Innovation, Licensing and Coopetition

Under Imperfect Appropriation Regime and Market Uncertainty

Abstract

We develop a model to examine the behavior of an innovator deciding on whether to license its new process technology to an incumbent rival in the face of an imperfect appropriation regime and uncertain market demand. The innovator must select its innovation effort upfront and later decide whether to license the technology to its rival and whether to propose a fixed fee or a royalty payment scheme. Firms operate in the product market after a delay when market demand uncertainty is resolved. We analyze how the degree of uncertainty and the risk of spillover from imitation impact the innovator's upfront innovation effort and the resulting coopetition strategy among the rivals.

1. Introduction

Competitive advantage can accrue from either superior product or process technology. Patents have typically been used as a means to encourage innovation by providing temporary monopoly protection to an innovator (Arrow, 1962), but not all technology is amenable to patent protection. The appropriation and enforcement regime is often imperfect because certain features of an innovation may be unpatentable or subject to only weak protection via patenting. For instance, certain process technologies, particularly those that involve business model innovations, are difficult to patent. Even when it is possible to secure a patent, imitators may be able to modify the process beyond the parameters specified in the patent and attain roughly the same technological outcomes. An example is the difficulty that Procter & Gamble faced in protecting its liquid detergent technology via patenting (Bartlett, 1989). High imitability and free-riding with adverse spillover effects in many industries benefit the rival at the expense of the innovator. In such cases an innovator may well consider licensing its innovation to the rival rather than pursuing costly and likely ineffective legal action or abandoning the pursuit of patenting altogether. Whether to license an innovation to a rival or keep it proprietary for own exploitation is a dilemma of considerable interest to both strategy and international business (IB) scholars and practitioners.

In the extant literature, an imperfect appropriation regime is in general considered a strong deterrent to licensing and a motivation for the innovator to utilize the innovation internally (e.g., Buckley & Casson, 1976; Teece, 1986). A basic assumption in this literature is that an imperfect appropriation regime makes it difficult to enforce the innovator's rights in a licensing contract though it allows the innovator to keep the technology proprietary. In our study, we consider an even less perfect appropriation regime whereby the innovator may be unable to keep its superior process technology proprietary even if it attempts to hide the technology from potential rivals. This plausible change in the assumed strength of the appropriation regime, as shown via the model presented in this study, yields very different policy recommendations for the optimal licensing strategy.

Licensing policy has also been studied extensively from an industrial organization (IO) and game theory perspective in a deterministic setting (e.g., Kamien and Tauman, 1986; Wang, 1998), but the role and impact of an imperfect appropriation regime under demand uncertainty on these choices and the degree of optimal innovation effort under these circumstances have not been adequately addressed. Few strategy and IB scholars have focused on process innovation to examine how an innovator can make the best of the adverse spillover effects in the face of substantial imitability and under demand uncertainty. In this study we examine how market uncertainty and spillover effects from imitation under an imperfect appropriation regime influence an innovator's choice of whether to license its technology to a rival, and if so on what licensing terms. Our innovation is in endogenizing this choice to understand the conditions in terms of market demand, imitation spillover and demand uncertainty that drive the dilemma between cooperating via licensing or competing aggressively by exploiting the process innovation to one's own proprietary benefit (i.e., not license).

We consider a market entrant that contemplates developing an innovation that would help it achieve a cost advantage over the incumbent rival. Such an innovation, typically referred to as a *process* innovation, can potentially help the entrant displace the incumbent if the cost advantage is sufficiently large to make the incumbent unable to sustain profitable operations (a case of drastic innovation). We assume the firms decide on their production output in a noncooperative duopoly game: if both firms operate ("à la Cournot") without reaching a licensing deal, the market entrant would enjoy a cost advantage keeping the new technology proprietary; if they do agree on a licensing deal, they would then compete in the market with the same (lower) unit production cost. The market entrant decides on its innovation effort before knowing the exact level of market demand. Because of the cost-reducing process innovation, the innovator's payoff is more convex in the state of demand. If demand uncertainty is higher, the innovator has a greater incentive to develop the technology because it can benefit from the upside potential, while being protected from the downside (i.e., no entry with zero payoff). We assume the innovation has two key features. First, it involves the use of a new technology (e.g., electric batteries) that the innovator may be able to protect via a patent or secrecy. Second, the process innovation involves some significant redesign of the production equipment or process (e.g., via a modular redesign) or a reorganization of the value chain activities (e.g., involving a new untapped sourcing strategy). The latter can be a form of business model innovation that is difficult to protect from imitation. If the incumbent identifies the innovation as a serious threat, it can itself re-organize its production process and value chain to imitate those features. We refer to such a risk of imitation by the rival as spillover that benefits the incumbent. This setup might apply, for instance, to the steel industry where entrants–using mini mills that allowed them to produce at a 20% lower cost–displaced incumbents using integrated steel technology. An interesting tension in this setting is, how much effort should an innovator exert to develop its process innovation given uncertain market demand and the risk of being undermined by the incumbent's free-riding?

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. In this article, we further explore what unfolds when the entrant innovator allows the incumbent rival to license its innovation and uses licensing as a means to ensure compensation for its innovation efforts. Treating as a choice variable whether to pursue proprietary deployment of one's technological innovation or share the technology and resulting benefits via licensing with a rival is analogous to choosing whether to compete aggressively or collaborate. Collaboration in this context takes the form of agreeing to license the innovator's superior technology to an incumbent rival. We consider two types of licensing deals. A fixed-fee scheme, e.g., involving a contract whereby the innovator "transfers" the technology to the licensee (e.g., transferring special equipment), and a royalty scheme involving "leasing" the technology, with the licensee paying a compensation commensurate with its utilization of the technology or the resulting sales. The question then is, under what conditions should an innovator deploy its proprietary innovation to compete aggressively instead of sharing the benefits of the technology with a rival via licensing? In the case of collaboration via licensing, what licensing fee structure maximizes the innovator's value while also being acceptable to the licensee? In making this choice, we show that the entrant's licensing strategy will depend on whether the incumbent is likely to be displaced or stay on producing in the market, which ultimately depends on the level of future market demand and the degree of the entrant's innovation cost advantage. If the incumbent's operations would become so unprofitable that it decides to exit the market, the entrant might prefer to keep its innovation advantage for own exclusive commercial use. If the incumbent is unlikely to be displaced, however, and particularly if spillover effects from imitation are substantial, then the innovator might be better off to license out its innovation to the incumbent rival, proposing either a fixed-fee or a royalty rate licensing scheme depending on market conditions. To keep the model tractable, we abstract away from considerations as to the timing decision of the market entrant (in the spirit of Dixit and Pindyck, 1994) or the product-market differentiation strategies potentially followed by the entrant vs. the incumbent (e.g., in spirit of disruptive innovation by Christensen, 1997). We focus instead on the effects of imitation spillover and market uncertainty on the choice of innovation effort by the innovator, and the optimal licensing strategy and fee structure policy.

We thereby address (and make a contribution to) several interrelated topics. First, we determine how demand uncertainty and spillover effects influence an entrant's effort in process innovation. Second, given the amount of upfront innovation effort, the level of demand and the uncertainty conditions, we determine contingencies in which the entrant should follow an aggressive technology deployment strategy by keeping the innovation for its own commercial exploitation or instead follow an accommodating or collaborative stance by agreeing to share the innovation with an incumbent rival. We show how this choice depends on the degree of innovation effort expended (which drives the degree of cost advantage) and on whether the incumbent can remain profitable following entry by the innovator.

Another distinctive feature of our model is that we allow both the licensor (in our case, a market entrant with a process innovation) and the licensee (incumbent rival) to compete over output in the product market as part of the licensing deal (cooperation), thus entertaining a form of coopetition (e.g., Brandenburger and Nalebuff, 1996; Lado, Boyd and Hanlon, 1997). Most extant models on patent licensing (e.g., Arrow, 1962; Kamien and Tauman, 1986; Kamien, 1992) assume that either the innovator (licensor) or the licensee operate in the product market as a monopolist post-licensing. In this respect, our study fills another important gap in the literature because how the innovator and its rival (potential licensee) will behave when they can both operate in the product market has not been given adequate attention. A noted case where licensor and licensee(s) compete in the market post licensing is the chemical processes industry discussed in Fosfuri (2006). Another example may be a Blue-ray disc player maker licensing its technology to a rival (or cross-licensing to each other). Other recent examples of firms licensing their technology while also competing with other firms (though not necessarily involving process innovation) are: Microsoft licensing its Windows operating system to other hardware manufacturers even while it sells the Surface line of tablets and notebooks; Google making Motorola smartphones for a period of time after it acquired the company even though it also licensed the Android operating system to other phone makers; and China's Alibaba sourcing products directly from producers (fishermen and orchards) in competition with other sellers of the same products on its Taobao and T-Mall platforms. Given the interplay between spillover effects and potential coopetition in the product market, we show that the market entrant can use the licensing agreement to create a cost advantage by effectively imposing an additional "tax" on the rival's marginal operating cost via the royalty-rate scheme. In this regard, we find that the royalty-rate licensing scheme may be a preferred licensing strategy under certain conditions, such as in high demand states and volatile future demand. Our finding obtained under demand uncertainty is in contrast to an established result in extant literature that fixed-fee licensing always dominates royalty-rate licensing in a deterministic setting where only one firm operates in the market post-licensing (Kamien and Tauman, 1986).

