilon,\gamma) = \begin{cases} 0, & x \le \bar{x}(\varepsilon,\gamma) \\ \frac{[x - \bar{x}(\varepsilon,\gamma)]^2}{9b}, & x > \bar{x}(\varepsilon,\gamma). \end{cases} \tag{4}$$

From equation (4), the entry barrier $\bar{x}(\varepsilon,\gamma)$ can alternatively be interpreted as the *opportunity* cost incurred by rival firm *j* when competing with the innovator (firm i).

The innovator's contingent strategy is as follows: it will not operate ex post if demand is very low ($x \le c_i(\varepsilon)$), it will operate as a (temporary) monopolist in an intermediate demand range where rival entry is deterred ($c_i(\varepsilon) \le x \le \bar{x}(\varepsilon,\gamma)$), and it will compete in production

[4] See the Appendix for the derivations of the monopoly price, monopoly and duopoly profits.
[5] We might consider Stackelberg or differentiated Bertrand competition as alternate strategic competition setups.

with the rival à la Cournot if rival entry is accommodated ($x > \bar{x}(\varepsilon, \gamma)$). The innovator's profit function is thus given by:

$$\pi_i(x, \varepsilon, \gamma) = \begin{cases} 0, & x \leq c_i(\varepsilon) \\ \frac{[x - c_i(\varepsilon)]^2}{4b}, & c_i(\varepsilon) \leq x \leq \bar{x}(\varepsilon, \gamma) \\ \frac{[x - \delta(\varepsilon, \gamma)\bar{x}(\varepsilon, \gamma)]^2}{9b}, & x > \bar{x}(\varepsilon, \gamma), \end{cases} \tag{5}$$

with $\delta(\varepsilon, \gamma) = e^{(\gamma - 1)\varepsilon}$. In the high demand region when entry is accommodated ($x > \bar{x}(\varepsilon, \gamma)$), in the absence of a licencing deal the innovator enjoys a cost advantage over its rival as captured by the (innovation advantage) factor $\delta(\varepsilon, \gamma)$ (≤ 1) in equation (5). Innovation effort helps improve this cost advantage (because $\partial\delta/\partial\varepsilon \leq 0$) but spillover effects will erode it (because $\partial\delta/\partial\gamma \geq 0$). If the firms agree to a licensing deal, they will both use the same (superior) technology and hence both will earn

$$\pi_i(x, \varepsilon) = \pi_j(x, \varepsilon) = \begin{cases} 0, & x \leq c_i(\varepsilon) \\ \frac{[x - c_i(\varepsilon)]^2}{9b}, & x > c_i(\varepsilon). \end{cases} \tag{6}$$

Spillover effects – captured by γ – are detrimental to the innovator as they lower the entry barrier or the rival's opportunity cost ($\partial\bar{x}/\partial\gamma < 0$). The innovator's effort ε that minimizes the risk of rival entry, namely $\bar{\varepsilon}(\gamma) \equiv (\ln 2\gamma)/(\gamma - 1)$, is driven by the degree of spillovers (γ).[6] If spillovers are negligible (γ is small), any effort contributed by the innovator helps reduce the risk of rival entry (as $\bar{\varepsilon}(0) = \infty$). If spillovers are high (γ greater than ½), increasing innovation effort also increases the risk of rival imitation and entry (because $\bar{\varepsilon}(1/2) = 0$). The spread between the innovator/monopolist entry threshold $c_i(\varepsilon)$ and the rival/imitator entry threshold $\bar{x}(\varepsilon, \gamma)$, given by

$\bar{x}(\varepsilon, \gamma) - c_i(\varepsilon) = 2c\left(e^{(1-\gamma)\varepsilon} - 1\right),$

[6] Indeed, it readily obtains from (3) that $\partial\bar{x}/\partial\varepsilon \leq 0$ if $\varepsilon \leq \bar{\varepsilon}(\gamma)$ and $\partial\bar{x}/\partial\varepsilon \geq 0$ if $\varepsilon \geq \bar{\varepsilon}(\gamma)$, proving that $\varepsilon \mapsto \bar{x}(\varepsilon, \gamma)$ attains its minimum at $\bar{\varepsilon}(\gamma)$.

increases in innovation effort ε, hence increased ex-ante effort ε enhances the innovator's chances to benefit from a monopoly status ex post (for a given level of spillover γ).

Because ex-post demand is unknown at the time the firm decides on its innovation effort ε, its optimal effort depends on its demand expectation as well as its expectation on how the game unfolds. The optimal innovation effort does not necessarily consist in minimizing the risk of rival entry by exerting an effort $\bar{\varepsilon}(\gamma)$.

4. Licensing choices

At intermediate time, τ, the innovator has two main choices. Either it uses its superior technology for own exploitation despite facing the threat of imitation and spillover erosion by the rival, or it agrees to license the technology to its rival. We discuss the innovator's main choices in turn.

