Discussion paper

Licensing and Innovation with Imperfect Contract Enforcement

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Licensing and Innovation with Imperfect Contract Enforcement[*]

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Abstract

Licensing promotes technology transfer and innovation, but enforcement of licensing contracts is often imperfect. We explore the implications of weak enforcement of contractual commitments on the licensing conduct of firms and market performance. An upstream firm develops a technology that it can license to downstream firms using a fixed fee and a per-unit royalty. Strictly positive per-unit royalties maximize the licensor's profit if competition among licensees limits joint profits. Although imperfect contract enforcement lowers the profits of the upstream firm, weak enforcement lowers prices, increases downstream innovation, and in some circumstances can increase total economic welfare.

1 Introduction

Licensing allows inventors and licensees to profit from the transfer of technology. Graham et al. (2009) found that nine out of ten venture-backed biotechnology startups negotiated licenses to gain (at least in part) access to technology, information, or know-how. In 2004 the top 20 pharmaceutical companies derived 19.5% of their sales of drugs from licensed products (Datamonitor, 2005). This paper focuses on markets in which licensing is desirable to transfer technology but enforcement of licensing contracts is imperfect. An application is the use of licenses to facilitate technology transfer to licensees that operate in jurisdictions with weak enforcement of intellectual property rights. Studies have found that stronger intellectual property rights encourage cross-border licensing (Smith, 2000) and increase technology transfer within multinationals (Brandstetter, 2006). In a study of licensing by Japanese firms, Nagaoka (2009) suggests that stronger intellectual property regimes encourage the substitution of patent licensing for foreign direct investment.

Technology licensing contracts that require the licensee to pay the licensor a combination of fixed and variable fees are common. According to the Association of University Technology Managers, royalties that vary with licensee sales accounted for about three-quarters of the revenues collected from licensing technologies developed by major universities, hospitals and research organizations over the period 2009-2012 (AUTM Reports). These "running royalties" allow the licensor and licensee to share the risk of uncertain demand for the licensed technology (Bousquet et al. 1998), address managerial incentives (Saracho, 2002), and provide a means for a cash-strapped licensee to finance the cost of the technology. Relative to using only fixed or variable fees, a combination of fixed fees and fees that vary with sales allows a licensor to extract more revenue from licensees that differ in their willingness to pay for the technology (Schmalensee, 1981). Furthermore, fees that depend on sales allow a licensor to soften competition for products that employ the licensed technology, potentially increasing the total profits available to the licensor and licensees and allowing greater total licensing revenues including fixed fees (Kamien, 1992, Hernández-Murillo and Llobet, 2006). We focus on the use of variable

fees to soften competition, although our analysis is applicable to other licensing arrangements in which the use of variable fees increases joint profits.

A technology rights owner may be at risk from under-reporting of contractually required payments by a licensee if the licensor cannot perfectly monitor and enforce the conduct of the licensee. A report of audited licenses for intellectual property found that 89 percent of the licensees under-reported their royalty obligations (Stewart and Byrd, 2014). Under-reporting typically was not interpreted as cheating but rather was a consequence of differences in contract interpretation. A recent example is a dispute between Microsoft and Samsung in which Samsung maintained that its licensing agreement with Microsoft, which obligated Samsung to pay royalties for each smartphone it sells, did not apply after Microsoft acquired Nokia's handset business (Waters, 2014). In other situations a licensor may conclude that a licensee has abused a license by employing the licensed technology in unauthorized applications or locations. Schuett (2012) considers the probabilistic enforcement of contract terms for patent licenses that contain a field-of-use restriction. Under-reporting also can occur from disallowed deductions, misuse of transfer prices, and failure to report sub-licenses. In our contracting model, licensees have incentives to cheat on licensing terms, but royalties are chosen such that cheating does not occur in equilibrium. That characterization is not inconsistent with the survey of licensees, which attributes under-reporting primarily to differences in contract interpretation rather than strategic failures to comply with agreed upon contract terms (i.e., cheating).