2. Background and antecedent literature

The role of patents and licensing in innovation and value appropriation has been an early focus in the economics literature (e.g., Arrow, 1962; Gallini, 1984; Gallini and Winter, 1985; Hall and Ziedonis, 2001; Katz and Shapiro, 1985, 1986, Kamien, 1992), as well as in technology commercialization and firm strategy (Hill, 1992; Teece, 2000; Arora, Fosfuri and Gambardella, 2001; Marx, Guns and Hsu, 2001; Arora and Fosfuri, 2003; Arora and Ceccagnoli, 2006; Davis, 2008) with attention given to the structure of licensing contracts (e.g., Ananda and Khanna, 2000) and appropriability (Fosfuri, 2006; Ceccagnoli, 2009; Reitzig and Punaram, 2009; Somaya, Kim and Vonortas, 2010).

Following Schumpeter's (1942) work on the role of innovation and entrepreneurship in creative destruction, Christensen (1997) examines the process of innovation to explain why new technologies seem to come from entrants and not from incumbents. He cites many markets, including tube table radios (displaced by portable transistors), cameras, and disk drives. There are many other examples in which firms innovate to reduce the cost of existing products and gain market share. Christensen talks about hydraulic technology displacing the old mechanical technology in the excavator market, while Schilling (2005) talks about the Nano car, competition among chip makers, etc. Many of the new multinationals from China, such as Huawei in telecommunications and Haier in home appliances, expanded their shares of the global markets via cost innovations (Yang, 2016; Khana et al., 2006). In many of these markets, technological innovation shook up established production processes and led entrants to displace incumbents.

Christensen (1997) noted that when the entrant's innovation is initially applied to a less profitable or to a new or thus far neglected part of the market (particularly when it improves over time until eventually it is nearly functionally equivalent to the existing product of the incumbent in terms of meeting its current customer requirements) but can be offered at a lower cost, it can cause the market to shift and the incumbent to cease operating, especially when it fails to use the new technology to bring a product that is competitive in terms of price to the market. In this case, the entrant with a process innovation could disrupt the market and replace the incumbent. A noted example is the steel industry where entrants used low-cost mini mill steel technology (melting scrap in electric furnaces), which was 20% cheaper than integrated steel technology used by large incumbents, to enter the market and drive out incumbents. In principle, it is possible that either the entrant can displace an incumbent or the incumbent can deter entry by an innovator (if it imitates or adopts the new low-cost technology) if they both pursue an aggressive product market competitive strategy.

The competitive situation can change fundamentally, however, if rivals can choose to collaborate rather than compete aggressively in the market. Licensing agreements have often been used as a form of collaboration allowing joint exploitation of a technology among a licensor and licensee with complementary capabilities (e.g., Arora and Fosfuri, 2003; Arora and Ceccagnoli, 2006). Part of the licensing literature has focused on technology licensing or rationalizing the choice between fixed-fee and royalty payments and examining related empirical implications (e.g., Ziedonis, 2007; Crama et al., 2008; Dechenaux et al., 2009).

A number of scholars have more generally addressed early on the related tradeoff between competition and collaboration (e.g., Wernerfelt and Karnani, 1987; Hamel, Doz and Prahalad, 1989; Jorde and Teece, 1989; Ang, 2008). Trigeorgis and Reuer (2017) suggest that the dilemma between competition and cooperation remains a fundamental research gap in the literature on strategic management. The key issue we address here is when an innovator is better off cooperating rather than competing in the marketplace in an uncertain environment. We extend related work on option games (Smit and Trigeorgis, 2004, 2017; Chevalier-Roignant and Trigeorgis, 2011), treating as a choice variable whether an innovator should take an aggressive or accommodating stance (licensing its technology to the rival), highlighting the conditions when the firm should follow a competitive or cooperative strategy by keeping the technology to oneself or licensing it out to a rival.

3. Model setup

We consider a situation where an entrant develops an innovation to achieve a lower unit production cost when it enters the market. Our model setup consists of three stages: (i) at time $t = 0$ (the "outset" or "ex ante") the innovator decides on its innovation effort, (ii) at a subsequent time τ the innovator and incumbent rival make a decision to license (or not), and (iii) with some delay h, at time $T = \tau + h$ ("ex post"), firms decide on whether to operate in the market and on their production rates. Figure 1 below summarizes the model setup timeline, discussed at more length next.

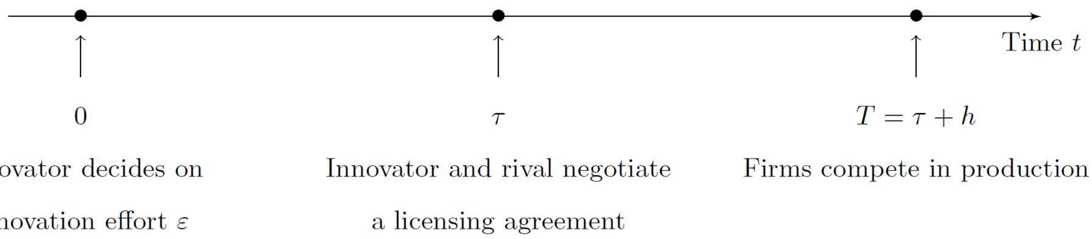

Figure 1: Model setup timeline

At the outset ($t = 0$), the *innovator* (firm i) pursues a technological *process* innovation and decides on the level of its innovation effort ε (≥ 0). The cost to exert such an effort ε, noted $C(\varepsilon)$, is convex increasing in ε. We consider a situation where the innovator has a proprietary hold on the technology (via a patent or secrecy), but the incumbent can imitate some aspects or features of the innovation. The innovator's effort ε will affect its own unit production cost when it enters the product market at time T ("ex post") but also the rival's (firm j's) cost as the latter can imitate or free-ride benefiting from *spillover* effects. Parameter $\gamma \in [0,1]$ captures the degree of spillover. When $\gamma = 0$ the appropriation regime is perfect, with no spillover; at the other extreme, when $\gamma = 1$, the rival free rides fully. High spillover (high γ) reduces the innovator's incentive to expend effort in cost-reducing process innovation.

At the intermediate stage (at time τ), the parties decide whether they can reach a licensing agreement. Specifically, the innovator must decide whether to keep its superior technology exclusively for own exploitation in the product market or follow a cooperative approach licensing it out to the rival for a commensurate fee. If the two parties agree on a licensing deal, they both get to use the more efficient production technology and compete in the product market. Otherwise, if no licensing agreement is reached, the incumbent rival can partly benefit from the innovation via imitation and spillover effects as the appropriation regime is imperfect. In negotiating the terms of the licensing agreement, the innovator and potential licensor acts as a "principal," while the potential licensee is effectively an "agent." In making an offer to its rival (firm j), the innovator-licensor (firm i) also decides on how to structure the licensing agreement (setting a fixed fee or royalty rate) with a view to maximize its own expected ex-post profit. The rival (potential licensee), however, will not agree to the licensing terms unless it benefits as well. If the two firms agree to license, the innovator incurs a one-time contractual cost β covering transaction costs such as lawyer and administrative fees. Under the royalty contract scheme, the innovator will also incur additional monitoring costs, B, to ensure the revenue figures are objectively reported by the licensee.

At time T, the innovative firm i can reap the benefits of its (ex-ante) costly innovation effort ε, enjoying a reduced unit production cost given by $c_i(\varepsilon) = ce^{-\varepsilon}$.[i] If the two firms cannot reach a deal (at time τ), the rival (firm j) will regardless benefit to some extent from the innovator's efforts owing to imitation *spillover*, with its own unit cost reduced to $c_j(\varepsilon, \gamma) = ce^{-\gamma\varepsilon}$. Here, the parameter γ captures the degree of spillover ($0 \le \gamma \le 1$). The rival firm would operate using the old, inferior and more costly technology ($c_j(\varepsilon, 0) = c$) if proprietary rights can be effectively and fully enforced ($\gamma = 0$). Finally, both firms incur fixed costs to operate in the product market, noted I_i and I_j. [ii]For simplicity, we assume $I_i \le I_j$. Closing a licensing agreement at time τ results in the incumbent using the same production technology and hence having the same (lower) production cost as the innovator entrant (effectively setting $\gamma = 1$). The two firms subsequently compete over output in the product market at time T (an interval of time h later) facing linear demand

$$p(x, Q) = x - bQ, \tag{1}$$

where x is the "state of demand," Q is 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. The ex post demand, noted X_T –which is unknown at the outset ($t = 0$) as well as at the licensing-agreement time τ–is lognormally distributed (driven by a geometric Brownian motion). At time 0, the innovator observes the current state of demand x and forms an expectation about the future demand X_t at time t. From today's perspective, $\ln(X_t)$ is normally distributed with mean $\ln(x) - (\mu + \sigma^2/2)t$ and standard deviation $\sigma\sqrt{t}$. We use E_x to denote the expectation given the current demand is x. We proceed backwards to determine the optimal licensing deal and optimal innovation effort.

