On the duration of technology licensing

John Gordanier, Chun-Hui Miao *

Department of Economics, University of South Carolina, Columbia, SC 29208, United States

A R T I C L E   I N F O

Article history:
Received 19 July 2010
Received in revised form 4 April 2011
Accepted 11 April 2011
Available online 20 April 2011

JEL classification:
D86
L13
L24

Keywords:
Innovation
Licensing
Patent
Royalty
Technology leakage
Time consistency

A B S T R A C T

We model an innovator's choice of payment scheme and duration as a joint decision in a multi-period licensing game with potential future innovations and some irreversibility of technology transfer. We find that it may be optimal to license the innovation for less than the full length of the patent and that royalty contracts can be more profitable than fixed-fee licensing even in the absence of information asymmetry and risk aversion. Moreover, licensing contracts based on royalty have a longer duration than fixed-fee licenses and are more likely to be used in industries where innovations are frequent and intellectual property protection is weak. Our paper also highlights an important link between the study of technology licensing and the theory of durable goods.

Technology transfer through licensing is a common method to utilize a patent. A large body of literature has studied the optimal payment scheme of selling a cost-reducing innovation. It has been shown that licensing by means of a royalty is inferior to that of a fixed-fee for an outside innovator, regardless of the industry size or the magnitude of the innovation (Kamien et al., 1992; Kamien and Tauman, 1984, 1986, 2002). Subsequent studies have tried to explain the wide prevalence of royalties in practice by examining the many variants of the standard model. However, surprisingly few studies have examined the duration of technology licensing, even though it is an important dimension of every contract. More concretely, should the innovator license the innovation for the entire length of the patent, or should a series of short-term contracts be used? While existing theoretical models implicitly assume that a license remains in effect for the duration of the patent, most actual contract agreements terminate before the underlying patents expire. A more interesting fact is the variation in the duration of licensing contracts. Macho-Stadler et al. (1996) study a sample of 241 contracts between Spanish and foreign firms and find that contracts based on royalties tend to have a longer duration than fixed-fee contracts. Of the contracts containing fixed-fee payments, 24.5% are one-year contracts, while this proportion falls to 6.2% in the set of contracts containing royalty payments. At the other extreme, 58% of the 174 contracts with royalty payments are long-term contracts (at least five years), while only 15% of the contracts with fixed-fee payments had a duration of at least five years. Using the same dataset, Mendi (2005) studies the impact of contract duration in determining scheduled payments in technology transfer. He finds a positive relationship between contract duration and the probability of scheduling royalty-based payments.

In this paper, we introduce a model of technology licensing that analyzes the duration of contracts as well as the payment scheme. We focus on an outsider innovator's optimal licensing policy in a setting with potential future innovations and some irreversibility of technology transfers. We find that it can be optimal to issue a license for less than the length of the patent; even in the absence of information asymmetry and risk aversion, royalty can be more profitable than...
fixed-fee licensing.\footnote{For models with asymmetric information, see e.g., Gallini and Wright (1990), MacAvoy and Pérez-Castillo (1991), Beigl (1990), Podder and Sinha (2002) and Sen (2005b); with risk aversion, see e.g., Bouquet et al. (1998).} Moreover, licensing contracts based on royalty tend to have a longer duration and are more likely to be used in industries where innovations are frequent and intellectual property protection is weak.

Our model builds on two observations. First, technology advances are destructive. A new innovation often renders past ones obsolete. This means that an innovator who engages in a series of innovations potentially faces a time-consistency problem in technology licensing: once a license is sold, the innovator may have an excessive incentive to invest in new technologies. This decreases the value of the initial license. At the same time, it may be too costly to write a complete long-term contract in which license fees are contingent upon the outcome of risky investments for future improvements (Williamson, 1975). Therefore, a long-term fixed-fee license may be sub-optimal.

Second, the transfer of knowledge is irreversible. Once transferred, it is difficult for the innovator to retract the knowledge from a licensee (Brousseau et al., 2007; Caves et al., 1983). This means that a licensee may be able to utilize an innovation even after the license has expired.\footnote{According to Arora (1996), “[k]now-how, once provided, cannot be taken back from the licensee.... For instance, transfer of chemical process technology will typically involve training the licensee in a variety of issues such as how to handle and store chemicals, how to control the production process and return it to operation after unscheduled breakdowns caused by accidents, or by impurities in feedstocks.... Given that much of the know-how is tacit, once the licensee has learned the know-how, it cannot be forced to ‘unlearn’ it.” There are also famous court cases involving the kind of technology leakage discussed in this paper. In C&F Packaging v. IBP and Pizza Hut (Fed. Cir. 2000), C&F had developed a process for making a precooked sausage that had the appearance and taste of freshly cooked sausage and had obtained a patent on the equipment to make the sausage. Pizza Hut agreed to pay from C&F on the condition that C&F divulge its process to several other Pizza Hut suppliers (one of which was IBP), which subsequently learned how to duplicate C&F’s results. Pizza Hut then told C&F that it would not purchase any more of their sausage without drastic price reductions. In this case, C&F was able to successfully challenge Pizza Hut in the court. However, in Regina Glass Fibre Ltd v Werner Schuller (RPC 229, 1972; FSR 141, 1972), the Court of Appeal concluded that “there was no general proposition of law that when confidential information was given under an agreement and that agreement came to an end, the right to use the confidential information also came to an end. In many cases, as in the present one, when confidential information or know-how was given so as to enable a business to be established, it was given for all time; when the agreement came to an end, there was no right to acquire further information, but the recipient could go on using that which he had already received; he was not bound to close down the business which he had built up by using it.”} This means that an innovator who engages in a series of innovations might take in advance of the R&D effort, making it difficult to resolve the innovator’s time-consistency problem, since the investment level that minimizes her loss from technology leakage ex post generally deviates from her optimal investment ex ante. Long-term royalty contracts do not entail a time-consistency problem, but monitoring a licensee’s output may be costly. Based on these trade-offs, we derive conditions under which it is optimal for the innovator to license the technology for less than the length of the patent and conditions under which the uses of royalty contracts are optimal.

It should be noted that, in a world of costless and complete contracts, the innovator could resolve any time-consistency problem by making fees in a long-term contract contingent upon the outcome of future R&D efforts. However, there are a number of reasons for why contracting upon future innovations might be difficult. There may be extensive costs associated with describing each state of nature (Battigalli and Maggi, 2002), search costs associated with evaluating contracts’ implications (Klein, 2002), complexity costs associated with transfers that are state specific (Anderlini and Fell, 1994, 1999), or simply physical costs associated with writing lengthy contracts (Dye, 1985). All these costs are salient in contracts that are contingent upon future innovations. In particular, it is practically impossible to specify all possible forms that an innovation might take in advance of the R&D effort, making it difficult to write a contract contingent upon any specific innovation (Anderlini and Fell, 1999). Even a contract that does not specify a future innovation but instead is based upon the degree of cost savings of any innovation will require the courts be able to verify the degree of cost savings. Therefore, we view our model as relevant to those markets, in which complete contracts are too costly to write.

To our knowledge, Gandal and Rockett (1995) and Antelo (2009) are the only theoretical papers that have examined the optimal duration of licensing contracts.\footnote{Farrell and Shapiro (2008) consider a variable royalty rate, contingent upon the outcome of a court challenge of the validity of the patent. In their model, the innovator offers licenses to all downstream firms by assumption, therefore a fixed-fee license is offered only if the downstream firm has no competition. In an extension of their model, they consider short-term licenses, which are contracts that do not survive a single period.} The first paper focuses on the licensing of a sequence of exogenous innovations by fixed fees.\footnote{Oster (1995) is the only other paper that considers the optimal licensing scheme in a sequence of innovations. By way of an example, she explores the strategic opportunities created by exclusive licensing in a research-intensive market, but contracts are short-term by assumption in her model.} They derive conditions under which the innovator licenses the initial technology bundled with all future improvements and conditions under which licenses to each innovation are sold period-by-period. The latter paper focuses on royalties in a model of asymmetric information, in which a licensee’s output in a short-term contract signals her cost. Neither paper compares different payment schemes, nor are they concerned with the innovator’s time-consistency and technology leakage problems identified in this paper.