We address how the risk of under-reporting affects the design of licensing contracts, competition, and incentives for investments to improve the licensed technology. Although the form of the intellectual property right is not crucial for the analysis, we assume that it is a patent, which gives its owner the exclusive right to make, use or sell the technology covered by the patent unless the patentee chooses to share or transfer that right through a licensing agreement. We also note that the implications of weak enforcement for the design of licensing contracts are relevant to other vertical relationships, such as contracts between a franchisor and a franchisee and contracts between a manufacturer and downstream distributors of the

manufacturer's products.[1]

When enforcement of licensing contracts is imperfect, royalties that depend on the conduct of the licensee create incentives to cheat (or otherwise evade licensing terms) by under-reporting royalty obligations. We explore the implications of weak enforcement for prices and incentives for innovation. High per-unit royalties maximize joint profits when licensees supply products that are close substitutes, but weak enforcement constrains the maximum royalty that the licensor can charge without inducing licensees to cheat. Imperfect enforcement of licensing contracts undermines the use of per-unit royalties to soften downstream competition and is more likely to impose a constraint on royalties when downstream products are close substitutes. When the cheating constraint is binding, a central conclusion is that weak enforcement increases incentives for innovation for licensees and in some circumstances may increase total welfare. However, if contract enforcement is very weak, the licensor may abandon the use of variable royalties to regulate downstream competition and instead choose to license a technology exclusively or vertically integrate with one or more potential licensees.

Several authors have focused on the economic consequences of potential infringement by unauthorized technology users and addressed licensing as a means to deter infringement that would occur without a license. Examples include Gallini (1984, 1992), Gallini and Winter (1985), and Aoki and Hu (1999). In these papers the purpose of the license is to offer an alternative to infringing conduct and licensing, when it occurs, is enforced perfectly.

We focus on compliance with licensing contracts and ignore the possibility that firms without a license may infringe or invent around the licensed product. Situations commonly occur in which a firm that is not a licensee cannot practically compete by imitating a supplier's product. The firm may require know-how, research tools or materials that are vital to make or sell a commercial product or may not have the technological resources to invent around the licensed product. In other settings, a franchisee or distributor may be unable to sell a product that is a close substitute for the product supplied by a franchisor or a manufacturer, but may act

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[1]Improved monitoring technologies allow more effective contract enforcement. Mortimer (2008) shows that the contracts between a distributor and retail stores changed from only fixed fees to profit sharing (a form of running royalties) when cheaper computer systems improved monitoring of retail sales.

opportunistically in ways that contradict a contractual arrangement between the parties.

Imperfect enforcement of licensing contracts differs from imperfect enforcement of patents: if a patent turns out to be invalid, other firms can use the technology for free. There is a public good feature involved in challenging the validity of a patent (Farrell and Shapiro, 2008). Breach of a licensing agreement is different in the sense that successful breach of the contract does not make the technology freely available to others. A firm's incentives to challenge a patent are weakened by increased competition because the gains from litigating the patent are small. In contrast, breach of a licensing contract lowers only the breaching licensee's costs and increases only that licensee's profit.[2]

Our analysis is related to the literature on cumulative innovation (Scotchmer, 1991) in that a focus is on innovation by technology users. Also related is research on market structure and innovation by Spulber (2013), who concludes that strong intellectual property rights complement competition in creating incentives for innovation. However, we find that when licensing contracts are enforced perfectly, an increase in competition can cause a rights owner to charge higher royalties that vary with output, which leads to a reduction in investment by licensees to improve the licensed products. In contrast, weak contract enforcement promotes innovation by lowering the royalties that the rights owner can profitably sustain without inducing licensees to cheat on their contracted payments. Thus, in our model, it is not strong patent rights, but rather weak enforcement of patent rights that facilitates downstream competition and investment. Moreover, we find that perfect contract enforcement is never privately optimal if monitoring is costly and, in some circumstances, weak contract enforcement can increase total economic welfare.

2 Joint profit-maximizing outputs and investments

We are concerned with the enforcement of licensing contracts and how imperfect enforcement affects contract design, competition, and innovation. There is a single upstream firm denoted by

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[2]This distinction between challenging the validity of a patent and violating a licensing contract does not arise if there is no competition in the market (i.e., the licensee is a monopolist).