Proprietary stance (no licensing)

Consider first the time-τ value for the innovator of keeping the superior technology proprietary. In the product-market stage at time $T\ (= \tau + h)$, the innovator's future random profit is $\pi_i(X_T, \varepsilon, \gamma)$, with π_i given in equation (5). Firm i cannot perfectly forecast future demand at time τ. Suppose demand follows a geometric Brownian motion, with mean and volatility parameters μ and σ, respectively. Then the expected time-τ value of keeping the technology proprietary is $\Pi(x, \varepsilon, \gamma) \equiv E_x[\pi_i(X_T, \varepsilon, \gamma)]$ assuming the demand process reaches state x at time τ, where E_x denotes the expectation operator provided time-τ demand is x.[7] Figure 1 shows the innovator's expected profit under a proprietary strategy for distinct delay periods h. At time T, the innovator (firm i) suffers a profit drop when rival firm j enters at demand

[7] At time τ, the innovator observes the time-τ state of demand x and forms expectation about time-τ demand X_T. From the perspective of time τ, $\ln(X_T)$ is normally distributed with mean $\ln(x) - (\mu + \sigma^2/2)(T - \tau)$ and standard deviation $\sigma\sqrt{h}$.

threshold $\bar{x}(\varepsilon,\gamma)$ as shown for the curve for $h = 0$ in Figure 1. As the time interval between τ and T becomes larger ($h = 1$ vs 0.5), the effect on time-τ expected profit of competitor entry at threshold $\bar{x}(\varepsilon,\gamma)$ becomes smoother because future demand X_T is more disperse around $\bar{x}(\varepsilon,\gamma)$ owing to uncertainty. We observe (see Figure 1) an interesting concave-convex pattern resembling a "competitive wave." Uncertainty (which increases with the time horizon) seems to dissipate the negative impact of rival entry.

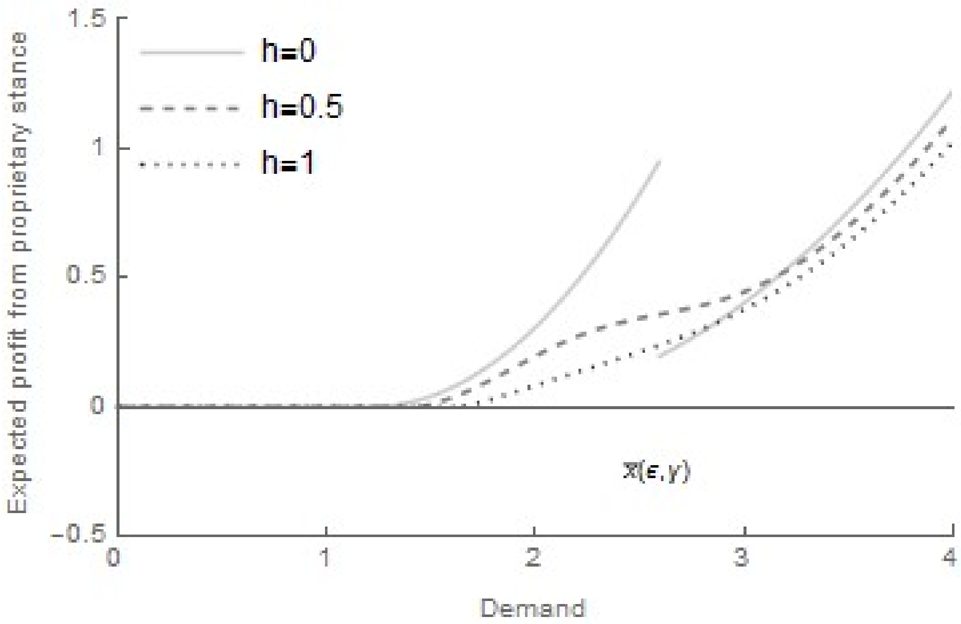

Figure 1: Innovator's expected (time-τ) profit as a function of (time-τ) for distinct delay periods ($h = 0, 0.5\ or\ 1$). Parameter values: $c = 2$, $\varepsilon = 0.5$ $b = 0.5$, $\sigma = 0.25, \mu = 0.0$.

A delay ($h > 0$) until product-market competition arises depresses the innovator's expected profit if demand is low or large, but not if demand is intermediate. This effect is unrelated to the time value of money (which is ignored here). It arises because at a low time-τ demand state x, a longer delay h makes it more likely for future demand X_T to reach a level (greater than $\bar{x}(\varepsilon,\gamma)$) at which rival entry is not deterred any longer, with the innovator suffering from a profit drop. At large time-τ demand, the expected profit is also depressed because lower-demand scenarios become more likely the longer the delay. At intermediate time-τ demand, just above $\bar{x}(\varepsilon, \gamma)$, a delay is good news because the innovator is likely to end up in a monopoly, with rival entry being deterred.