4. Market competition outcomes

Suppose at first the innovator (firm i) manages to displace the less efficient incumbent from the market. The gross profit of the innovator if it subsequently operates as a monopolist given the demand in (1) is given by $[x - c_i(\varepsilon)]^2/4b$, where $c_i(\varepsilon)$ is the unit production cost given an innovation effort ε (see the appendix). However, the entrant i will not produce–earning $\pi_i(x, \varepsilon) = 0$–if the state of demand, x, is not sufficient for it to recover both the unit cost $c_i(\varepsilon)$ and the fixed cost of entry I_i, i.e., if

$$x \leq \underline{x}(\varepsilon) := c_i(\varepsilon) + \sqrt{4bI_i}. \tag{2}$$

Only if $x > \underline{x}(\varepsilon)$, will demand be sufficiently large to accommodate profitable operations by the innovator/entrant.

Consider now that the incumbent (firm j) undermines the entrant's innovation effort through imitation at a rate γ and has a unit production cost of $c_j(\gamma, \varepsilon)$. Whether the incumbent can sustain profitable operations will depend on the future (currently unknown) state of demand and so the innovator cannot ensure upfront that the incumbent will exit. The incumbent will be displaced, however, if the entrant sets a monopoly price $p_M(x, \varepsilon) = [x + c_i(\varepsilon)]/2$ below the incumbent's production cost of $c_j(\gamma, \varepsilon)$, i.e., if $x \leq \alpha_j(\varepsilon, \gamma)c_i(\varepsilon)$ with

$$\alpha_j(\varepsilon, \gamma) := 2e^{(1-\gamma)\varepsilon} - 1.$$

Here, $\alpha_j(\varepsilon, \gamma)c_i(\varepsilon)$ can be interpreted as an *opportunity cost* incurred by the incumbent in competing in the product market with the entrant. If the incumbent manages to sustain profitable operations, it will make a *gross* profit of $\left[x - \alpha_j(\varepsilon, \gamma)c_i(\varepsilon)\right]^2/9b$.

We next address the issue of market displacement. We assume the incumbent faces a fixed operating cost, e.g., via increased advertising expenditures to be able to retain its customer base or in order to revamp its operations and remain competitive in the market following the rival's entry. The incumbent will consequently not operate in the market after the rival's entry if the aggregate gross profit from its operations is not sufficient to also recoup its fixed operating cost, I_j. Given the incurrence of a fixed advertising or revamp cost I_j, the incumbent decides not to operate in the market if $x \leq \bar{x}(\varepsilon, \gamma)$ where the demand threshold $\bar{x}(\varepsilon, \gamma)$ is given by

$$\bar{x}(\varepsilon, \gamma) := \alpha_j(\varepsilon, \gamma)c_i(\varepsilon) + \sqrt{9bI_j}. \tag{3}$$

Above this demand level, $x > \bar{x}(\varepsilon, \gamma)$, the two firms will compete in the product market as a Cournot duopoly. One might consider Stackelberg or differentiated Bertrand competition as alternate strategic competition setups. Spillover effects (captured by spillover rate γ) are detrimental to the entrant (firm *i*) as they lower the level below which the incumbent will be displaced and exit the market ($\partial\bar{x}/\partial\gamma < 0$). The innovator's effort that maximizes the chance of displacing the incumbent is

$$\bar{\varepsilon}(\gamma) \coloneqq (\ln 2\gamma)/(\gamma - 1)$$

and is thus driven by the degree of spillover (γ). If the spillover from imitation is negligible (γ is close to 0), an extra innovation effort helps increase the chance of incumbent displacement (as $\bar{\varepsilon}(0) = \infty$). If the spillover γ is high (greater than ½), increasing innovation effort also increases the risk of survival and imitation by the incumbent (because $\bar{\varepsilon}(1/2) = 0$).

In summary, the market entrant's profit is given by

$$\pi_i(x, \varepsilon, \gamma) = \begin{cases} 0, & x \le \underline{x}(\varepsilon) \\ \dfrac{[x - c_i(\varepsilon)]^2}{4b} - I_i, & \underline{x}(\varepsilon) \le x \le \bar{x}(\varepsilon, \gamma) \\ \dfrac{[x - \alpha_i(\varepsilon, \gamma) c_i(\varepsilon)]^2}{9b} - I_i, & x > \bar{x}(\varepsilon, \gamma), \end{cases} \tag{4}$$

with

$$\alpha_i(\varepsilon, \gamma) := 2 - e^{(1-\gamma)\varepsilon}.$$

The innovator will decide not to enter the market ex post if demand is very low ($x \le \underline{x}(\varepsilon)$). It will decide to enter to displace the incumbent and become a monopolist if $\underline{x}(\varepsilon) \le x \le \bar{x}(\varepsilon, \gamma)$. Finally, it will share the market with the incumbent if the incumbent can sustain profitable operations ($x > \bar{x}(\varepsilon, \gamma)$). In the latter case, thanks to the process innovation, the market entrant (firm i) will enjoy a cost advantage over its rival (firm j) given by

$$\delta(\varepsilon, \gamma) \coloneqq \frac{\alpha_i(\varepsilon, \gamma)}{\alpha_j(\varepsilon, \gamma)} \le 1.$$

An extra effort ε by the innovator will improve the relative cost advantage δ (since $\partial\delta/\partial\varepsilon \le 0$), whereas spillover effects from imitation will erode it (because $\partial\delta/\partial\gamma \ge 0$). Moreover, the spread between the innovator's entry threshold $\underline{x}(\varepsilon)$ and the incumbent's operating threshold $\bar{x}(\varepsilon, \gamma)$ above which it sustains operations profitably, given by $\Delta(\varepsilon, \gamma) \equiv \bar{x}(\varepsilon, \gamma) - \underline{x}(\varepsilon)$, increases in the degree of innovation effort ε if spillover effects are low (i.e., if $\gamma \le 1/2$) because $\partial\Delta/\partial\varepsilon = c_i(\varepsilon)\left[1 - 2\gamma e^{(1-\gamma)\varepsilon}\right]$). A larger upfront effort ε by the entrant enhances its chances to displace the incumbent ex post (for a given level of imitation spillover γ).

We now consider the decision by the incumbent (firm j) whether to exit the market after the innovator's market entry. The incumbent can sustain profitable operations if the state of demand exceeds the threshold $\bar{x}(\varepsilon, \gamma)$. Its net profit function is given by

$$\pi_j(x, \varepsilon, \gamma) = \begin{cases} 0, & x \leq \bar{x}(\varepsilon, \gamma) \\ \dfrac{\left[x - \alpha_j(\varepsilon, \gamma) c_i(\varepsilon)\right]^2}{9b} - I_j, & x > \bar{x}(\varepsilon, \gamma). \end{cases} \tag{5}$$

If the firms agree and both choose to operate in the market, they will enjoy the same lower unit production cost. Their profits are obtained by setting $\gamma = 1$ in equation (5) above.

Figure 2A illustrates the innovator's profit (at the commercialization time T) based on the profit function in (4) for a specified set of parameter values. We here consider different degrees of imitation spillovers ($\gamma = 0.1, 0.3, 1$), with the case $\gamma = 1$ representing the situation where the firms effectively use the same production technology because either they agree on a licensing deal or because the incumbent fully free-rides on the entrant's innovation. In Figures 2A and 2B the entrant's (firm i' s) profit drops at the incumbent's threshold $\bar{x}(\varepsilon, \gamma)$ above which the incumbent decides to stay in operation and grows at a lower rate above that threshold. A greater degree of spillover affects adversely the innovator because it improves the incumbent's chances of survival ($\partial\bar{x}/\partial\gamma < 0$) and it lowers the innovator's cost advantage in duopoly. In Figure 2A, the curve for $\gamma = 1$ shows the innovator's dissipated profit when the incumbent uses the entrant's technology as per the licensing agreement. The above does not account for the fair fee compensation to the licensor which is in addition to the Cournot profits.

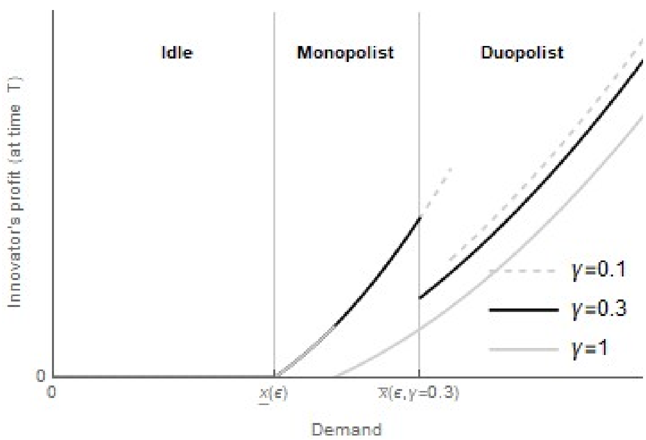

Figure 2A: Innovator's profit as a function of demand (x). Parameter values: $c = 2$, $\varepsilon = 0.5$ $b = 0.5$, $I_i = 1, I_j = 1.5$.