The model considered by Arora (1995, 1996) has much in common with ours in the conceptualization of technology leakage. In his model, an innovator licenses a technology package that contains both know-how and complementary inputs. When a contract expires, the licensee loses the rights to the complementary inputs, but can use the know-how to invent around the patents and continue to benefit from the initial technology transfer.\footnote{Bhattacharya and Guriev (2006) compare patenting with trade secrets licensing in the presence of technology leakage, which takes place when the innovator shops for a buyer.} The author uses the model to test both...
theorically and empirically the efficiency of contracts bundling know-how with complementary inputs. Because of its focus, the model takes the licensing scheme as given and assumes fixed-fee licensing with only one potential licensee. In addition, the model uses a reduced-form payoff function to quantify technology leakage and does not consider how the loss from leakage can vary with the R&D investment.

Our conceptualization of technology leakage is also related to papers by Macho-Stadler et al. (1996) and Choi (2001), who have developed incomplete contract models of a licensing relationship that is susceptible to moral hazard.\(^{10}\) They assume that the transfer of technology know-how is costly and cannot be contracted directly. A royalty-based contract is optimal because it reduces the innovator’s temptation of not actually transferring all the know-how. While these papers and ours share the prediction that the use of royalty is positively correlated with the amount of know-how involved in technology transfer, there are subtle differences. They implicitly assume that a technology can be transferred without transferring all necessary know-how; our paper complements theirs by assuming that technology know-how once transferred, cannot be withdrawn even after the contractual relationship ends.

In a related paper, Saracho (2011) independently develops a general intertemporal model to examine the dynamic considerations in licensing. Both her paper and ours recognize the irreversibility nature of technology licensing and the commitment problem faced by a patent holder in a dynamic setting. The combination of these two features leads both to find that royalty is sometimes preferable. Saracho also makes an important observation about welfare implications: a patent holder’s inability to commit to not issue additional licenses may lower both social welfare and consumer surplus. Despite many similarities, there are two key differences between Saracho’s paper and ours. First, the sources of the commitment problem are different. In her paper, the patent holder is unable to commit to not selling additional licenses (on the same patent) in future periods,\(^{11}\) but the commitment problem in our model is the patent holder’s inability to contract on future R&D and new innovations that might make the original patent obsolete. Second, the degree of irreversibility in technology licensing differs. In her model, technology transfer is completely irreversible so the duration of contracts is not a concern (as all contracts are effectively long-term). By allowing for partial irreversibility, our model is able to generate variations on the duration of contracts.

The remainder of the paper is organized as follows: Section 1 presents the environment and assumptions of our model and derives some preliminary results. Section 2 analyzes the model under Bertrand competition. We compare different licensing schemes and obtain our main result that royalties have a longer duration than fixed-fee licenses. Section 3 generalizes the main result by relaxing assumptions on the nature of downstream competition. Section 4 concludes. Any formal proofs omitted from the main text are contained in the appendix.

1. The model setup

Our model is an extension to the one-innovation licensing game introduced by Kamien and Tauman (1986) (henceforth, KT86). The industry consists of \(n\geq2\) identical firms all producing the same good with a linear cost function, \(C(q)=cq\), where \(q\) is the quantity produced and \(c>0\) is the constant marginal cost of production. In addition to the \(n\) firms, an innovator seeks to license a cost-reducing innovation to all or some of the \(n\) firms so as to maximize her licensing revenue.

In contrast to the one-innovation game, which ends after licensing and production take place, we assume that the innovator continues to innovate after licensing her initial innovation. More specifically, the game in our model lasts two periods. At the beginning of period 1, the innovator owns a patent on a cost-reducing innovation (innovation 1), which reduces the marginal cost of production from \(c_0\) to \(c_1\). The patent is valid for both periods. At the immediate beginning of period 2 (or during the interval between periods 1 and 2), the innovator can make a further R&D investment in the amount of \(I\). If the R&D effort is successful, then it will generate a second innovation (innovation 2) that reduces the cost of production further to \(c_2\). Hence \(c_2<c_1<c_0\). The probability of success for innovation 2 is \(p\), increasing in \(I\). For ease of exposition, we assume that \(Pr(I)=2\sqrt{pI}\), where \(0\leq p\leq 2[\text{Pr}(c_2)]^{-1}.\(^{12}\) The innovator stops R&D activities after two periods and the game ends. Fig. 1 shows the timeline of the game.

Both period 1, the demand function of the industry is given by \(Q=\text{Di}(p)\), where \(Q\) is the total production level, \(p\) is the price and \(D>0\). Denoting by \(pM(c_1)\) the monopoly price in the downstream market when the marginal cost is \(c\), we assume that innovation 1 is drastic, i.e., \(pM(c_1)>c_0\), but innovation 2 can be drastic or non-drastic (relative to innovation 1), i.e., \(pM(c_2)\) can be above or below \(c_1\). The assumption of a drastic initial innovation is not essential to our results, but significantly simplifies exposition. We show in Section 2.3.1 and Appendix B that our qualitative results remain the same if innovation 1 is non-drastic.

In order to model technology leakage, we assume that if a licensee of innovation 1 does not license any innovation in period 2, then its cost of production in period 2 is \(c^*=c_0\). According to this assumption, a licensee can retain some fraction of the cost saving from the initial technology transfer, even if it does not license that technology in period 2.\(^{13}\) If \(c^*=c_0\), then the technology transfer is completely irreversible, corresponding to the case studied in Saracho (2011), whereas \(c^*=c_0\) corresponds to the case of no technology leakage. For conciseness, throughout the paper, we call the magnitude of cost saving from the technology leakage the degree of leakage and the number of firms that receive the leakage the spread of leakage.

Our main interest is in the innovator’s choice of period 1 licensing contracts. We assume that \(I\) is not observable to outside parties; hence it cannot be contracted upon.\(^{14}\) While it is possible to write a contract that is contingent upon the outcome of innovation 2, it costs \(\varphi\) to write such a contract.\(^{15}\) Since we do not explicitly model the transaction cost \(\varphi\) and its impact on the choice of contracts is rather obvious, we do not consider contingent contracts in our model.\(^{12}\) Our model becomes the standard one-innovation licensing game if \(p=0\). The second inequity guarantees that the optional amount of investment will be an interior solution. Our qualitative results will not change if we use a more general functional form for \(Pr(I)\), as long as it satisfies \(Pr(0)=0\) and \(Pr(\cdot)>0\).\(^{16}\)

\(^{12}\) Our model becomes the standard one-innovation licensing game if \(p=0\). The second inequity guarantees that the optional amount of investment will be an interior solution. Our qualitative results will not change if we use a more general functional form for \(Pr(I)\), as long as it satisfies \(Pr(0)=0\) and \(Pr(\cdot)>0\).\(^{16}\)

\(^{10}\) Choi (2002) develops an incomplete contract model to consider sequential innovations by a potential licensee and shows that royalties (as well as grant-back clauses) can be used to overcome an innovator’s reluctance of licensing core technologies to a rival in the innovation market.

\(^{11}\) The author acknowledges that the applicability of this assumption may be limited. A typical licensing contract specifies the number of licenses on the same patent for the duration of the contract, e.g., an exclusive contract specifies the period of exclusivity and precludes the patent holder from issuing additional licenses during that period.