Fixed-fee licensing

We now assess the merits of the two alternative licensing schemes. Under the fixed-fee licensing scheme, the innovator proposes at time τ an agreement according to which rival firm j licenses the technology for a fixed upfront fee F. The licensee (firm j) will accept the deal if $j's$ expected (time-τ) profit net of the fixed fee F (weakly) exceeds the expected profit it is entitled to otherwise, i.e., if

$$E_x\left[\pi_j(X_T, \varepsilon, 1)\right] - F \geq E_x\left[\pi_j(X_T, \varepsilon, \gamma)\right].$$

Since its own payoff increases in the amount of the fee, F, the innovator (firm i) would want to set a fee F that gives the least acceptable profit to the licensee, i.e., it would select the cutoff fee $\hat{F}(x, \varepsilon, \gamma)$ such that it just satisfies the above inequality at the margin (as an equality).[8] The equilibrium fixed fee is monotone increasing in the demand state x because higher demand at time τ hints at larger ex post demand X_T, in which case rival firm j will benefit more from having a lower cost (by licensing in the new technology) and would therefore be more willing to accept a larger fee upfront. It is also monotone increasing in the innovation effort because an extra effort helps achieve a lower unit cost and increases the incentive of the rival firm to adopt the superior technology as well. Figure 2 illustrates the sensitivity of the equilibrium fixed-fee amount, $\hat{F}(x, \varepsilon, \gamma)$, to changes in demand x and the spillover parameter γ. Larger demand increases firm j's willingness to close a licensing deal to benefit from the new technology and accept terms favourable to the innovator, while larger spillover γ reduces its willingness because the cost differential shrinks. The equilibrium fee

[8] We provide an analytical expression for the optimal fixed fee $\hat{F}(x, \varepsilon)$ and the innovator's profit in the appendix.

amount $\hat{F}(x, \varepsilon, \gamma)$ decreases with γ and vanishes if rival firm j can perfectly free-ride ($\gamma \to 1$).[9] Demand volatility and delay time h have limited effects on the equilibrium fixed-fee amount because j 's willingness to pay to access a superior technology drives more the equilibrium fixed fee than the (probability) distribution of future demand.

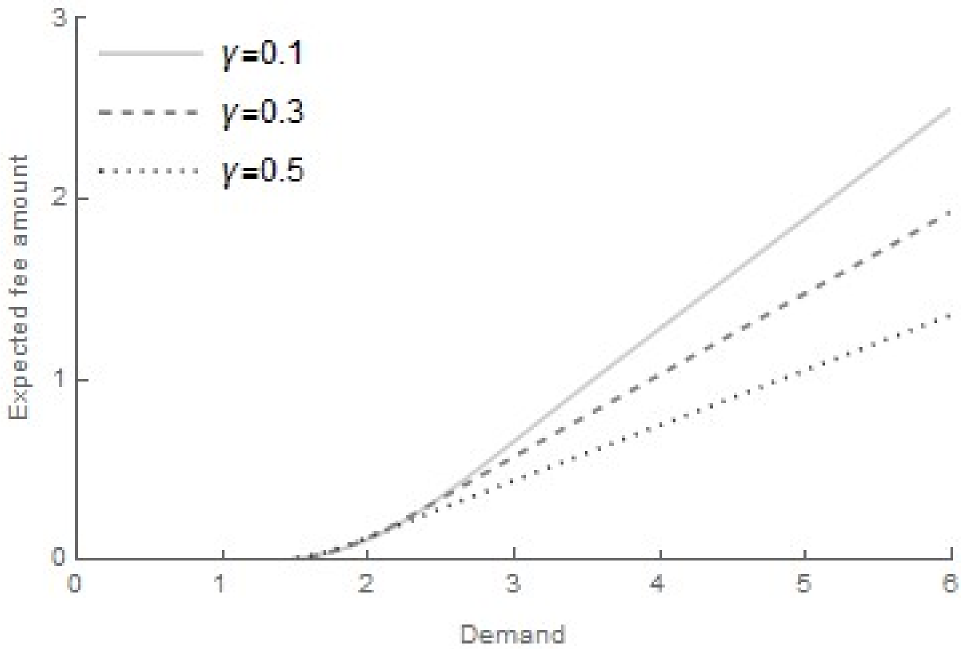

Figure 2: Equilibrium fixed fee amount $\hat{F}(x, \varepsilon, \gamma)$ depending on demand x and spillover parameter γ. Parameter values: $c = 2$, $b = 0.5$, $\sigma = 0.25, \mu = 0.0$, $h = 0.5$ and $\varepsilon = 0.5$.

The innovator's expected (time-τ) profit if it licenses under the fixed-fee scheme comprises the expected profit obtained when the two firms exploit the same superior technology and the equilibrium fixed fee amount $\hat{F}$. Because contracting is costly, at a lump-sum contracting fee β, innovator/ licensor firm i's expected profit is

$$\Phi(x, \varepsilon, \gamma) \equiv E_x[\pi_i(X_T, \varepsilon, 1)] + \hat{F}(x, \varepsilon, \gamma) - \beta.$$

Demand volatility is senn to have a depressing effect on the innovator's expected profit, primarily driven by the negative impact on $E_x[\pi_i(X_T, \varepsilon, 1)]$.

[9] We could also observe that the equilibrium fixed fee declines more sharply in γ when the innovative effort ε is greater. This is because, for a given γ, the reduction in j's unit cost is larger if i's effort is greater, with $e^{-\gamma\varepsilon_1} < e^{-\gamma\varepsilon_2}$ if $\varepsilon_1 < \varepsilon_2$. This reduces j's willingness to pay to access a superior technology as the differential shrinks.