Since ex-post demand (X_T) is unknown at the time the innovator decides on its licensing strategy and its innovation effort, these decisions depend on the innovator's demand expectations as well as its expectation on how the product-market competition game unfolds.

5. Licensing choices under uncertainty

At time τ at which the firms negotiate a licensing agreement, the innovator has two main choices. Either it does not agree to license, keeping the superior technology proprietary for its own commercial exploitation in entering the product market (despite facing the threat of imitation and spillover value erosion by the incumbent), or it enters an agreement to license its superior technology to the incumbent rival (in the spirit of *coopetition*) for a commensurate licensing fee. We discuss the innovator's main choices in turn.

Proprietary stance (no licensing)

Consider first the innovator's expected profit under uncertainty (over horizon h) if it decides to keep its innovation proprietary for its own commercial exploitation upon market entry. The entrant's profit at future commercialization time T $(= \tau + h)$, $\pi_i(X_T, \varepsilon, \gamma)$, is stochastic (with the function π_i given in (4)) as the innovator cannot perfectly forecast at time τ the state of future demand X_T. The innovator's expected profit from keeping the more efficient technology proprietary is then given by $\Pi(x, \varepsilon, \gamma) \equiv E_x[\pi_i(X_T, \varepsilon, \gamma)]$ whereby the demand state is x at time τ. Figure 2B illustrates the innovator's expected profit in the case of a proprietary no-licensing stance for different degrees of uncertainty over a given delay (demand revelation) period h. The innovator's profit drops at the threshold $\bar{x}(\varepsilon, \gamma)$ because the industry structure changes from monopoly to duopoly; this pattern is shown in Figure 2B under the deterministic case ($\sigma \to 0$) assuming imitation spillover $\gamma = 0.3$. As the volatility over the delay interval h (between τ and T) gets larger ($\sigma = 0.30$ vs. 0.15 vs. 0.0), the incumbent's operation above the threshold $\bar{x}(\varepsilon, \gamma)$ has a smoother impact on the innovator's expected profit because future demand X_T is more disperse around $\bar{x}(\varepsilon, \gamma)$ owing to demand uncertainty. An interesting concave-convex alternating pattern emerges (e.g., see middle curve at $\sigma = 0.15$) resembling a "competitive wave." Uncertainty here helps moderate the negative impact that the incumbent's sustained operating activity has on the entrant's expected profit.

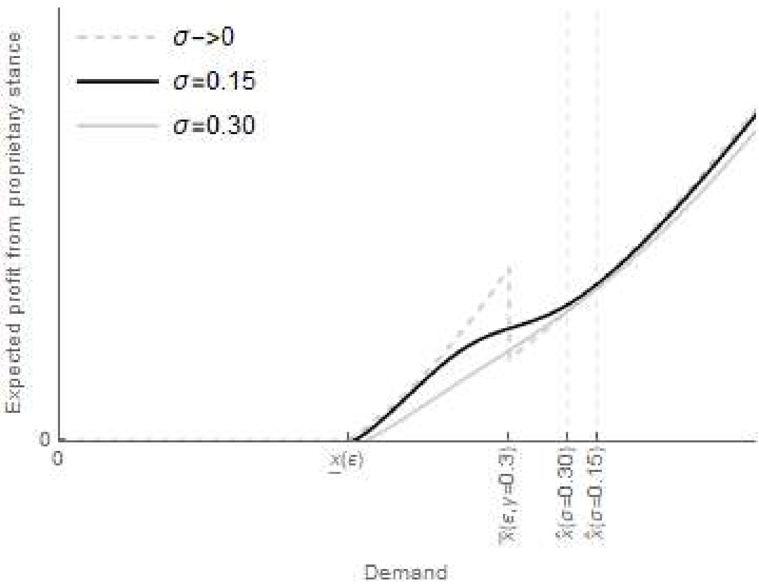

Figure 2B: Innovator's expected profit as a function of demand for distinct delay periods ($h =$ $0, 0.5\ or\ 1$). Parameters: $c = 2$, $I_i = 1, I_j = 1.5$, $\varepsilon = 0.5$ $b = 0.5$, $\mu = 0.0$, $\gamma = 0.3$.

Compared to the above deterministic case ($\sigma \to 0$), higher demand uncertainty (σ) reduces the entrant-innovator's expected profit in the extreme low ($x \leq \bar{x}(\varepsilon, \gamma)$) or high demand ranges ($x > \hat{x}(\sigma)$), but it benefits the innovator when demand is in the intermediate region ($\bar{x}(\varepsilon, \gamma) < x < \hat{x}(\sigma)$). This effect is not due to discounting at a higher rate to account for greater risk (we ignore discounting here to focus on the effect of uncertainty σ). At low initial demand ($x \leq \bar{x}(\varepsilon, \gamma)$), higher uncertainty creates a larger dispersion of ex-post demand X_T, thus increasing the likelihood of the incumbent staying in operation (probability of event $X_T \geq \bar{x}(\varepsilon, \gamma)$), with the entrant competing with the incumbent à la Cournot in the product market. At large initial demand ($x \geq \hat{x}(\sigma)$), a larger dispersion of ex-post demand depresses the innovator's expected profit compared to the deterministic case ($\sigma \to 0$) because scenarios where demand falls are more likely (probability of event $X_T \leq \bar{x}(\varepsilon, \gamma)$). If initial demand is in the intermediate demand region $\bar{x}(\varepsilon, \gamma) \leq x \leq \hat{x}(\sigma)$, by contrast, a greater dispersion of future demand benefits the innovator. That is mainly because the scenario where the incumbent is displaced is more likely (with probability of event $\underline{x}(\varepsilon) \leq X_T \leq \bar{x}(\varepsilon,\gamma)$). This benefit is moderated because there is also a chance that the innovator will not to enter the market (probability of event $X_T \leq \bar{x}(\varepsilon)$).

Once the innovator proposes a licensing deal, the incumbent decides to accept or reject the deal. In equilibrium, the innovator would thus propose a licensing deal that makes the incumbent indifferent between accepting or rejecting it.

Fixed-fee licensing

We next assess the relative merits of two alternate licensing schemes. Under the fixed-fee scheme, the innovator proposes at time τ a licensing agreement according to which the incumbent pays the licensor a fixed upfront fee F. The incumbent will accept the deal if its expected net profit as of time-τ (weakly) exceeds the expected profit it would receive if it does not license the superior technology (but accounts for imitation spillover benefits γ), 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 the innovator's expected payoff increases in the amount of the fee, F, it would set a fee F that gives out the least acceptable profit to the licensee (firm j), i.e., it would select a cutoff fee $\hat{F}(x,\varepsilon,\gamma)$ such that it just satisfies the above inequality at the margin (as an equality).[iii]

The effect of demand x and volatility σ on the equilibrium fixed-fee amount is shown in Figure 3A. The equilibrium fixed fee $\hat{F}(x,\varepsilon,\gamma)$ is not monotone increasing in the demand state x. In the deterministic case ($\sigma \to 0$), the prospect of being able to produce in the market with the superior technology (with $\gamma = 1$) rather than staying with the old technology (with $\gamma = 0.3$) makes the less efficient incumbent firm (j) willing to accept the licensing deal in the demand range ($\bar{x}(\varepsilon,1) < x < \bar{x}(\varepsilon,0.3)$).[iv] If the incumbent can sustain profitable operations without licensing the superior technology (i.e., if $x \geq \bar{x}(\varepsilon,0.3)$), its incentive to adopt the innovation and license is reduced at once. Yet, as demand builds up, the incumbent (firm j) would be willing to pay a substantially higher fixed licensing fee F because the superior technology can be more effectively and more profitably deployed in the market. Uncertainty (σ) here does not necessarily reduce the willingness of the incumbent to pay a higher (fixed) licensing fee, except in the intermediate demand range. For very low ($x < \bar{x}(\varepsilon,1)$) or large demand ($x > \bar{x}(\varepsilon,0.3)$), higher uncertainty makes the future scenario ($\bar{x}(\varepsilon,1) < X_T < \bar{x}(\varepsilon,0.3)$)

where the incumbent would operate in the market via licensing the new technology ($\gamma = 1$) rather than using the old one ($\gamma = 0.3$) more likely, which raises the incentive of the incumbent (firm j) to pay a higher fixed licensing fee (F).