\(^{13}\) According to Schwartz and Watson (2004), “Examples of ex ante contracting costs are (i) the effort and time that parties spend determining possible contingencies, calculating optimal terms, and drafting language; (ii) payments to third parties, such as attorneys, who facilitate this activity; and (iii) technological investments that make messages or state verification possible. Examples of ex post costs are (i) expenditures of time and money that the parties make during litigation, and (ii) risk premiums that risk-averse parties forfeit when enforcement has a random element.”
assume that ϕ is so large that a contingent contract is never optimal.16 Therefore, we only consider licenses that specify the payment scheme and the duration of the contract.

As in KT86, the innovator issues licenses to k ≤ n firms either by a fixed-fee or by a royalty.17 Under a fixed-fee scheme, denoted by F(f), the innovator sets a fixed fee f and makes a take-it-or-leave-it offer to every firm. Any firm that accepts the offer pays the fee and becomes a licensee. The number of licensees is a function of f, i.e., k = k(f). Under a royalty scheme, denoted by R(r), the innovator sets a royalty of r per unit output and awards a license to every firm that commits to paying it. The number of licensees is a function of r, i.e., k = k(r). A licensee’s right to use innovation 1 and either the royalty payments or the exclusivity (i.e., k = n) for fixed-fee contracts can last either one period (short-term) or two periods (long-term).18 Thus, there are in total four possible types of licensing contracts in period 1: short-term fixed-fee S(f), long-term fixed-fee LF(f), short-term royalty SR(r), and long-term royalty LR(r).

The licensing subgame consists of three stages. In the first stage, depending on the licensing scheme, the innovator announces either f or r as well as the duration. In the second stage, the firms simultaneously and independently decide whether or not to purchase a license; their decisions determine the set of licensees. In the third stage, the set of licensees becomes common knowledge and all firms, with and without licenses, engage in downstream competition.

If new licenses are issued in period 2 (e.g., upon expirations of short-term contracts), then the same sequence of licensing subgame takes place, except that new licenses last only one period. Therefore, the innovator can choose between F(f) and R(r) for period 2 licensing. To break ties, we assume that the innovator chooses F(f) if she is indifferent between the two.19 All fees and rates are nonnegative. All individuals maximize their expected total profits, with a common discount factor of δ. Our solution concept is the subgame perfect equilibrium.

Here is a collection of notations used throughout the paper. Let \( \Pi^M(c) \) and \( \Pi^N(c) \) be the single-period monopoly price and gross profits, respectively, in the downstream market when the marginal cost is c, that is, \( \Pi^M(c) = \arg\max_p (p - c)D(p) \) and \( \Pi^N(c) = \max_p (p - c)D(p) \). We denote by \( \Pi^S(f,t) \) the innovator’s gross licensing revenue at time t from innovation \( i \), where (licensing scheme) \( S \) is either (SF(f), LF(f), SR(r), LR(r)). The representation of the type of period 1 licensing contract and \( \Pi^S(f,t) \) is \( \Pi^S(f,t) = \max\{1 - \rho \Pi^{IE}(f,t) + \delta \Pi^{II}(f,t) - I \} \).

1.1. Preliminary results

Before we solve for the innovator’s choice of period 1 licensing contracts, we derive some preliminary results on the period 2 investment decision and on two benchmark cases, one involving an integrated innovator and the other involving zero technology leakage.

1.1.1. The investment decision and the value of investment

We first solve the innovator’s problem at the investment stage in period 2. Let \( \Delta = I_e^2 - I_e^1 \).

Lemma 1. (i) \( I_e^1 - \rho \Delta^2 \), then SF(f) and the innovator’s expected period 2 profits are \( I_e^1 + \rho \Delta^2 \); (ii) The expected period 2 profits increases in both \( I_e^1 \) and \( I_e^2 \).

Lemma 1 shows that the innovator’s incentive to invest in period 2 is essentially determined by \( \Delta \), the difference in period 2 licensing revenues from the two outcomes. Hence, \( \Delta \) can serve as a convenient indicator of a licensing scheme’s optimality, which we will use repeatedly in this paper.

1.1.2. A vertically integrated innovator

In a first-best scenario, the innovator is vertically integrated with a downstream firm and sells the final output by herself. There is neither a commitment problem nor technology leakage. Since \( p^M(c_2) < p^N(c_1) < \phi \), the innovator can monopolize the industry in both periods. Therefore, her incentive to innovate is perfectly aligned with the gain in industry profits, which is \( \Pi^M(c_2) - \Pi^M(c_1) \). By Lemma 1, we can immediately conclude that

\[
\Pi^V = (1 + \delta)\Pi^M(c_1) + \delta \phi \Delta^2, \quad \text{where} \quad \Delta = \Pi^M(c_1) - \Pi^M(c_2).
\]

Eq. (1) gives us the upper bound of licensing revenue that the innovator can obtain, which serves as a useful benchmark in comparing different licensing schemes. It also provides a necessary condition for any licensing scheme to replicate the integrated outcome: \( \Delta = I_e^2 - I_e^1 \) must equal \( \Pi^M(c_2) - \Pi^M(c_1) \). This is true because the optimal level of investment is proportional to \( \Delta^2 \), so the period 2 investment must be inefficient if \( \Delta \) deviates from \( \Pi^M(c_2) - \Pi^M(c_1) \).

1.1.3. Optimal contracts without leakage

Last, to see why technology leakage is crucial to our model, we establish another benchmark result.

Proposition 1. Let \( f^* = c_0 \) then SF(f) with \( f^* = \Pi^M(c_1) \) in period 1 and F(f) with \( f^* = \Pi^M(c_1) \) in period 2, where i denotes the latest innovation, replicate the integrated outcome.

Proposition 1 is a trivial extension of the KT86 result. It shows that, in the absence of technology leakage, the innovator’s inability to
commit to future investments poses no time-consistency problem. Through the use of period-by-period contracting, the innovator can reduce a two-period game into two one-period games, for which the standard fixed-fee licensing scheme remains optimal and the ability to commit is indifferent. It is also easy to see that the above result holds for any $c' \geq p(c_1)$, where leakage is so small that it does not have any effect on downstream competition.

2. A model of Bertrand competition

In this section, we solve the model by assuming that firms compete a la Bertrand. Under Bertrand competition, at most one firm can earn positive profits and therefore licenses can only be profitably sold to a single firm every period. This means that any fixed-fee licenses must be exclusive. Because of this simplification, we can most clearly see the intuition behind our results. We first derive some results on the impact of technology leakage; based on these results, we then look for the optimal contract by solving the licensing game for each scheme and comparing their profitability; last, we discuss our results under alternative assumptions and consider three extensions in detail.

2.1. The period 2 revenue loss from technology leakage

Due to technology leakage, the innovator obtains a smaller licensing revenue in period 2 than she would if the technology transfer were exclusive. Because of this simplification, we reduce a two-period game into two one-period games, for which the optimal contract by solving the licensing game for each scheme and comparing their profitability; last, we discuss our results under alternative assumptions and consider three extensions in detail.

2.2. Optimal contracts with leakage

According to Lemma 2, if $c' \geq p(c_1)$, then the loss from leakage is zero regardless of whether innovation 2 is successful (since $\pi^M(c_1, c') = \pi^M(c_1)$) and therefore Proposition 1 applies. Below we study the case of our main focus, where $c' < p(c_1)$ such that the loss from leakage is potentially positive.

2.2.1. Fixed-fee licensing

We first consider SF licensing. In contrast to Proposition 1, Lemma 3 shows that SF licensing fails to replicate the integrated outcome in the presence of technology leakage.

Lemma 3. If SF is maximized at $f^* = \pi^M(c_1)$, then $k(f^*) = 1$ in period 2, the innovator sells innovation i to a firm other than the original licensee for a fee of $\pi^M(c_1, c')$, where i denotes the latest innovation available; $f^2 = \pi^M(c_1, c') = \delta \pi^M(c_2, c') + \delta \pi^M(c_2, c') + (\pi^M(c_2, c') - \pi^M(c_1, c'))^2 + \delta \pi^M(c_1, c')$.