Royalty rate scheme

Under the royalty rate scheme, the innovator/licensor (firm *i*) will receive from the licensee (firm j) royalties proportional to the output, at a rate of R. This means that the licensee's (firm j's) unit cost now becomes $ce^{-\varepsilon} + R$.[10] The royalty rate, R, can thus be viewed as an additional per unit "tax," which reduces firm j's gross profit margin. Therefore, the royalty rate R implies higher unit cost ex post for the licensee (vs. the fixed-fee scheme) but involves no commitment to a fixed payment, while the fixed-fee scheme implies a lower unit cost (vs. the royalty scheme) with rivals being on an equal footing, but an upfront commitment to a fixed payment. We want to determine the equilibrium royalty rate, $\hat{R}$, the innovator would set at time τ, prior to product-market competition.

In this case the rival's entry will be deterred (ex post) if $p_M(x,\varepsilon) \leq ce^{-\varepsilon} + R$, where $p_M(x,\varepsilon) = [x + ce^{-\varepsilon}]/2$, occurring if $x \leq c_i(\varepsilon) + 2R$. Thus under the royalty-payment scheme (with a given royalty rate R), firm j's ex-post profit is given by

$$\hat{\pi}_j(x,\varepsilon,R) = \begin{cases} 0, & x \leq c_i(\varepsilon) + 2R \\ \frac{(x - c_i(\varepsilon) - 2R)^2}{9b}, & x > c_i(\varepsilon) + 2R, \end{cases} \tag{7}$$

The innovator-licensor's ex-post profit then is

$$\hat{\pi}_i(x,\varepsilon,R) = \begin{cases} 0, & x < c_i(\varepsilon) \\ \frac{[x - c_i(\varepsilon)]^2}{4b}, & c_i(\varepsilon) \leq x < c_i(\varepsilon) + 2R \\ \frac{[x - c_i(\varepsilon) + R]^2}{9b} + R\hat{q}_j(x,R), & x \geq c_i(\varepsilon) + 2R. \end{cases} \tag{8}$$

In the above, $\hat{q}_j(x,R) \equiv [x - c_i(\varepsilon) - 2R]/3b$ is firm j's Cournot output when the per-unit royalty fee is set at R. If the innovator (firm *i*) were to maximize its Cournot duopoly profit ex post, regardless of whether firm *j* would be willing to participate in a licensing deal or not, it would charge the licensee at the "monopoly price:"

[10] In practice, royalty rates are often set as a share of revenues. Here, we assume it is a set amount per unit of output.

$$R_M(x) = \frac{x - c_i(\varepsilon)}{2}.$$

If the innovator were to enforce such a royalty rate, the licensee would not make a profit [as confirmed from substituting $R_M(x)$ in equation (7)]. The innovator is therefore not likely to offer such a proposal to firm j because the latter would be better off not to agree to this licensing contract and instead compete heads-on, benefitting from spillovers, and earning $\boldsymbol{\pi_j(x, \varepsilon, \gamma)}$ as per equation (4).

Firm j may accept the innovator's proposed licensing contract (at time τ) if the expected profit under the royalty scheme (weakly) exceeds the expected profit obtained otherwise, i.e., if

$$E_x[\hat{\pi}_j(X_T, \varepsilon, R)] \geq E_x[\pi_j(X_T, \varepsilon, \gamma)].$$

Firm j thus gains from participating in the licensing deal if the royalty rate per unit of output given is below a specified threshold, $R \leq R_M(\bar{x}(\varepsilon, \gamma))$. Because the innovator's profit increases in the royalty rate, it will prefer to set R at the maximum acceptable level, with the equilibrium royalty rate thus being

$$\hat{R}(\varepsilon, \gamma) \equiv R_M\big(\bar{x}(\varepsilon, \gamma)\big) = c\big[e^{(1-\gamma)\varepsilon} - 1\big].$$

Interestingly, the equilibrium royalty rate does not depend on the demand state x at time τ because whether rival firm j actually pays out royalties to the innovator is dependent on future demand (not current demand x), while the equilibrium royalty rate is fixed contractually.[11]

The equilibrium royalty rate increases with the innovative effort ε ($\partial\hat{R}/\partial\varepsilon > 0$), but decreases in the level of spillovers ($\partial\hat{R}/\partial\gamma < 0$). Because

$$c_i(\varepsilon) + 2R_M\big(\bar{x}(\varepsilon, \gamma)\big) = \bar{x}(\varepsilon, \gamma),$$

[11] By construction, we considered a fixed royalty rate and not a scheme allowing for a rate depending on the actual output or revenues.

the decision to agree to the licensing terms does not lower (firm j's) entry barrier, nor does it improve its profit because

$$\hat{\pi}_j\left(x, \varepsilon, \hat{R}(\varepsilon, \gamma)\right) = \pi_j(x, \varepsilon, \gamma).$$

This is because, under the royalty-rate scheme, the innovator sets the royalty rate, $R_M(\bar{x}(\varepsilon, \gamma))$, with a view to extract the full benefit (future cost savings) of its superior innovation from the licensee, who is just indifferent between accepting the licensing terms or not.