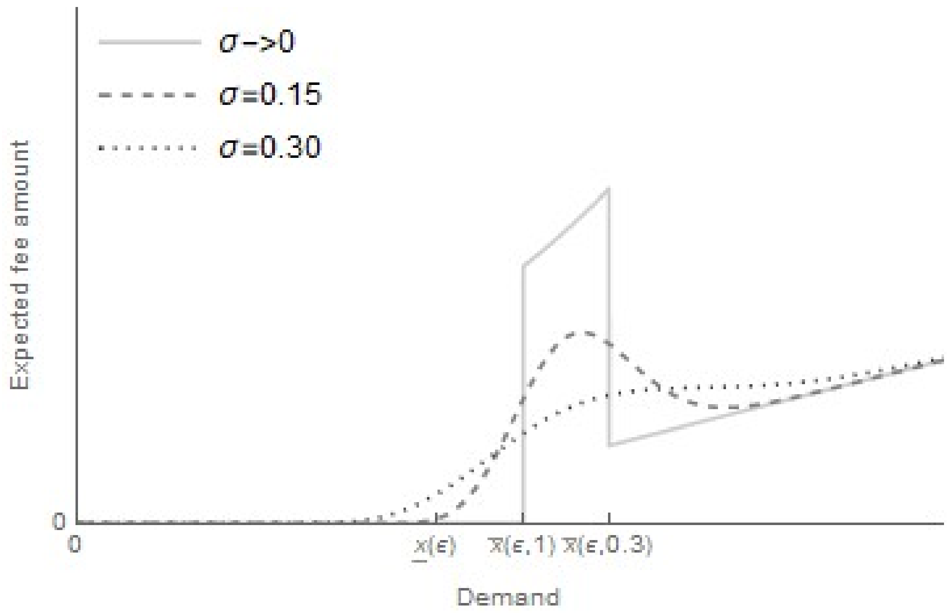

Figure 3A: Equilibrium fixed fee amount $\hat{F}(x, \varepsilon, \gamma)$ depending on demand x and volatility σ. Parameter values: $c = 2$, $b = 0.5$, $I_i = 1, I_j = 1.5$, $\mu = 0.0$, $h = 0.5$, $\gamma = 0.3$, and $\varepsilon = 0.5$.

Figure 3B illustrates further the sensitivity of the equilibrium licensing fixed-fee amount, $\hat{F}(x, \varepsilon, \gamma)$, to changes in the imitation spillover parameter γ. Larger spillover rate γ reduces the incumbent's incentive to close a licensing deal; the equilibrium fixed fee amount $\hat{F}(x, \varepsilon, \gamma)$ vanishes when the incumbent (firm j) can fully free-ride ($\gamma \rightarrow 1$) (a case not shown on Figure 3B).[v] The (equilibrium) fixed licensing fee can be shown to be monotone increasing in the innovation effort ε since extra effort helps the innovator achieve a lower unit cost, and increases the incumbent's incentive to license the superior technology.

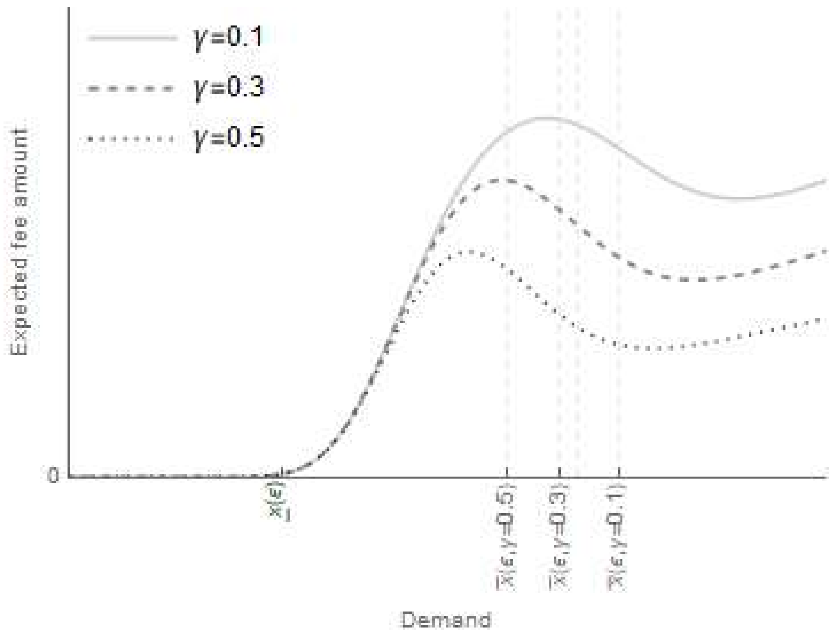

Figure 3B: Equilibrium fixed fee $\hat{F}(x, \varepsilon, \gamma)$ depending on demand x and spillover γ. Parameter values: $c = 2$, $b = 0.5$, $\sigma = 0.15$, $\mu = 0.0$, $I_i = 1$, $I_j = 1.5$, $h = 0.5$ and $\varepsilon = 0.5$.

The innovator's expected profit when it licenses under the fixed-fee scheme comprises the expected profit attained when the two firms produce in the market using the new cost-efficient technology plus the (equilibrium) fixed fee received. Because contracting is costly, involving payment of a lump-sum contracting fee β, the innovator's expected profit is

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

It is noteworthy than for low demand, the innovator may be better off not to license for a fixed fee because its expected profit will get reduced in the case of licensing (from $E_x[\pi_i(X_T, \varepsilon, \gamma)]$ to $E_x[\pi_i(X_T, \varepsilon, 1)]$) while it additionally has to incur a contracting fee β.

Royalty rate scheme

Under the royalty rate licensing scheme, the innovator/licensor (firm i) is to receive from the licensee (firm j) royalties proportional to the output produced, at a rate of R. This means that the incumbent licensee's (firm j's) unit cost now becomes $ce^{-\varepsilon} + R$. The royalty rate R implies higher unit cost ex post for the incumbent (vs. the fixed-fee scheme). This can be viewed as an additional per unit "tax," which reduces the incumbent's gross profit margin. The royalty-rate scheme thus offers a different risk sharing mechanism to the parties than the fixed-fee scheme. Should the licensee decide not to operate in the market using the licensed technology at time T, it is not liable to make any payment to the licensor (under the pure royalty-rate scheme), by contrast to the fixed-fee scheme. We next determine the equilibrium royalty rate, $\hat{R}$, that the market entrant would optimally set at time τ, prior to engaging in product-market competition with the incumbent an interval h later.

Under the royalty rate scheme, the incumbent will be able to sustain profitable operations ex post if the demand x is sufficiently large for it to also cover its higher fixed operating costs associated with increased advertising or revamping of its operations to remain competitive in the face of the entrant's superior technology, I_j, i.e., if

$$x \geq \hat{x}(\varepsilon, R) \coloneqq c_i(\varepsilon) + 2R + \sqrt{9bI_j} = \bar{x}(\varepsilon, 1) + 2R.$$

Under the royalty scheme (with a given royalty rate R), the incumbent's profit in state x is

$$\hat{\pi}_j(x, \varepsilon, R) = \begin{cases} 0, & x \leq \hat{x}(\varepsilon, R), \\ \dfrac{(x - c_i(\varepsilon) - 2R)^2}{9b} - I_j, & x > \hat{x}(\varepsilon, R), \end{cases} \tag{6}$$

while the entrant's (firm *i*) ex-post profit is

$$\hat{\pi}_i(x, \varepsilon, R) = \begin{cases} 0, & x < \underline{x}(\varepsilon) \\ \dfrac{[x - c_i(\varepsilon)]^2}{4b} - I_i, & \underline{x}(\varepsilon) \leq x < \hat{x}(\varepsilon, R) \\ \dfrac{[x - c_i(\varepsilon) + R]^2}{9b} + R\hat{q}_j(x, R) - I_i, & x \geq \hat{x}(\varepsilon, R). \end{cases} \tag{7}$$

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

$$R_M(x) = \frac{x - c_i(\varepsilon)}{2} \tag{8}$$

per unit. If the licensor were to enforce such a royalty rate deal, the incumbent would be displaced from the market as it would not make a profit [as confirmed from substituting $R_M(x)$ for R in (7)]. The innovator/entrant is therefore not likely to propose this to the incumbent because the latter would simply refuse the licensing contract and instead compete heads-on benefiting from imitation spillover, earning $\pi_j(x, \varepsilon, \gamma)$ as per (5).

The set royalty rate at contract signing time (τ) will affect the licensee's (firm j) profitability ex post, along with the future demand realization X_T. Whether the incumbent can sustain profitable operations ex post (and therefore make royalty payments to the innovator), rather than being displaced by the entrant, depends on the realized demand X_T relative to the set royalty rate. The incumbent might accept the entrant's licensing deal (at time τ) if the incumbent can expect to make a profit while licensing in excess of the (expected) profit achieved when it does not license the technology (yet benefits from spillover γ):

$$E_x\left[\hat{\pi}_j(X_T, \varepsilon, R)\right] \geq E_x[\pi_j(X_T, \varepsilon, \gamma)]. \quad (9)$$

Figure 4 depicts the innovator/entrant's excess (expected) profit across a range of demand states x assuming a given royalty rate R. Panel A exhibits its *gross* excess (expected) profit, i.e., ignoring fixed costs, while Panel B considers its *net* excess (expected) profit. We can see that, while the entrant is willing to propose a royalty scheme over a wider set of demand states x, the *magnitude* of this incentive changes across demand states x. In the deterministic case ($\sigma \to 0$), the innovator's gross excess (expected) profit from licensing is nil if the incumbent would decide to exit the market (if $x < \hat{x}(\varepsilon, R)$) because the innovator would dilute its cost advantage by licensing its superior technology to the incumbent. If the incumbent cannot sustain profitable operations with the old (inferior) technology but can do so with the superior one ($\hat{x}(\varepsilon, 1) < x < \bar{x}(\varepsilon, \gamma)$ for a given parameter $\gamma < 1$), then it would be more willing to license the technology. Finally, if the incumbent can sustain profitable operations with the inferior technology ($x > \bar{x}(\varepsilon, \gamma)$), then it will be less willing to license the superior technology; yet, as demand builds up, its willingness increases together with the prospects of its increasing profit margin. Operating in this market is costly for the incumbent given the fixed operating costs it faces to remain competitive following entry by the rival. If the incumbent licenses in the entrant's superior technology, these costs result in lower net excess (expected) profit. Uncertainty here again blurs somewhat the picture because given a state of current demand x, the firm is not sure about the state of future demand X_T. The larger the uncertainty σ, the smoother the overall shape of the incumbent's incentive structure because volatility leads to a more disperse future demand X_T and a more ambiguous prediction whether future demand will be in the intermediate region $\hat{x}(\varepsilon, R) < x < \bar{x}(\varepsilon, \gamma)$.