Proof of Lemma 3. From the proof of Lemma 2, we know that $I_2 = \pi^M(c_1, c')$, and that a firm other than the original licensee acquires the period 2 license. Hence, $\Delta = \pi^M(c_2, c') - \pi^M(c_1, c')$ and $I_2 = \pi^M(c_1, c') + \rho (\pi^M(c_2, c') - \pi^M(c_1, c'))$. Since the original licensee does not earn positive profits in period 2, it is willing to pay $f^* = \pi^M(c_1)$ for the period 1 license. Therefore, $f^1 = f^* + \delta I_2 = \pi^M(c_1) + \delta \pi^M(c_1, c') + \delta \pi^M(c_2, c') - \pi^M(c_1, c')$. Since $\pi^M(c_1, c') = -\pi^M(c_1)$ and $\pi^M(c_2, c') = -\pi^M(c_2, c')$, by Lemma 1, we have $f^1 = f^1$.

There are two sources of loss in the innovator’s profits. First, there is a direct loss due to technology leakage: in period 2, the innovator is unable to extract the full monopoly profits because of competition between the original licensee and the new one. Second, technology leakage causes the innovator to over-invest in order to minimize the loss from leakage. It can be most clearly seen by examining $\Delta = I_2^1 - I_2^1$, which equals $\pi^M(c_2, c') - \pi^M(c_1, c')$. Thus, as long as the losses from leakage are not identical under different innovation outcomes, i.e., $\pi^M(c_1) - \pi^M(c_2, c') \neq \pi^M(c_1) - \pi^M(c_1, c')$, the innovator’s incentive to invest will deviate from the optimal level and lead to her profit loss. As will be shown later in Section 2.3.2, while the first loss can potentially be avoided by giving the original licensee the Right of First Refusal or via the use of auction licensing, the second loss cannot and is therefore the fundamental reason why fixed-fee licensing is not optimal.

Lemma 4. If SF is maximized at $f^* = \pi^M(c_1)$, then $k(f^*) = 1$ in period 2, no licensing takes place if innovation 2 fails, otherwise the innovator sells innovation 2 to a firm other than the original licensee for a fee of $\pi^M(c_1, c_2); f^2 = (1 + \delta \pi^M(c_1, c_2) + \delta \pi^M(c_2, c_2)) \leq f^2, where the equality holds only if $\rho = 0$.

Proof of Lemma 4. By definition, $I_2^1 = 0$. From the proof of Lemma 2, we know that $I_2^2 = \pi^M(c_2, c_2)$ and that a firm other than the original licensee licenses innovation 2. The original licensee earns positive profits in period 2 only if innovation 2 fails. Hence, $\Delta = \pi^M(c_2, c_1) + \delta \pi^M(c_1, c_2)$ and $I_1 = \pi^M(c_1) + \delta (1 - 2 \rho) \pi^M(c_1, c)$. Therefore, $f^2 = (1 + \delta \pi^M(c_1, c_2) + \delta \pi^M(c_2, c_2)) \leq f^2, where the equality holds only if $\rho = 0$.

While LF licensing protects the innovator against technology leakage, it aggravates the innovator’s commitment problem: if an innovation is sold once and for all, then the licensee becomes the owner, so the innovator has the greatest incentive to invest in new technologies that render the innovation obsolete.20 Foreseeing the innovator’s time-consistency problem, firms bid less for the initial license, lowering the innovator’s total profits.

---

20 In our model, a follow-up clause that gives a licensee the rights to all future improvements upon the licensed technology in a long-term fixed-fee contract (van Dijk, 2000) does not solve the time-consistency problem, for it leads to under-investment. In the extreme case in which the licensee is entitled to future improvements exclusively, then the innovator will not receive any additional licensing revenue in period 2 and therefore will not make any investment. More commonly used is a Right of First Refusal clause, discussed in Section 2.3.2.
2.2.2. Royalty licensing

**Lemma 5.** \( \Pi^{LR(\cdot)} \) is maximized at \( r = n^M(\cdot) - c_i \), where \( k(r^*) = n; \) in period 2, the innovator sells innovation i for a fee of \( n^i_2(\cdot, c') \) to one of the n firms, where i denotes the latest innovation available; \( \Pi^{LR} = n^M(\cdot) + \delta n^M(\cdot, c') + \rho n^i_2(\cdot, c') - n^i_1(\cdot, c') \), \( \delta, r, \) and \( \rho \) are the royalty rate, fixed fee, and market price in period 2.

**Proof of Lemma 5.** Under Bertrand, only the lowest two costs matter, hence the loss from leakage does not depend on the spread of leakage. Therefore, a more appropriate interpretation of Proposition 2 is that firms licensed in period 2 by the same royalty scheme, and hence the loss from leakage does not depend on the spread of leakage.

It should be noted that the above \( LR \) contract is also renegotiation-proof. Suppose that the innovator can modify licensing contracts with individual licensees in period 2 even when innovation 2 fails, then it may be optimal to move from the royalty scheme to fixed-fee licensing in period 2. But this possibility changes neither the period 1 royalty nor the period 2 licensing revenues, since \( H_2 \) remains \( n^M(\cdot) \) when a fixed-fee license is sold.

**Proposition 2.** Under Bertrand competition, if \( c' < n^M(\cdot) \), then (i) \( LR \) licensing is optimal; (ii) \( \Pi^{LR} - \Pi^F \) decreases with \( c' \) and goes to 0 if \( c' \rightarrow 0 \); (iii) \( \Pi^{LR} - \Pi^F \) increases with \( \mu \) and goes to 0 if \( \mu \rightarrow 0 \).

It should be noted that we do not intend to interpret Proposition 2 as implying that a LR contract should always be used in practice. This is because royalty licensing has some downsides that are not modeled in this paper but quite obvious. For example, it has a potential double-marginalization problem (KT86); and it may require costly monitoring of a licensee’s output (Katz and Shapiro, 1985, 1986). Once these downsides are taken into account, LR licensing is not always optimal. Therefore, a more appropriate interpretation of Proposition 2 is that it provides two testable hypotheses: first, it suggests that licensing contracts based on royalty have a longer duration than fixed-fee licenses; second, since a greater degree of leakage leads to a smaller c', it suggests that royalty-based contracts are more likely to be used in industries where innovations are frequent and intellectual property protection is weak. As mentioned in the introduction, our first prediction is broadly consistent with the stylized empirical facts presented by Macho-Stadler et al. (1996) and Mendi (2005). Additional empirical research can further test the validity of our second prediction.

We end our analysis of the basic model by briefly discussing how our results are affected by a second implicit assumptions on period 2 licensing. First, it is assumed that a firm that does not produce in period 1 can still license in period 2. If this assumption is not satisfied, then any innovation, new or old, can only be licensed to the original licensee in period 2, rendering all contracts effectively long-term and causing the innovator to under-invest in fixed-fee contracts.

The underlying mechanism is similar to a follow-up clause that gives a licensee the rights to all future improvements discussed earlier (footnote 20). Second, we assume that the innovator cannot commit to a period 2 payment scheme in period 1. It is consistent with our key assumption that contracts contingent on the innovation outcome are too costly to write. Real world contracts also rarely specify future payment schemes; in fact, changes of payment schemes are not uncommon. Most importantly, the proof of Lemma 2 shows that \( F(f) \) and \( R(r) \) in period 2 licensing result in identical payoffs for all players. Therefore, the above results will not change even if the innovator has the ability to commit to either scheme.

3. Extensions

In this section, we consider extensions of the basic model to check robustness of the results.