The innovator's (optimal) profit given the above equilibrium royalty scheme is obtained by substituting $R_M(\bar{x}(\varepsilon, \gamma))$ for R in the expression for the innovator's profit in equation (8). In contrast to firm j, the innovator is not indifferent whether firm j agrees to license or not. If the firms agree on the licensing terms, the innovator will receive a royalty payment contingent on its rival's output. The above ignores the notion of fairness shown in some experiments (e.g., Camerer and Thaler, 1995).

Optimal licensing strategy of the innovator

The strategy choice at time τ amounts to a coopetition situation where the innovator either chooses to be competitive/aggressive with the rival by keeping its superior technology proprietary or to be cooperative/accommodating, sharing the benefits of its superior patented technology with its rival. Figure 3 summarizes the expected profits arising for each of the three alternate strategic choices as a function of demand x for a given volatility level $\sigma = 0.25$: (i) the innovator keeps the technology proprietary for its own exploitation; (ii) licenses it out to its rival for a fixed-fee payment F or (iii) licenses it for a royalty rate R.

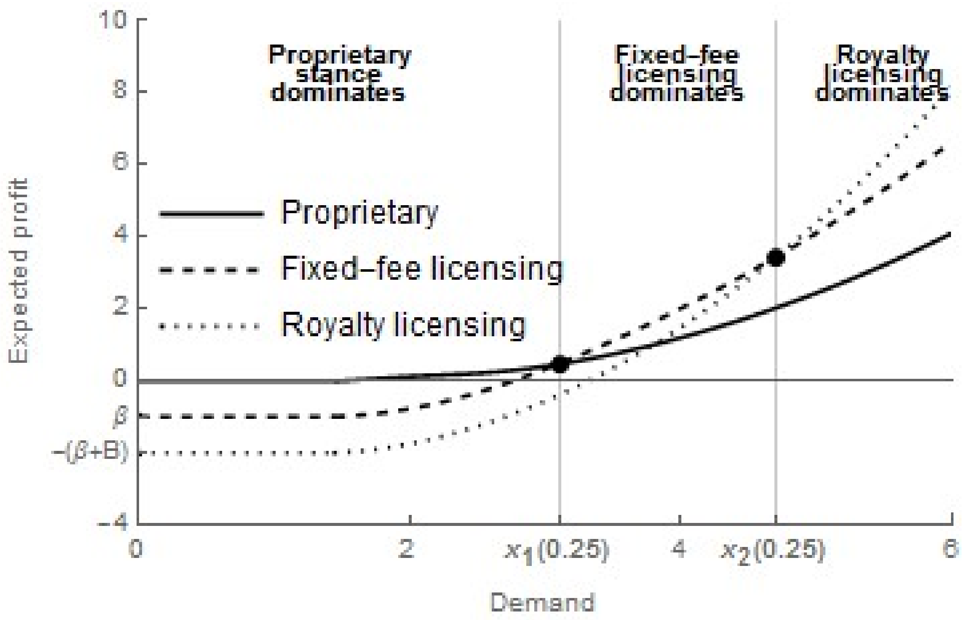

Figure 3: Expected profit as at time τ (as a function of demand) for distinct strategic stances. Parameter values: $c = 2$, $b = 0.5$, $\mu = 0.0$, $h = 0.5$, $\varepsilon = 0.5$, $\sigma = 0.25$, $\beta = B = 1$, and $\gamma = 0.3$

Recall that the innovator also incurs a one-time contracting cost (β) if both parties agree on any licensing agreement, as well as monitoring costs (B) under the royalty scheme as the innovator wants to verify revenues/output reporting.

If demand is low, i.e., below $x_1(0.25)$, the rival is not likely to enter the market (with the old technology) nor willing to pay a substantial compensation to license the new technology. Because the innovator would pay a transaction cost due to contracting fees β if it agrees to license out the technology, it is better off keeping a proprietary wait-and-see stance. At intermediate demand, i.e., between $x_1(0.25)$ and $x_2(0.25)$, as the rival becomes more likely to enter (even with the old technology), it is more willing to agree to licensing terms which are favourable to the licensor. The innovator is better off adopting an accommodating stance (with monetary compensation) than entering cut-throat competition with the rival (the licensor is able to recoup the transaction cost β). The innovator's expected profit from a royalty licensing scheme grows at a larger rate than the expected profit from fixed-fee licensing because the innovator benefits more from the upside in case of royalty licensing (with total compensation being convex increasing in demand). Yet, because the innovator has to ensure the licensee reports truthfully its output/revenue figures, with unit monitoring costs B, the curve in Figure 3 for the expected profit under royalty licensing starts at a lower level. At some point, $x_2(0.25)$, royalty licensing dominates, with the innovator optimally adopting this strategic choice.