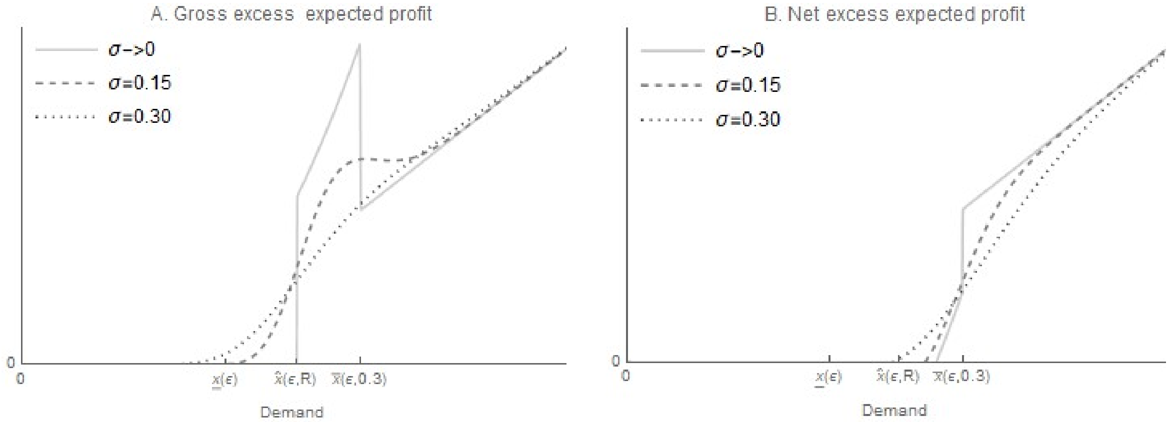

Figure 4: For a given royalty rate $R = 0.1$, gross and net excess (expected) profit of the licensor depending on demand x and demand volatility σ. Parameter values: $c = 2$, $b = 0.5$, $\mu = 0.0$, $I_i = 1, I_j = 1.5$, $\gamma = 0.3$, $h = 0.5$ and $\varepsilon = 0.5$.

In designing the licensing contract, the innovator can exploit its understanding of its rival's incentives and propose a royalty rate just sufficient for the incumbent to accept the deal; this royalty rate is such that inequality (9) is satisfied at the margin as an equality. The incumbent would not be willing to pay a royalty rate larger than

$$\hat{R}(\varepsilon, \gamma) \coloneqq \frac{\alpha_j(\varepsilon, \gamma) - 1}{2} c_i(\varepsilon). \tag{10}$$

The above rate corresponds to the "monopoly rate" in (8) set at $x = \alpha_j(\varepsilon, \gamma) c_i(\varepsilon)$, which is the incumbent's opportunity cost. While its incentive varies with the state of demand x and with uncertainty (see Figure 4), the equilibrium royalty rate $\hat{R}(\varepsilon, \gamma)$ is a given amount. By definition of the royalty rate (which is proportional to firm j's output), committing to a royalty rate at time τ at a low demand state x and high expected volatility σ involves little if any downside risk for the incumbent because it will only have to pay a royalty payment if it actually produces at time T. Yet, committing to paying more than the royalty amount $\hat{R}(\varepsilon, \gamma)$ involves more risk for the incumbent because it would end up worse off if it licenses the superior technology than using the old one. The innovator would not be willing to agree on a royalty rate R lower than $\hat{R}(\varepsilon, \gamma)$, because it would result in a lower chance of displacement of the incumbent (compared to the no-deal outcome) because

$$R < \hat{R}(\varepsilon,\gamma) \Leftrightarrow \hat{x}(\varepsilon,R) < \hat{x}\left(\varepsilon,\hat{R}(\varepsilon,\gamma)\right) \equiv \bar{x}(\varepsilon,\gamma).$$

Offering a lower royalty rate R would also help the incumbent attain a better competitive (cost) position at the expense of the innovator/entrant because

$$R < \hat{R}(\varepsilon,\gamma) \Leftrightarrow c_i(\varepsilon) + 2R < c_i(\varepsilon) + 2\hat{R}(\varepsilon,\gamma) \equiv \alpha_j(\varepsilon,\gamma)c_i(\varepsilon).$$

In brief, under the royalty-rate scheme, the innovator can set the royalty rate with a view to extract the full benefit (future cost savings) of its superior technology from the incumbent licensee who is left indifferent between accepting the licensing deal or not (indeed, $c_i(\varepsilon) + 2\hat{R}(\varepsilon,\gamma) = \alpha_j(\varepsilon,\gamma)c_i(\varepsilon)$ and $\hat{x}\big(\varepsilon,R^\star(\varepsilon,\gamma)\big) = \bar{x}(\varepsilon,\gamma)$). The equilibrium royalty level, $\hat{R}(\varepsilon,\gamma)$, increases with the innovation effort ε ($\partial\hat{R}/\partial\varepsilon > 0$) and decreases with the level of imitation spillover γ ($\partial R^\star/\partial\gamma < 0$). The incumbent's ex-post profit given the above equilibrium royalty scheme is obtained by substituting $\hat{R}(\varepsilon,\gamma)$ for R in equation (6), which is equivalent to $\pi_j(x,\varepsilon,\gamma)$ in (5).

Optimal licensing strategy of the innovator

The above licensing strategy choices (at time τ) amount to a situation where the innovator either chooses a competitive/aggressive strategy vis-à-vis the incumbent rival (by keeping its superior technology proprietary for its own commercial exploitation) or follows a cooperative/accommodating strategy (sharing the benefits of its superior technology with its rival in exchange for a licensing fee). The latter involves two possibilities, either a fixed-fee or a royalty rate payment. Figure 5 summarizes the expected profits to the innovator arising for each of the three alternate licensing choices as a function of initial demand x (for a given volatility level $\sigma = 0.15$): (i) the innovator decides not to license keeping the technology proprietary for its own exploitation; (ii) it licenses it out to its incumbent rival for a fixed-fee payment $\hat{F}$; or (iii) it licenses it to the rival for a royalty rate $\hat{R}$. We here introduce two other demand thresholds, $x_1(\sigma)$ and $x_2(\sigma)$, corresponding to the intersection (indifference) points for the related curves.

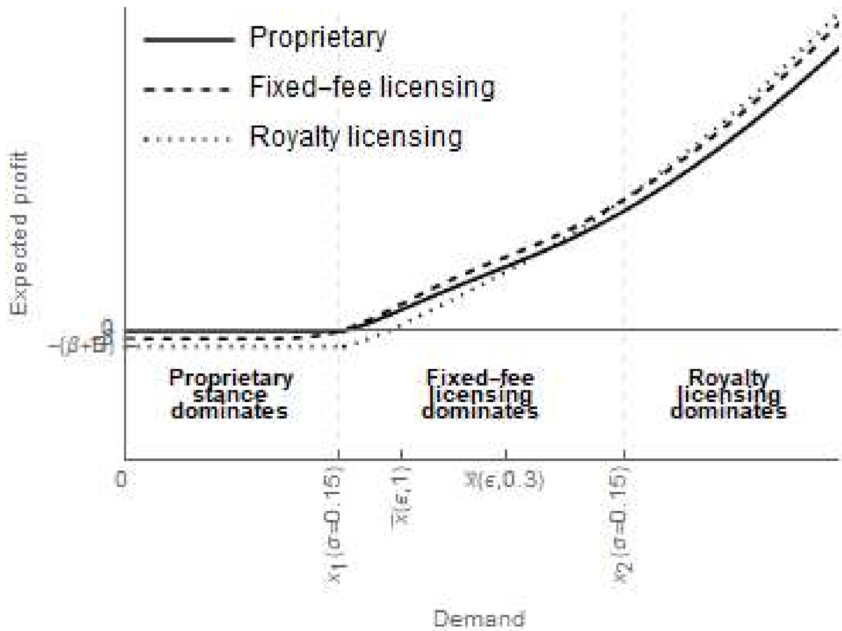

Figure 5: Innovator's expected profit (as of time τ) as a function of current demand x (for a given volatility level $\sigma = 0.25$) for three alternate strategies: (i) the innovator does not license keeping the technology proprietary, (ii) it licenses it to its rival for a fixed-fee payment $\hat{F}$, or (iii) it licenses it for a royalty rate $\hat{R}$. Parameter values: $c = 2$, $b = 0.5$, $\mu = 0.0$, $h = 0.5$, $\varepsilon = 0.5$, $\sigma = 0.25$, $\beta = 1, B = 2$, and $\gamma = 0.3$.