3.1. Non-italic innovations

The above analysis assumes drastic innovations in period 1, but the main result is unchanged if innovation 1 is non-italic. To see this, we only need to show that \( LR \) licensing replicates the integrated outcome, while fixed-fee licensing does not. First, we note that for an integrated innovator, \( I_1 = I_2 = n^i(\cdot, c_0) \) and \( I_2 = n^i(\cdot, c_2) \). Now consider a \( LR(r) \) contract that stipulates \( r = c_0 - c_1 \) for both periods. A licensee’s effective cost remains \( c_0 = c_1 + r \), which also becomes the period 1 market price. The innovator’s licensing revenue is thus \( I_1 = I_2 = n^i(\cdot, c_0) \), and \( I_2 = I^F(\cdot, c^0) \), replicating the integrated outcome.

It should be noted that the above \( LR \) contract is also renegotiation-proof. Suppose that the innovator can modify licensing contracts with individual licensees in period 2 even when innovation 2 fails, then it may be optimal to move from the royalty scheme to fixed-fee licensing in period 2. But this possibility changes neither the period 1 royalty nor the period 2 licensing revenues, since \( I_2 \) remains \( n^M(\cdot) \) when a fixed-fee license is sold.

**Proposition 2.** Under Bertrand competition, if \( c' < n^M(\cdot) \), then (i) \( LR \) licensing is optimal; (ii) \( \Pi^{LR} - \Pi^F \) decreases with \( c' \) and goes to 0 if \( c' \rightarrow 0 \); (iii) \( \Pi^{LR} - \Pi^F \) increases with \( \mu \) and goes to 0 if \( \mu \rightarrow 0 \).

It should be noted that we do not intend to interpret Proposition 2 as implying that a LR contract should always be used in practice. This is because royalty licensing has some downsides that are not modeled in this paper but quite obvious. For example, it has a potential double-marginalization problem (KT86); and it may require costly monitoring of a licensee’s output (Katz and Shapiro, 1985, 1986). Once these downsides are taken into account, LR licensing is not always optimal. Therefore, a more appropriate interpretation of Proposition 2 is that it provides two testable hypotheses: first, it suggests that licensing contracts based on royalty have a longer duration than fixed-fee licenses; second, since a greater degree of leakage leads to a smaller c’, it suggests that royalty-based contracts are more likely to be used in industries where innovations are frequent and intellectual property protection is weak. As mentioned in the introduction, our first prediction is broadly consistent with the stylized empirical facts presented by Macho-Stadler et al. (1996) and Mendi (2005). Additional empirical research can further test the validity of our second prediction.

We end our analysis of the basic model by briefly discussing how our results are affected by a second implicit assumptions on period 2 licensing. First, it is assumed that a firm that does not produce in period 1 can still license in period 2. If this assumption is not satisfied, then any innovation, new or old, can only be licensed to the original licensee in period 2, rendering all contracts effectively long-term and causing the innovator to under-invest in fixed-fee contracts.

The underlying mechanism is similar to a follow-up clause that gives a licensee the rights to all future improvements discussed earlier (footnote 20). Second, we assume that the innovator cannot commit to a period 2 payment scheme in period 1. It is consistent with our key assumption that contracts contingent on the innovation outcome are too costly to write. Real world contracts also rarely specify future payment schemes; in fact, changes of payment schemes are not uncommon. Most importantly, the proof of Lemma 2 shows that \( F(f) \) and \( R(r) \) in period 2 licensing result in identical payoffs for all players. Therefore, the above results will not change even if the innovator has the ability to commit to either scheme.

3.2. Right of first refusal in fixed-fee licensing

In the basic model, there is a direct loss from technology leakage under fixed-fee licensing. It arises because leakage causes the original licensee to compete with a new licensee in period 2, lowering both the market price and industry profits. Moreover, since the original licensee gains nothing from receiving technology leakage, the innovator is unable to extract any rents from the original licensee for the leakage.

For example, Apple Inc. and Microsoft have both recently changed their payment schemes for some of their licensing programs. “Apple Changes iPod License Fee”, David Richards, Smarthouse, October 5, 2006; “Microsoft Concedes in European Antitrust Case”, Steve Lohr and Kevin J. O’Brien, New York Times, October 22, 2007.

21 Muto (1993) studies a Bertrand-type duopoly with differentiated goods in one-period licensing model. He finds that royalty is superior to fixed-fee for small innovations, but not for large innovations.
even though the leakage presumably makes the initial license more valuable. This is unsatisfactory from the innovator’s perspective. It is also unsatisfactory from the modeling perspective, because it negatively affects fixed-fee licensing but not royalty licensing, and one may wonder whether it is this feature that drives our results.

We show in the following that, while there is a potential remedy for the above problem, it is still insufficient to restore the optimality of fixed-fee licensing. More specifically, we assume that the innovator can offer a licensee the Right of First Refusal (ROFR) for future licenses.24 The ROFR allows the original licensee to match what other firms are willing to pay and capture rents from technology leakage. Since the innovator can extract the rents through a higher license fee, offering the ROFR increases the value of the initial license as well as the profitability of fixed-fee licensing. Nevertheless, we find that the distortion in the innovator’s incentive to invest due to leakage remains intact and prevents fixed-fee licensing from replicating the integrated outcome. Let \(\Pi_{ROFR}^{1}\) be the innovator’s total discounted profits when she offers ROFR to period 1 licensees.

Lemma 7. \(\Pi_{ROFR}^{1}\) is maximized at \(f^* = n^{\Pi}(c_1) + \delta(1 - 2\delta)c_1) + 2\beta\Delta[n^{\Pi}(c_2) - n^{\Pi}(c_1, c_2)]\), where \(\Delta = n^{\Pi}(c_2, c_1) - n^{\Pi}(c_1, c')\) and \(k(f^*) = 1\); in period 2, the original licensee exercises the ROFR to exclusively license the latest available innovation for a fee of \(n^{\Pi}(c_1, c')\). \(\Pi_{ROFR}^{2} = \Pi_{ROFR}^{1} + \delta \Pi_{ROFR}^{1} \cdot (n^{\Pi}(c_1, c') - n^{\Pi}(c_2, c_1)) - n^{\Pi}(c_2) - n^{\Pi}(c_2, c_1))/2 \leq \Pi_{ROFR}^{1}\).

By studying the use of the ROFR in fixed-fee licensing, we gain additional insights into the model. With the inclusion of the ROFR, the innovator’s period 2 revenue loss from technology leakage no longer translates into a loss in total licensing revenue: after all, expecting leakage, potential licensees are willing to pay more for the initial license. However, the differing degree of revenue loss from leakage under different innovation outcomes and the innovator’s ensuing attempt to minimize the loss from leakage causes a distortion in her incentive to invest in future innovations and lowers a licensee’s willingness to pay for the initial innovation. An analogous result holds for LF licensing, and accordingly we obtain Proposition 3.

Lemma 8. \(\Pi_{ROFR}^{1}\) is maximized at \(f^* = \delta \Pi_{ROFR}^{1} + 2\beta\Delta[n^{\Pi}(c_2) - n^{\Pi}(c_1, c_2)]\), where \(\Delta = n^{\Pi}(c_1, c_2) - n^{\Pi}(c_1, c')\) and \(k(f^*) = 1\); in period 2, no licensing takes place if innovation 2 fails, otherwise the original licensee exercises the ROFR to obtain innovation 2 for a fee of \(n^{\Pi}(c_2, c_1)\).

Proposition 3. Offering the ROFR in fixed-fee licensing increases its profitability, but Proposition 2 still holds.