Figure 4 illustrates how the initial demand state x and demand volatility σ influence the innovator's licensing decisions. As demand volatility σ increases, the upside from royalty licensing becomes riskier, with the range of demand values for which the innovator prefers fixed-fee licensing widening. For low initial demand x, a proprietary stance dominates because the compensation the innovator would receive under the licensing agreement would not sufficiently cover for the contracting and monitoring costs. As demand volatility σ rises, the innovator has a somewhat greater incentive to maintain a wait-and-see approach, though the effect is very limited. For intermediate demand x, fixed-fee licensing is preferred, especially when volatility is higher as the fixed fee is hardly sensitive to market uncertainty, while the upside from royalty compensation is negatively impacted by demand uncertainty. For a high degree of spillovers, e.g., $\gamma = 0.5$, fixed-fee licensing is preferable if demand is intermediate, e.g., $x \leq \bar{x}(0.5,0.3)$, though this is not the case if demand is large, e.g.,, if $x \geq \bar{x}(0.5,0.3)$. If demand is large ($x \geq \bar{x}(0.5,0.3)$) and spillover effects are very high ($\gamma = 0.5$), the rival's expected profit gain from licensing (influencing the cutoff fixed-fee amount)is reduced, while for the royalty rate it is fixed.

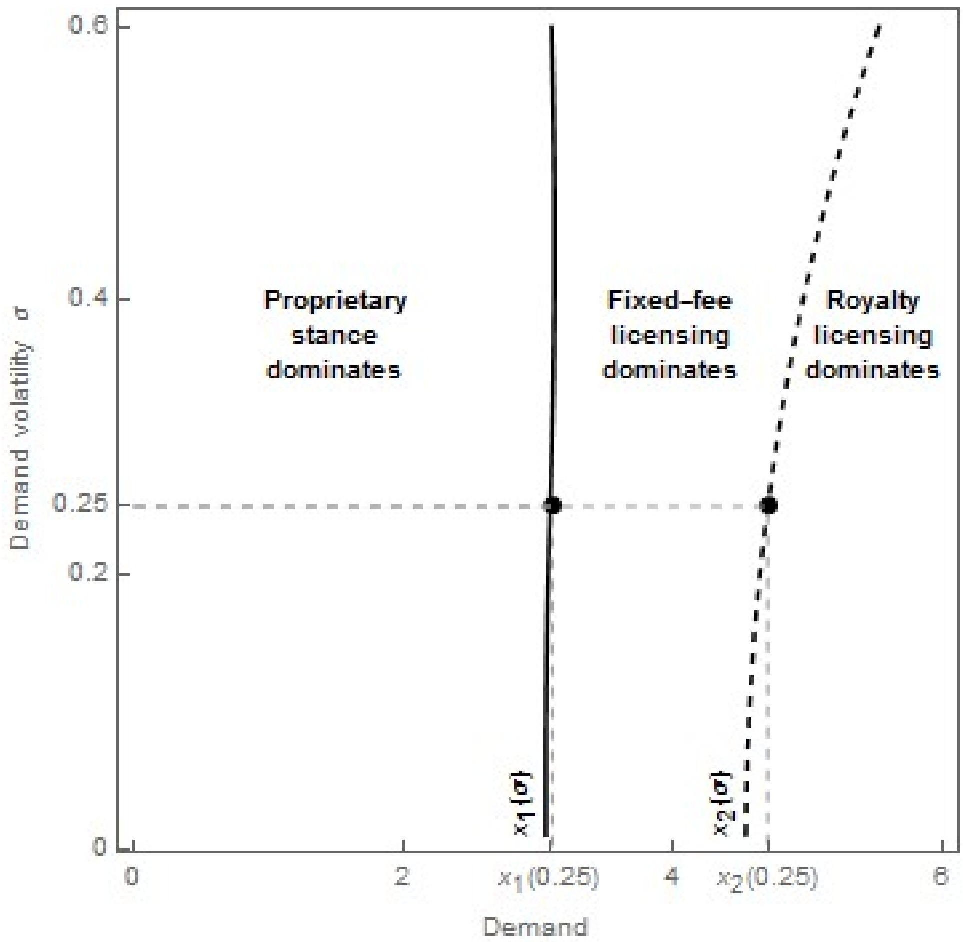

Figure 4: Dependence of the innovator's licensing decision on (time τ) demand x and demand volatility σ. Parameter values: $c = 2$, $b = 0.5$, $\mu = 0.0$, $h = .5$, $\varepsilon = 0.5$ and $\gamma = 0.3$

The above result differs from Kamien arnd Tauman (1986) who find – under deterministic conditions – that licensing by means of a fixed fee is always preferable for an innovator. Our more nuanced result that shifts the balance more in favor of the royalty rate scheme here under high initial demand x partly stems from the innovator competing in the product market and the royalty rate licensing giving an increased cost advantage to the innovator through the royalty payment acting as an additional marginal cost ("tax") for the licensee. This extra marginal cost advantage for the innovator (at the disadvantage of the licensee) is not present under fixed-fee licensing. We assume the innovator follows the above optimal licensing strategy and turn to determining the innovator's optimal innovation effort.