If the market appears to be a niche, i.e., if $x \leq x_1(\sigma)$, the entrant using the more cost-efficient technology is likely to displace the incumbent who would be unable to operate profitably under adverse technological *and* demand conditions and hence would be unwilling to pay considerable fees to license the new technology. Moreover, since the licensor would also incur transaction costs in the form of contracting fees β and B, it does not make much sense for the entrant to license its technology in this case either. This case is illustrated in Figure 5 for $\sigma = 0.15$. In the intermediate demand region at time τ with $x_1(\sigma) < x < x_2(\sigma)$, where the incumbent can sustain profitable operations thanks to the superior technology (but not with the inferior one), the two firms may reach an agreement whereby the incumbent pays a sufficient compensation to the licensor for the latter to recoup its costs. The innovator here is better off adopting a cooperating stance by licensing its technology (given appropriate licensing fee compensation) than keeping it proprietary.

The innovator's expected profit from entering a royalty licensing scheme or fixed-fee licensing are both monotone increasing. The innovator benefits more from the demand upside in case of royalty licensing (with compensation being convex increasing in demand). Yet because the innovator has to ensure that the licensee reports its output/revenue figures truthfully, which involves incurring monitoring costs B, the curve for the innovator's expected profit in Figure 5 under royalty licensing starts at a lower level, $-(\beta + B) < -\beta$. Beyond some demand threshold, $x_2(\sigma)$, royalty licensing dominates.

Figure 6 further illustrates how the demand state x (as of time τ) and volatility σ influence the innovator's optimal licensing decision. For a low-to-intermediate range of demand at time τ ($x \leq x_1(\sigma)$), a proprietary stance of no-licensing dominates. As demand volatility σ rises (moving to the top of Figure 6), the innovator has a lower incentive to keep the technology proprietary as the risk of incumbent displacement declines and the incumbent may be more willing to compensate the licensor for using its superior technology at higher demand. For the intermediate demand range, $x_1(\sigma) < x \leq x_2(\sigma)$, fixed-fee licensing is generally preferred especially when volatility σ is higher. As demand volatility σ increases over the interval h, whether the rival will produce and be charged with royalties becomes more uncertain such that the range of demand for which the innovator prefers fixed-fee licensing widens. When demand prospects get high, beyond $x_2(\sigma)$, royalty licensing dominates since compensation grows with demand while the fixed-fee scheme does not share in the upside.

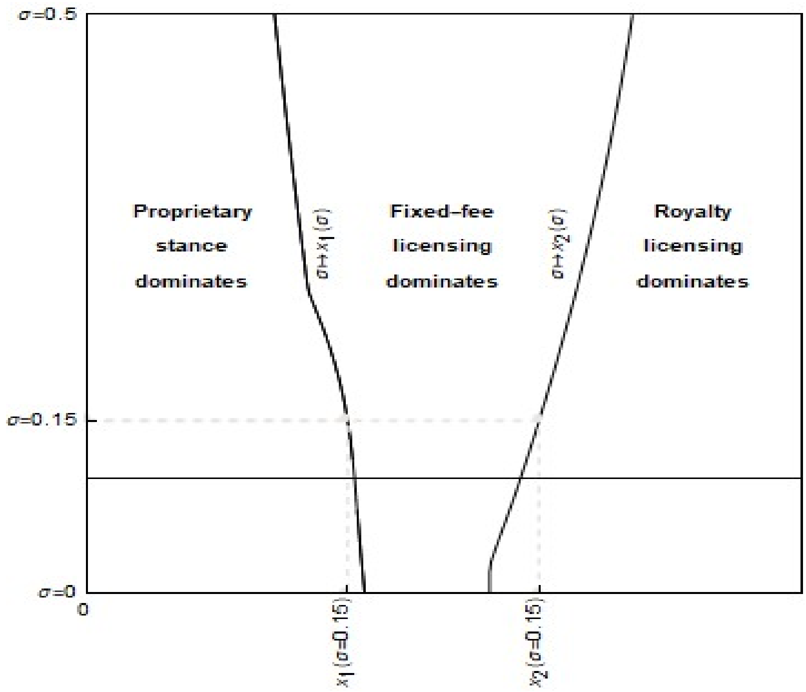

Figure 6: Dependence of the innovator's licensing decision on (time τ) demand x and demand volatility σ. Vertical separating curves shown for a given volatility level of $\sigma = 0.25$.
Parameter values: $c = 2$, $b = 0.5$, $\mu = 0.0$, $h = .5$, $\varepsilon = 0.5$, $b = 0.5$, $B = 1$,and $\gamma = 0.3$.

The above result differs from Kamien arnd Tauman (1986) who find that licensing by means of a fixed fee is always preferred by an innovator. Our more nuanced result that shifts the balance towards the royalty rate scheme here under high demand x (the rightmost region in Figures 5 and 6) stems from the innovator competing in the product market alongside the incumbent licensee (due, for instance, to the inability to impose territorial restrictions) and the royalty rate scheme giving an enhanced cost advantage to the innovator through the royalty payment acting as an additional marginal cost ("tax") for the licensee. This greater cost advantage for the innovator is not present under fixed-fee licensing. Furthermore, under high demand uncertainty, if the parties agree on a royalty rate scheme at time τ but at the later product market stage T demand drops such that the licensee does not produce (given its relative cost disadvantage due to the royalty "tax rate") and hence does not pay royalties, there is an adverse scenario possibility involving an opportunity cost for the innovator; this opportunity loss, however, is partially cushioned by the higher monopoly-like profits. Such asymmetry in the operating behaviors of the two rivals does not arise under the fixed-fee scheme since, in the latter case, both parties use the superior technology and incur the same unit production costs. This additional contingent monopoly-like benefit in conjunction with the marginal "tax" advantage of royalty-rate licensing may increase the appeal of the royalty scheme for a broader range of demand scenarios than previously considered. Hence, our assumption that the licensor competes with the licensee in the product market under uncertainty conditions leads to results that differ qualitatively from those in the extant literature that have typically assumed that either the innovator or the licensee operate as a monopolist (post-licensing) in a deterministic setting and obtained that fixed-fee licensing is always preferred. Surmising that the innovator follows the optimal licensing strategy, we next turn to the innovator's optimal innovation effort.

6. Optimal innovation effort

Several value drivers seem to affect the innovator's optimal effort, such as the degree of innovation spillover (γ) and demand volatility (σ). We have obtained analytic formulas for the value of the innovator's expected profits under various licensing policies and have determined the licensing strategy that maximizes the innovator's expected payoff (from time τ onwards) across a range of demand states. To obtain the innovator's expected value upfront as of time $t = 0$, we next determine the expected profits net of the upfront cost incurred to expend the innovation effort. We then solve for the effort level ε that maximizes the net current value of the innovation investment. The optimal innovation effort ($\hat{\varepsilon}$) reflects the contingent optimal licensing strategy as of time τ, involving a proprietary stance conditional on low demand, fixed-fee licensing at intermediate demand and royalty-rate licensing conditional on high demand (Figures 5 and 6).

Figure 7A illustrates how the incentive to pursue a cost-reducing process innovation (the optimal innovation effort $\hat{\varepsilon}$) varies as a function of initial demand x for three distinct levels of imitation spillover γ. First, higher initial demand encourages the innovator to exert more innovation effort because the expected profit function is convex in the state of demand x. Spillover effect erosion discourages the innovator from pursuing greater effort as a higher degree of spillover enables the incumbent to sustain profitable operations (without licensing) and gives it greater negotiating power in the intermediate stage of licensing discussions.

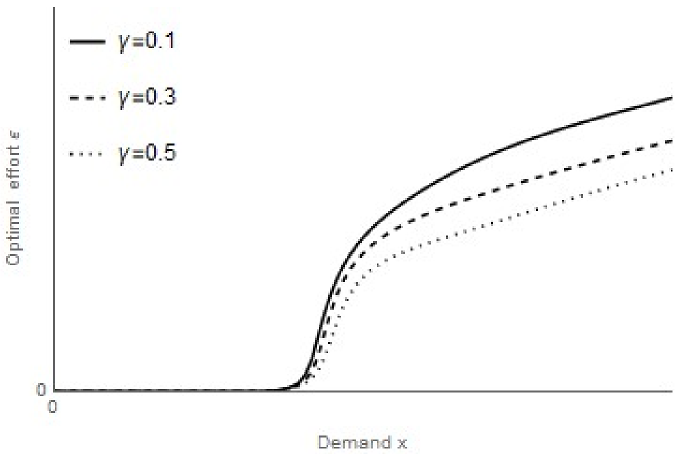

Figure 7A: Innovator's optimal innovation effort as a function of demand state x for different degrees of spillover γ. Parameter values: $c = 2$, $b = 0.5$, $\mu = 0.0$, $h = 0.5$, $\tau = 1$, $\sigma = 0.15$, $\beta = B = 0.25, C(\varepsilon) = 3\varepsilon^2$.