In the working paper version of this article, we also find that allowing the innovator to auction licenses in period 2 produces the same outcome as fixed-fee licensing that contains the ROFR.25 The intuition is easy to understand: losing the license in an auction not only deprives the original licensee of the right to a superior technology, but also gives another firm the technology advantage; thus the original licensee has a strong incentive to match other firms’ bids and win the license in order to continue to monopolize the market, but this is equivalent to exercising the ROFR.26

23.3. Installment payments in LF licensing

Here, we have assumed that all fees are paid upfront in fixed-fee contracts. In a long-term contract, upfront payment means the complete transfer of technology ownership, hence the innovator has the strongest incentive to invest in new innovations. A natural question to ask is whether an installment payment plan, in which the second installment is paid only if a licensee wishes to continue the contract in period 2, can dampen the innovator’s excessive incentive to invest and therefore solve her commitment problem. Here we address this question.

We further enlarge the contracting space of fixed-fee licensing by allowing the innovator to specify a period 2 payment, \(f_2\), in a long-term contract.27 Denote it by \(LP[f_1, f_2]\). Following Mendi (2005), we assume that a licensee is allowed to terminate a LF contract by not paying \(f_2\) before period 2 licensing, if any, takes place; in the event of an early termination, the licensee no longer has the rights to innovation 1 and the innovator issues new licenses. Since fixed-fee licensing is more attractive when the ROFR is used, we assume that it is also included in the contract.

Lemma 9. \(LP[f_1, f_2]\) is maximized at \(f^* = n^{\Pi}(c_1) + \delta(1 - 2\beta\Delta c_1, c_1) + 2\beta\Delta c_1, c_2)c_1) - n^{\Pi}(c_1, c_2)\), and \(f_2 = n^{\Pi}(c_1, c_2)\), where \(\Delta = n^{\Pi}(c_1, c_2) - n^{\Pi}(c_1, c')\) and \(k(f^*) = 1\). The period 1 license is terminated in period 2 regardless of the innovation outcome, replicating the outcome of SF licensing.

Lemma 9 shows why giving a licensee the option to terminate early mitigates but does not eliminate the innovator’s excessive incentive to invest in new technologies. Only a sufficiently high \(f_2\) can discourage the innovator from over-investing, but it also induces the original licensee to terminate the contract regardless of the innovation outcome. As a result, LF licensing is, at best, subject to the same distortion as a SF contract. It should also be noted that allowing early termination does not change our result on LR licensing either, since it does not add value to a LR contract hence will not be part of the contract.

Proposition 4. Offering installment payments in LF licensing increases its profitability, but Proposition 2 still holds.

3. A more general model of downstream competition

In the previous section, we show that, under Bertrand competition, royalties on average have a longer duration than fixed-fee contracts. Here we generalize this result by relaxing assumptions on the nature of downstream competition. We do so by making two observations: first, SF licensing is sometimes optimal; second, SR licensing is weakly dominated by SF licensing. The first observation is quite obvious, since SF licensing always replicates the integrated outcome in the absence of technology leakage. Therefore, the following analysis focuses on the sub-optimality of SR licensing.

In order to derive our result, we impose only the following restriction on the structure of the downstream competition. Denote by \(\eta_i(\bar{c})\) the gross profit for each, \(i = 2, \ldots, n\), and \(\bar{c} = \{c_1, C_2, \ldots, C_n\}\).

Assumption 1. The profit of a firm is weakly increasing in any competitor’s cost, i.e., \(\eta_i(\bar{c}) / \partial \bar{c}_i \geq 0\), for all \(j \neq i\).

This assumption is fairly weak, and encompasses a wide range of downstream oligopoly behavior, including both Bertrand competition and Cournot competition (Katz and Shapiro, 1986).

Proposition 5. SR licensing cannot be more profitable than SF licensing.

It is not difficult to see the intuition behind Proposition 5: compared with SF licensing, SR licensing generates a smaller period 1 licensing

---

24 Right of First Refusal (ROFR) is a contractual right that gives its holder the option to purchase a property before the owner is entitled to sell the property to a third party on exact or approximate transaction terms (Engling, 1996).

25 Whether to allow the innovator to auction licenses in period 1, in addition to fixed-fee licensing, does not make any difference under Bertrand competition.

26 The property that ROFR can replicate an auction outcome has been noted by, among others, Riley and Samuelson (1981) and Choi (2009).

27 It should be noted that this extra degree of freedom only makes fixed-fee licensing, but not royalty, more attractive. It is also easy to see that the upfront payment case corresponds to the special case of \(f_2 = 0\).

28 The underlying assumption is that the innovator can commit not to renegotiate fees. It has already been shown in Lemma 6 that a LR contract is renegotiation-proof so allowing for renegotiation does not change its optimality. For LF licensing, losing the ability to commit can only make the innovator worse off, strengthening our result.
revenue and leads to more widespread technology leakage, which in turn lowers the licensing revenues in period 2. From Proposition 5, we can once again conclude that licensing contracts based on royalty on average have a longer duration than fixed-fee contracts. It should be noted that, Proposition 5 is proved under the assumption that innovation 1 is drastic. Without this assumption, it is difficult to determine the payoff of a nonlicensee who has a cost of \( c_0 \). As a result, we will not be able to prove that \( I_{\Pi}^{\text{long}}(F_2) > I_{\Pi}^{\text{short}}(F_2) \). However, if we give the innovator slightly more freedom in period 2 licensing, namely, the ability to offer fixed-fee licensing and royalty licensing simultaneously, then not only can we prove the above result for the case of non-drastic innovation 1, but also in a much simpler and more intuitive way, as shown in Appendix B.

3.1. Discussion

Proposition 5 is established when the licensing policies are confined to either pure fixed fees or pure royalties. Here we discuss what happens if the innovator can use more general licensing schemes, such as ad valorem royalties, two-part tariffs and hybrid licenses.29

3.1.1. Ad valorem royalties

While most of the technology licensing literature considers per-unit royalties, ad valorem royalties are important in practice, particularly in hi-tech industries. According to Bousquet et al. (1998), over 90% of the royalty contracts offered by CNET (the research center of France Telecom) specifies an ad valorem scheme. Allowing ad valorem royalties does not change our results.

Under Bertrand competition, since a per-unit royalty replicates the integrated outcome (Lemma 6), there is no advantage from using an ad valorem royalty. Even under the more general form of competition considered in this section, the relative merits between royalty and fixed-fee contracts remain the same. To see why, recall the two key results in our model: first, a long-term royalty may be optimal and thus allowing ad valorem royalties can only strengthen this result; second, our result that a short-term royalty cannot be more profitable than short-term fixed-fee licensing continues to hold even if ad valorem royalties are used. Note that the proof of Proposition 5 relies on two arguments: \( I_{\Pi}^{\text{long}}(F_2) > I_{\Pi}^{\text{short}}(F_2) \), and \( I_{\Pi}^{\text{long}}(F_2) < I_{\Pi}^{\text{short}}(F_2) \). The first follows from the observation that the use of royalty leads to more widespread technology leakage and the second follows from the observation that royalty cannot be more profitable than fixed-fee licensing in a standard (complete information) one-period model. Both observations remain true even if ad valorem royalties are used.

3.1.2. Two-part tariffs

Next we discuss what happens if the innovator can use two-part tariffs, i.e., a combination of fixed fees and royalties, to license her innovations. This question is especially relevant in light of the recent finding by Sen and Tauman (2007) that two-part tariffs may be optimal even in an one-period setting. Because of the additional degrees of freedom afforded by a two-part tariff, it is exceedingly difficult to obtain a complete solution.28 Therefore, we focus on our main result that royalty-based contracts have a longer duration than fixed-fee licenses and show that it remains valid.

In our basic model of Bertrand competition, a long-term royalty replicates the integrated outcome so it has to be optimal even after the inclusion of two-part tariffs. In the more general model, consider a two-part tariff implemented via an auction plus royalty policy introduced by Sen and Tauman (2007), where the innovator first announces the level of royalty then auctions off one or more licenses for an upfront payment. In a long-term contract, if \( r = 0 \), then the innovator receives no more payment unless innovation 2 succeeds. Such a contract is thus subject to the same over-investment problem discussed earlier, but the innovator’s incentive to over-invest can be dampened by royalty income in period 2. This means that the payoff of the innovator has to be increasing at \( r = 0 \) and that long-term fixed-fee licensing cannot be optimal, so our main result does not change.