5. Optimal innovation effort

Several drivers can be seen to affect the innovator's optimal effort, including the degree of spillovers (γ) and demand volatility (σ). We obtained closed-form expressions for the expected profits under each of the above strategies and determined the optimal licensing strategy that maximizes the innovator's expected payoff from time τ onwards. To obtain the innovator's expected value at time $t = 0$, we then calculate the (weighted average) time$-\tau$ optimal profits, net of the costs incurred to exert an innovative effort. We then determine numerically the effort level ε that maximizes the net present value of the process innovation investment. The optimal innovation effort embeds the contingent optimal licensing decision at time τ, involving a proprietary stance conditional on low demand, fixed-fee patenting at intermediate demand, and royalty licensing conditional on high demand (as seen in Figures 3 and 4).

Figure 5 Panel A illustrates how the incentive to pursue a cost-reducing process innovation (the optimal innovation effort ε^*) varies as a function of demand x for three distinct levels of spillovers γ. First, higher demand encourages the innovator to exert more innovation effort because the profit function is convex in the state of demand x. For large demand, as expected, the innovator invests less in innovation if spillovers are high. For intermediate demand, however, the innovator may invest more in R&D, albeit the innovation also benefits the rival though high spillovers. Overall, however, the effect of spillovers on the optimal innovation effort is relatively limited, with the current (time-0) state of demand being the main driver.

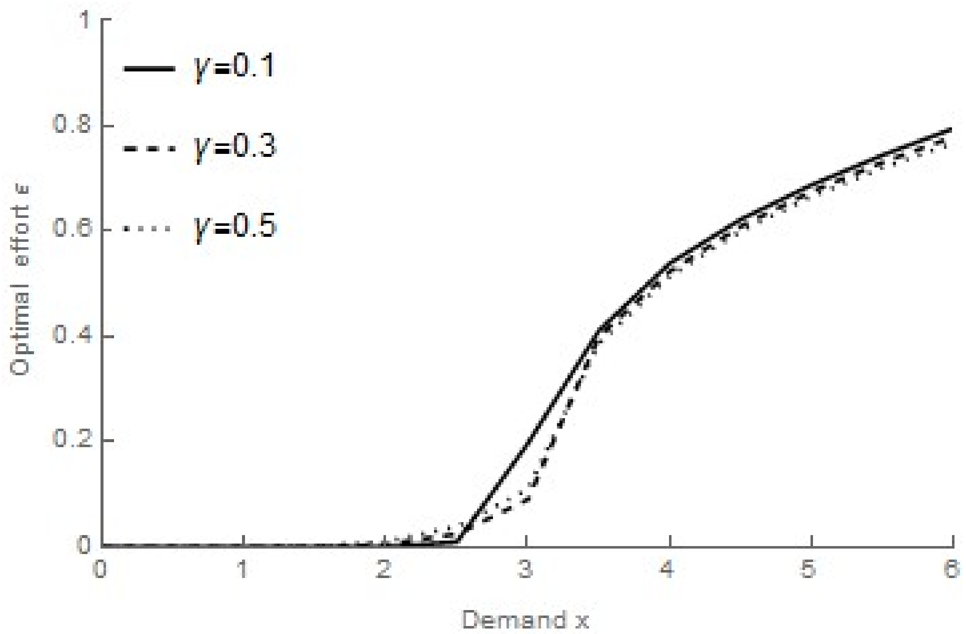

Figure 5 Panel A: Innovator's optimal innovation effort as a function of demand state x for different degrees of spillover γ. Parameter values: $c = 2$, $b = 0.5$, $\mu = 0.0$, $h = 0.5$, $\tau = 2$, $k = 3$, $\sigma = 0.25$, $\beta = B = 1$.

Figure 5 Panel B illustrates the innovator's optimal innovation effort (ε^*) as a function of time-0 demand x for three distinct levels of demand volatility (σ). The (deterministic) case with σ negligible is an upper bound for the optimal innovation effort but only in the case of large demand (here, $x \geq 3.4$). At intermediate initial demand x ($2 < x < 3.4$), higher demand uncertainty σ encourages more innovation effort as competitive entry is more likely and the innovator wants to build up stronger competitive advantage that has the ability to preempt the rival if it chooses to follow an aggressive strategy (or extract higher rents in case of collaboration via licensing). When demand is moderate-to-large, however, volatility may depress the incentive to invest in innovation (the pre-emption incentive is less significant). Ignoring the presence and impact of demand volatility and spillover effects in a traditional deterministic analysis of market entry and patent licensing may cause significant mis-investment in R&D and innovation.