Figure 7B illustrates the innovator's optimal innovation effort ($\hat{\varepsilon}$) as a function of initial demand x for three distinct levels of demand volatility (σ). The (deterministic) case with negligible uncertainty ($\sigma \to 0$) is a lower bound for the optimal innovation effort in case of low ($x \leq x_\star$) or large demand ($x \geq x^\star$). By contrast, under considerable uncertainty ($\sigma > 0$), if initial demand is low ($x < x_\star$), the entrant has an incentive to expend a greater effort at developing the process innovation because a larger dispersion of future demand states makes it more likely for the entrant to displace the incumbent and also increases the incumbent's willingness to accept a larger compensation for licensing the technology. [vi] At intermediate demand x ($x_\star < x < x^\star$), when the market is more likely to accommodate one but not both firms, higher demand uncertainty (σ) discourages the entrant's innovation effort to build up a stronger cost advantage because the entrant is unsure whether it can displace the incumbent (on the left of this region) and whether it should enter a licensing contract (on the right of this region). Recall also that when initial demand x is in the intermediate region (just below $\overline{x}(\varepsilon, \gamma)$ in Figure 2A), high volatility reduces the innovator's expected value (and hence incentive to exert effort) since it may end up in the extreme demand regions, either the low demand region, which is unprofitable, or the high demand region where the innovator's value takes a downward jump as it switches from a monopoly-like to a competitive duopoly profit regime (with a more severe value drop the higher the spillover rate γ). When the incumbent is likely to keep operating in the market ($x \geq x^\star$), however, higher volatility encourages the entrant to invest in innovation as the entrant wants to build a stronger cost advantage, which it can sustain via a royalty-rate scheme (because of the "unit tax" charged to the incumbent). Ignoring the presence and impact of demand volatility and spillover effects in a traditional deterministic analysis of market operation and technology licensing may result in significant mis-investment in R&D and distort innovation efforts.

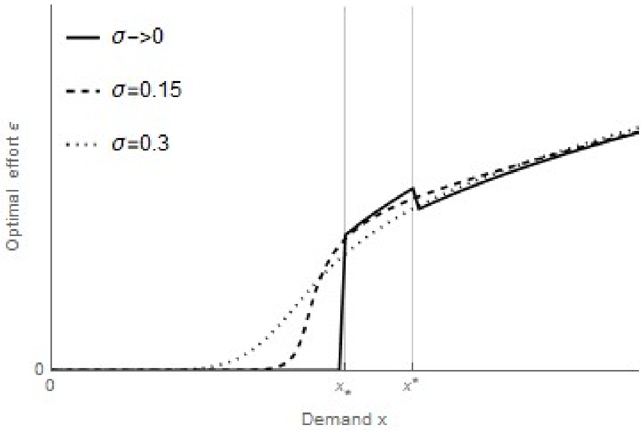

Figure 7 B: Innovator's optimal innovation effort as a function of demand state x for different degree of demand volatility σ. Parameter values: $c = 2$, $b = 0.5$, $\mu = 0.0$, $h = 0.5$, $\tau = 2$, $k = 3, \gamma = 0.3$, $\beta = B = 1$.

7. Conclusions

In this study, we modeled a type of innovation that has received limited attention in the extant literature but has become increasingly common in today's global marketplace. The innovation considered herein has three distinguishing features. First, it is attempted by a late entrant who develops a process technology that potentially gives itself a cost advantage in the face of uncertainty about the market demand. Second, the process innovation is potentially difficult to protect via patenting and can be subject to a substantial risk of imitation due to imperfections in the appropriation regime. Third, being a late entrant, the innovator will have to compete or cooperate with the incumbent rival unless its innovation is sufficiently drastic to drive out the incumbent. Recent examples that more or less show these features include Tata Motors' introduction of the Nano Car (Shilling, 2013), Nissan-Dongfeng's development of the Venucia line of low-cost cars in China (Reinhardt, Yamazaki and Donovan, 2013), and Huawei Technologies' global expansion in the telecommunications equipment market that was largely based on cost competitiveness (Yang, 2016). We examined the focal firm's innovation and competitive strategy in this setting and analyzed specifically how the degree of imitation spillover and the extent of uncertainty affect the innovator's optimal choice between commercializing the process technology alone and sharing it with the incumbent rival via licensing, the optimal design of a licensing agreement, and ultimately its innovation effort.

The distinguishing but plausible features of the above setting enabled our model to yield insights that enrich our previous understandings of these trade-offs. Depending on demand conditions and the degree of spillover and whether the incumbent will exit the market, the entrant may be better off keeping the technology for itself (proprietary) or collaborating and sharing its technology with the incumbent for a commensurate fixed fee or a royalty-rate compensation. We find that in a low region of demand when the incumbent will likely be displaced (which is endogenously driven by the innovation effort and demand conditions) the innovator may rationally choose not to license out its superior technology, pursuing a proprietary strategy. When demand is sufficiently large such that the incumbent would sustain profitable operations with the less efficient technology, the entrant will prefer to follow a more collaborative or accommodating stance, sharing the technology with the rival via licensing out its technology while striving to extract the full benefits under appropriate compensation. This finding differs from existing analyses that suggest a less perfect appropriation regime deters licensing and encourages the innovator to go it alone (e.g., Buckley & Casson, 1976; Teece, 1986). A main reason for the difference is that our model assumes not only an imperfect contracting regime but also a potentially high risk of imitation by the rival.

Among the two main alternate licensing schemes, we find fixed-fee licensing is preferable at an intermediate region of demand, while the royalty-rate payment scheme under which the innovator also benefits more from the upside (due to the "unit tax") is preferred for large demand. The innovator can set an equilibrium licensing royalty rate to extract the largest benefits of its innovation from the incumbent while keeping the costs marginally acceptable to the licensee. Our findings here contrast with the main result in Kamien and Tauman's (1986) deterministic game where a fixed-fee scheme always dominates. Under demand uncertainty and the novel assumption that the innovator/licensor can itself compete in the product market along with the incumbent licensee, the innovation effort in conjunction with a collaborative strategy can potentially alter the industry structure (beyond its direct impact through technological cost savings) enabling the innovator to extract the most benefit from its technology while moderating the impact of spillover losses in an imperfect appropriation regime through optimal licensing design, particularly the use of a royalty rate scheme (most beneficial in a high region of demand).

Our paper makes several contributions to the literature. In particular, we endogenize the innovator/licensor's choices concerning (i) whether to pursue a proprietary strategy to innovation exploitation or follow an accommodating or collaborative licensing strategy; (ii) whether to follow the royalty rate or fixed-fee payment scheme in case of licensing out the technology, and (iii) analyzed the role and impact of spillover effects and demand uncertainty on the innovator's ex-ante decision on how much (effort) to invest in the innovation process. We find that the optimal innovation effort increases with the state of demand while it is moderated by the degree of spillover effects and demand uncertainty during the delay period. Whether demand volatility has a negative effect on the innovation effort depends on the state of initial demand. When demand is moderate, demand volatility during the delay period may depress the incentive to invest in innovation because the innovator is concerned with the likely future industry structure, whereas volatility may encourage a greater innovation effort when current demand is low or large because the innovator is more confident about the benefits of holding a more efficient technology. We conclude that ignoring the role of spillover effects in an imperfect appropriation regime and the impact of demand uncertainty when pursuing a traditional analysis of technology licensing strategy could lead to significant valuation errors and mis-investment in technological process innovation. Our broader findings that help delineate contingencies and conditions under which an innovator entrant would license out its superior technology to an incumbent rival also differ from existing literature that generally suggests that a less perfect appropriation regime tends to deter licensing.

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Endnotes

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i If the innovator made no effort ($\varepsilon = 0$), its ex-post unit cost will be $c_i(0) = c$, which is the cost under the old production technology.

ii Here we assume the incumbent with the inferior or costlier technology faces higher fixed operating costs, such as higher advertising expenditures, to maintain its customer base after the entry of the rival.

iii We derive an analytic expression for the optimal fixed fee $\hat{F}(x, \varepsilon, \gamma)$ and the innovator's profit in appendix.

iv We set γ equal to 1 in $\bar{x}(\varepsilon, 1)$ and to 0.3 in $\bar{x}(\varepsilon, 0.3)$: we are in effect comparing the case where the firms agree on a licensing deal (in which case $\gamma = 1$) with a case where the firms do not, with $\gamma = 0.3$.

v The equilibrium fixed fee declines more sharply in the spillover rate γ when the innovative effort ε is greater. This is because, for a given γ, the reduction in rival firm j's unit cost is larger if innovative firm i's effort is greater, with $e^{-\gamma\varepsilon_1} < e^{-\gamma\varepsilon_2}$ if $\varepsilon_1 < \varepsilon_2$. This reduces firm j's willingness to pay a licensing fee to access the superior technology as the time differential shrinks.

vi In the instance, the first incentive corresponds to the likelihood of the event $\underline{x}(\epsilon) < X_T < \bar{x}(\epsilon, \gamma)$– which is raised–while the second motivation relates to the likelihood of the event $\bar{x}(\epsilon, 1) < X_\tau < \bar{x}(\epsilon, \gamma)$.