3.1.3. Hybrid licenses

Although our analysis focuses on cases where the transfer of technology is inseparable from the transfer of know-how, here we discuss what happens if it is possible to separate the two. We find that it is generally not optimal to withhold know-how in order to avoid leakage and transfer in period 1 only the part of the technology that can be reversed.31 To see why, note that the cost saving due to the part of technology transfer that is reversible is \( c - c_1 \). Upon receiving only this part, a licensee’s cost is \( c = c_0 - (c - c_1) = c_1 + (c_0 - c) \). This means that the cost-saving technology is not fully utilized and industry profits in period 1 are not maximized. The innovator would be better off by using a hybrid license, which contains separate contracts that cover different aspects of the innovation, e.g., patented technology vs. know-how, and accordingly allocate royalties to each of the rights (Jorda, 2007). For the hybrid license, we view our analysis as relevant to the contract covering the portion of the transfer that is not entirely reversible.

4. Conclusion

In this paper, we have extended the literature on technology licensing by adding to the literature on the duration of contracts and a model of technology leakage. We show in this framework that it may be optimal for the innovator to limit the length of fixed-fee licenses to less than that of the underlying patent. We find that long-term, but not short-term, royalty contracts can be optimal, even under complete information and risk neutrality, because they allow the innovator to resolve a time-consistency problem caused by the interplay between R&D investment and technology leakage. This implies that royalty contracts are on average of longer duration than fixed-fee contracts, a result generally consistent with empirical findings.

It has long been recognized that the market of technology licensing is imperfect (e.g., Caves et al., 1983). While others in the literature of technology licensing have dwelt on incomplete information, moral hazard, risk and uncertainty, our paper focuses on the irreversibility of technology transfer and the incentive to engage in future innovations. In particular, we formally model technology leakage and find it an important determinant of an innovator’s choice of licensing contracts. Nonetheless, it remains an under-explored topic, which we believe will lead to fruitful research.

The model presented here has made strong assumptions that can be potentially relaxed. First, one may examine whether our results extend beyond the artificial two-period model. Second, we assume that the R&D investment affects only the probability of success; an alternative is to allow it to affect the magnitude of innovation, i.e., the size of cost-reduction. Last, we have contented ourselves with a

---

29 We are grateful to an anonymous referee for suggesting the analyses in this section.
30 In another version of the paper (available upon request), we solve for optimal two-part tariffs by limiting our attention to only exclusive licenses in both periods. Our qualitative results remain the same.
31 Macho-Stadler et al. (1996) find that an innovator may choose not to transfer know-how when fixed-fee contracts are used. There are two reasons why our model generates a different prediction: first, in their model, there is an explicit cost of transferring know-how so an opportunistic licensor will try to minimize the amount of know-how transferred, but in our model transferring know-how itself is costless so any withholding of the transfer entails a direct efficiency loss. A more subtle difference between the two models is the assumption on timing. In their model, contracts are signed before licensees observe the magnitude of cost-saving (which is affected by the amount of know-how transferred), while we assume the opposite; therefore our model may be more appropriate to situations where a licensor can demonstrate the degree of cost saving to potential licensees, e.g., licensing to foreign producers. Creane and Konishi (2009) also consider partial technology transfers, but their focus is on licensing to rivals.
positive analysis, but new and interesting questions will arise in a normative analysis. These questions are left for future research.

Acknowledgements

We are grateful to Tony Creane and Editor Bernard Caillaud, who provided detailed comments and suggestions on an earlier draft. We also benefited greatly from the comments and suggestions by Jing-Yuan Choiu, Morton Kamien, Pedro Mendzi, David Myatt, Michael Waldman, participants at the University of South Carolina Brownbag seminar, 2009 International Conference on Game Theory, 2009 meeting of the Southern Economic Association and 2010 International Industrial Organization Conference and two anonymous referees. We thank Ann Bartow for sharing her expertise in intellectual property law and Jessica Adachi for her excellent research assistance. All remaining errors are ours.

Appendix A. Proofs

Proof of Lemma 1. (i) The innovator’s expected profit in period 2 is \(I_{B,i} = \max I_{B,i} + Pr(I_{A,i} = i)\), where \(\Delta = I_{B,i} - I_{H,i}\) and \(Pr(i) = 2\sqrt{\Delta}. The FOC is thus \(\sqrt{\Delta}\). So \(Pr(i) = 2\sqrt{\Delta}. Hence, \(\Delta = I_{B,i} - I_{H,i}\). The envelope theorem, \(dI_{B,i}/d\pi = \pi_{B,i} - \pi_{H,i}\). (ii) By the envelope theorem, \(\Delta = I_{B,i} - I_{H,i}\).

Proof of Lemma 2. We prove for the case of \(i = 1\). The proof for the case of \(i = 2\) is completely analogous. Without loss of generality, we call (one of) the firm that has a cost of \(c\) firm 1.

(i) We show that the innovator’s period 2 licensing revenues, firm profits and market prices are all the same under both \(F(f)\) and \(R(f)\). Suppose that \(c < p^H(c_1)\).

Fixed-fee \(F(f)\).

First, any other firm than firm 1 is willing to pay \(p^H(c_1, c)\) for an exclusive license, since they have to compete with firm 1 whose cost is \(c\). Second, firm 1’s willingness to pay for the license is \(p^H(c_1)\). Since \(p^H(c_1)\), we must have \(p^H(c_1)\). Since \(p^H(c_1)\). Therefore, \(\Delta = p^H(c_1)\). By the envelope theorem, \(\Delta = p^H(c_1)\).

(ii) First, \(\pi_{B,i}(c_1)\). Since \(c > p^M(c_1)\), the licensing revenue without leakage (i.e., \(c = c_1\)) is \(\pi_{B,i}(c_1)\). Therefore, the loss from leakage is \(\pi_{B,i}(c_1)\). Hence, \(\pi_{B,i}(c_1)\). At the same time, \(\pi_{B,i}(c_1)\). So \(\Delta = \pi_{B,i}(c_1)\).

Proof of Proposition 2. (i) is immediate from Lemma 3-6. (ii) According to Lemma 2, we have \(\partial p^H(c_1, c)/\partial c < 0\) for \(i = 1, 2, \text{Hence, } \partial I_{B,i}/\partial c < 0\) by Lemma 1. Since \(\partial I_{B,i}/\partial c < 0\), we must have \(\partial I_{B,i}/\partial c < 0\).

Proof of Lemma 7. First, we show that the original licensee wins the period 2 license if it has the ROFR. According to Lemma 2a, if the firm is the original licensee and is willing to pay \(p^H(c_1, c)\) for innovation \(i\) and thus the innovator will offer innovation \(i\) to the original licensee. To check whether the original licensee accepts the same offer, we compare its payoffs. By accepting the offer, it gets \(p^H(c_1, c)\); by refusing it, it gets 0. Since \(p^H(c_1, c) > 0\), it accepts. This means that \(I_{B,1} = I_{B,1}^H\) and \(I_{B,2} = I_{B,2}^H\). Hence, \(\Delta = p^H(c_1, c)\).

The original licensee earns a net profit of \(p^H(c_1, c)\) in period 2 because of technology leakage and is thus willing to pay \(f^*(\pi_{B,i}(c_1, c) + \delta p^B(c_1, c) - \pi_{B,i}(c_1, c))\) in period 1 for the initial license, where \(Pr = 2\Delta\). Hence, \(I_{B,R} = (1 + \delta)\pi_{B,i} + \delta^2 I_{B,i}(\pi_{B,i} - \pi_{B,i}(c_1, c))^2 - \delta\pi_{B,i}(c_1, c)\). Hence, \(\Delta = p^H(c_1, c)\).