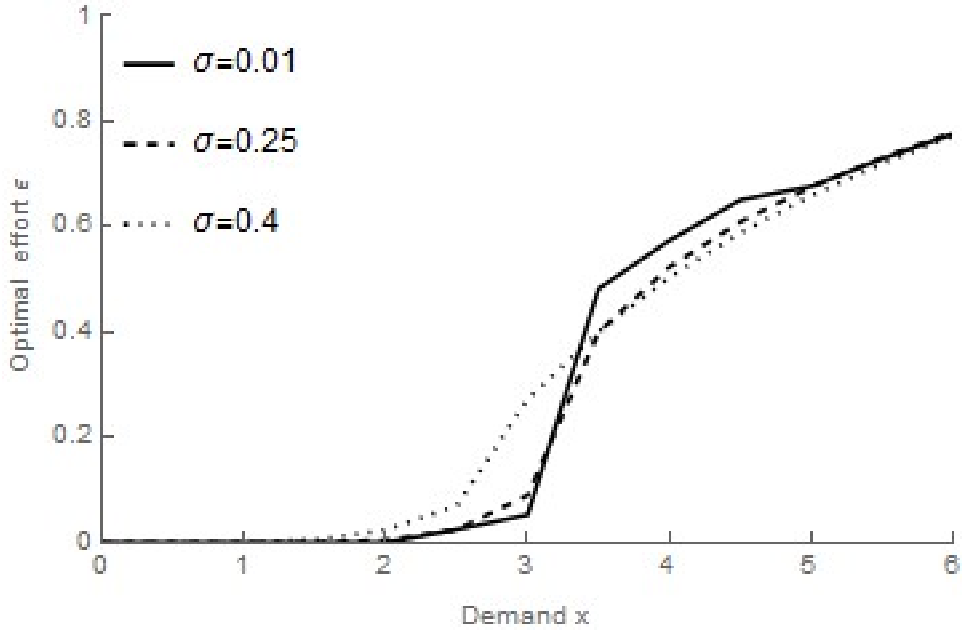

Figure 5 Panel B: Innovator's optimal innovation effort as a function of demand state x for different degree of demand volatility σ. Parameter values: $c = 2$, $b = 0.5$, $\mu = 0.0$, $h = 0.5$, $\tau = 2$, $k = 3, \gamma = 0.3$, $\beta = B = 1$.

6. Conclusions

A technological process innovation that lowers future production costs enables an innovator to raise entry barriers protecting against rivals, absent significant spillover effects. Yet, rival entry cannot always be blockaded as a rival might enter if the appropriation regime is imperfect and demand is sufficiently large and uncertain. Licensing out a new technology to a rival helps the innovator compensate for its initial innovation efforts and investment in the event a rival enters. We here focus on the role of spillover effects and of demand uncertainty and their impact on the innovator's effort and incentive to invest in process innovation and the type of licensing fee structure that is optimal. Innovation investment has strategic value because it creates more favorable conditions for the innovator in the product-market stage, moderated by spillover effects and demand uncertainty. Innovators typically protect their intellectual property since rival imitation and spillover effects can be detrimental. A key dilemma facing the innovator is whether it should pursue a proprietary strategy and keep the superior patented technology for own exploitation, attempting to blockade rival entry, or whether to follow an accommodating/shared strategy of collaborating with the rival by licensing out its technology, and under what conditions and fee structure terms to license.

We examine the innovation effort and conditions under which scheme the innovator should license the new technology when facing spillover effects under demand uncertainty. Depending on demand conditions and the degree of spillovers and whether entry is deterred or accommodated the innovator may be better off keeping the technology for itself (proprietary) or collaborating and sharing its patented technology with the rival, for a commensurate fixed-fee or royalty-rate compensation. We find that in a low region of initial demand when entry is deterred (which is endogenously driven by the innovation effort as well as demand conditions) the patent holder will rationally choose not to license out its superior technology, pursuing a proprietary strategy to blockade rival entry and earn higher monopoly profits based on proprietary advantage. When the demand is sufficiently large such that the innovator cannot blockade rival entry, it will prefer to follow a more collaborative, accommodating stance, sharing the innovation benefits with the rival via licensing out its technology for appropriate compensation. Among the two main alternative licensing schemes, we find the fixed-fee licensing scheme is preferable at intermediate states of demand, while the royalty-scheme upon which the innovator also benefits more from the upside is preferred for large demand. The innovator can set an equilibrium licensing royalty rate to extract the largest cost benefits of the innovation at the expense of the licensee, while keeping the costs marginally bearable for the licensee. This result contrasts with the main result in Kamien and Tauman (1986) that always favors a fixed-fee payment in a deterministic setting. Under demand uncertainty the innovation effort in conjunction with a collaborative strategy can change the industry structure (beyond its direct impact through cost savings) and enable the innovator to extract most benefit from its innovation effort while bypassing spillover losses from an imperfect appropriation regime through an optimal licensing design.

In this paper we endogenize the choices concerning (i) whether to pursue a proprietary strategy to innovation exploitation or an accommodating (shared or collaborative) licensing strategy; (ii) whether to follow the royalty rate or fixed-fee payment scheme in case of a decision to license out the technology and, (iii) examine the role and impact of spillover effects and demand uncertainty on the ex-ante decision how much (effort) to invest in the innovation process. We find that the optimal innovation effort increases in the state of demand x and is moderated by the degree of spillover effects and demand uncertainty. Whether spillovers or demand volatility have a negative or positive effect on the innovation effort depends on the state of initial demand. When demand is moderate-to-large, volatility may depress the incentive to invest in innovation, while volatility may increase the optimal effort when demand is intermediate. We conclude that ignoring the role of spillover effects and the impact of demand uncertainty when pursuing a traditional deterministic analysis of patent licensing could cause significant valuation errors and under/overinvestment in technological process innovation decisions.

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