Next, we separate firm 2 further into two regions: a) \(f < \pi^H(c_1, c)\) and b) \(\pi^H(c_1, c) < f < \pi^H(c_1, c)\).

a) The original licensee pays \(f_2\) to stay in the contract regardless of the innovation outcome. This means that \(I_{B,2} = f_{2}\). Hence, \(\Delta = \pi^H(c_1, c)\). So the innovator’s incentive to invest is independent of\(f_2\). Therefore, her licensing revenue is a constant if \(f_2 < p^H(c_2, c_1)\).

b) The original licensee pays \(f_2\) to stay in the contract only if the innovation is unsuccessful. This means that \(f_2 = f_2\). Hence, \(\Delta = \pi^H(c_2, c_1)\).

In sum, \(I_{B,R}(f_2, f_1)\) increases with \(f_2\) on the entire interval of \([0, \pi^H(c_1, c)]\) and early termination takes place for any \(f_2 \geq \pi^H(c_1, c)\).

Proof of Proposition 5. Since we allow any form of demand function and almost any type of downstream competition, it is impossible to write down the optimal licensing scheme in period 2, so there is no explicit solution for either \(I_{B,2}^R\) or \(I_{B,2}^H\). Hence, our plan of the proof is to show that all three terms, \(I_{B,1}, I_{H,1}\) and \(I_{B,2}\) are lower under \(SR(r)\) than under \(SF(1)\) and therefore the same must be true for \(II\) according to Lemma 1. More specifically, we prove that (i) \(I_{B,2,1}(R)(S) \leq I_{B,2,1}(H)(S)\); (ii) \(max(\delta I_{B,2,1}(R)(S), \delta I_{B,2,1}(H)(S))\); (iii) \(\alpha I_{B,3,1}(R)(S) \leq \alpha I_{B,3,1}(H)(S)\), and therefore \(\delta I_{B,2,1}(R)(H) + \delta I_{B,3,1}(R)(H) \leq \delta I_{B,2,1}(H)(H) + \delta I_{B,3,1}(H)(H)\), where \(\delta I_{B,2,1}(R)(H) = \delta I_{B,2,1}(R)(H)\).

First, since \(\delta I_{B,2,1}(R)(H) = \pi^H(c_1, c)\), we have \(\delta I_{B,2,1}(R)(H) \leq \pi^H(c_1, c)\).

(ii) can be proved by showing that \((i.a) \Pi_2^{2,1}(F(f)) \geq \Pi_1^{2,1}(F(f))\) and \((i.b) \Pi_2^{2,1}(R(r)) \geq \Pi_1^{2,1}(R(r))\).

(iii.a) Because of leakage, n firms have a cost of \(c\) at the beginning of period 2 under \(\Pi_2\), but only firm \(1\) has \(c\) under \(\Pi_1\); if all other firms have a cost of \(c \sim c'\). Denote by \(n_1(n_1, n_2, n_3)\) (resp. \(n_1, n_2, n_3\)) a licensee's (resp. non-licensee's) gross profit when n firms (including the licensee) produce at a cost of \(c, c'\), produce at a cost of \(c_n, c_n'\) produce at a cost of \(c_n, c_n'\), respectively. Under \(\Pi_2\), if the innovator sells licenses in period 2, then the fee has to be \(f = \Pi_1(k, n, 0) - \Pi_1(k, n - 1, 0)\), so \(\Pi_2^{2,1}(F(f)) = \max(k, c_n')\).

(iii.b) Under \(\Pi_2\), if the innovator uses \(R(r)\) in period 2, denote by \(r^\ast\) the optimal rate, then all firms' effective costs become \(c_r + r^\ast\), so we must have \(r^\ast \leq c - c_r\). This means that \(r^\ast\) will also be accepted by all firms under \(\Pi_1\) and generate the same revenue.

Therefore, \(\Pi_2^{2,1}(R(r)) \geq \Pi_1^{2,1}(R(r))\).

Similarly, we can prove (iii). Therefore, \(\Pi^2 \geq \Pi^1\).

Appendix B. An alternative proof for Proposition 5

In this Appendix, we construct a simpler proof for Proposition 5 and extend it to the case of non-dramatic innovation 1 by assuming that the innovator can offer both fixed-fee licenses and royalty licenses in period 2. It is also necessary to replace Assumption 1 by the following one:

Assumption 1'. Fixed-fee licensing is more profitable than royalty licensing in a one-period licensing game.

Assumption 1' is a standard result in technology licensing (KT86, Kamien et al., 1992).

Lemma 10. For an innovation that reduces the cost of production to \(c\), suppose that there are \(n\) potential licensees, among which \(k\) have a cost of \(c\) and \(n - k\) have a cost of \(c_n\), where \(c \leq c_n \leq c_0\). Denote by \(\Pi_1(k, n - k)\) the innovator’s licensing revenue, \(\Pi_1(n, 0)\).

Proof of Lemma 10. Our method of proof is to first show that the optimal outcome under \((n, 0)\) can always be replicated by the innovator under \((k, n - k)\), then draw the conclusion based on a revealed-preference argument. Denote by \(O\) the optimal licensing scheme under \((n, 0)\). We are agnostic about the exact form of \(O\), be it fixed-fee or royalty. Now consider a licensing scheme \(O'\) that is a combination of \(O\) and \(R(r)\), where \(r = c - c \). Under \(O'\), a firm can choose to only participate in \(O\), only accept \(R(r)\), or accept both, but its effective cost has become \(c + r = c\), because of the optional royalty contract. This means that \(\Pi^{O'}(k, n - k) = \Pi^n(0, 0)\). Therefore, \(\Pi_1(k, n - k) = \max(\Pi^{O'}(k, n - k), \Pi^n(0, 0)) = \Pi^n(0, 0)\).

If we replace by \(c, c_n, i = 1, 2, c_0\) by \(c\), and \(c_0\) by \(c_0\), then \(k\) represents the spread of technology leakage and \(\Pi(n, k)\) corresponds to the negative of the revenue loss. Hence, Lemma 10 implies that the more widespread the leakage is, the greater the revenue loss will be. While Lemma 10 is quite intuitive, it is non-trivial, since the spread of leakage can potentially weaken the bargaining power of an individual firm thereby strengthening the innovator’s bargaining position. However, the proof shows that the innovator cannot do worse when the spread of leakage becomes more limited, since she can always “create” additional leakage by transferring technology via a low-rate royalty and use the royalty rate to fine-tune the degree of leakage.

Proof of Proposition 5. Again, our plan of the proof is to show that all three terms, \(I_1, I_2\), and \(I_3\), are lower under \(\Pi_2\) than under \(\Pi_1\) and therefore the same must be true for \(I = I_1 + \delta I_2 + \gamma \Pi_1 I_2\). According to Lemma 1. First, \(\Pi_{2,1}^{2,1} \leq \Pi_{1,1}^{2,1}\) (by Assumption 1) and the fact that \(\Pi_{1}^{1,1} \Pi_{1}^{1,1}\) must be greater than the one-period fixed-fee licensing revenue. Second, we compare \(I_{2,1}^{2,1}\) and \(I_{2,1}^{1,1}\), i.e., the period 2 licensing revenue if innovation 2 fails. In this case, the best technology available remains \(c_1\). Because of leakage, all firms have a cost of \(c\) at the beginning of period 2 under \(\Pi_2\) licensing, but only 1 firm has \(c\) under \(\Pi_1\) licensing. By Lemma 10, we have \(I_{2,1}^{2,1} \leq I_{2,1}^{1,1}\). Similarly, \(I_{2,1}^{2,1} \leq I_{2,1}^{1,1}\).

References