U and two downstream firms denoted by $j = 1, 2$. The upstream firm invests $u > 0$ to develop a new technology that enables production at constant marginal cost c_j. The upstream firm does not produce final goods, but instead licenses the technology to the downstream firms. The incremental cost of licensing is zero. The downstream firms choose prices and also may invest to improve the quality of the product. The products of the downstream firms are differentiated, which gives the upstream firm an incentive to license both downstream firms.

Let p_j be the price set by downstream firm j with $\boldsymbol{p} = (p_1, p_2)$ and let e_j be the investment by downstream firm j with $\boldsymbol{e} = (e_1, e_2)$. Demand for firm j's product is $q_j(\boldsymbol{p}, \boldsymbol{e})$ for $j = 1, 2$.

We use the following notation. Define

$$\rho_j = c_j + r_j,$$

$$\pi_j(\boldsymbol{p}, \rho_j, \boldsymbol{e}) = (p_j - \rho_j) \, q_j(\boldsymbol{p}, \boldsymbol{e}),$$

and

$$\pi_j(p_i, \rho_j, \boldsymbol{e}) = \max_{p_j} (p_j - \rho_j) \, q_j(p_j, p_i, \boldsymbol{e}),$$

where p_i is the price set by Firm $i \neq j$.

Production with the licensed technology repeats indefinitely under stationary conditions. If Firm j accepts a license and reports royalty obligations truthfully, the firm earns

$$\frac{1}{1 - \delta} \pi_j(p_i, \rho_j, \boldsymbol{e}) - e_j - F_j \tag{1}$$

where $\delta \in [0, 1\rangle$ is the per-period discount factor.

Assumption 1: Firm j's profit without a license is zero.

Assumption 1 simplifies the analysis by making the reservation value of a downstream firm equal to zero if the firm does not have a license, either because the firm has refused the offer of a license or has a license revoked for cheating. Assumption 1 also implies that a firm cannot profitably infringe the technology owned by the upstream firm by operating without a license.

As discussed in the introduction, this situation can occur, for example, because the license conveys know-how or materials that are essential for the firm to operate profitably.

We begin by establishing as a baseline for the analysis the outputs and investments that maximize the joint profits of the licensor and her licensees. Joint profits are

$$\Pi^J(\boldsymbol{p}, \boldsymbol{c}, \boldsymbol{e}) = \frac{1}{1-\delta}\left[\pi_1(\boldsymbol{p}, c_1, \boldsymbol{e}) + \pi_2(\boldsymbol{p}, c_2, \boldsymbol{e})\right] - e_1 - e_2, \tag{2}$$

where $\boldsymbol{c} = (c_1, c_2)$. Conditional on investments (e_1, e_2), the joint-profit maximizing prices are

$$(p_1^J, p_2^J) = \arg\max_{p_1, p_2}[\pi_1(\boldsymbol{p}, c_1, \boldsymbol{e}) + \pi_2(\boldsymbol{p}, c_2, \boldsymbol{e})].$$

The joint-profit maximizing solution has $q_j^J = q_j(\boldsymbol{p}^J, \boldsymbol{e}) > 0$ for $j = 1, 2$.

We add the usual assumptions to assure unique interior solutions for the profit-maximizing prices and investments.

Assumption 2 (Uniqueness):

i) The profit functions satisfies[3]

$$\frac{\partial^2 \pi_i}{\partial p_i^2} + \frac{\partial^2 \pi_i}{\partial p_i \partial p_j} < 0 \qquad i, j = 1, 2 \text{ and } j \neq i$$

to ensure a unique equilibrium in the price setting game.

ii) To ensure that the optimal investments are positive and unique we assume that $\partial \Pi^J(\boldsymbol{p}, \boldsymbol{c}, \boldsymbol{e})/\partial e_j > 0$ at $e_j = 0$, $\lim_{e_j \to \infty} \Pi^J(\boldsymbol{p}, \boldsymbol{c}, \boldsymbol{e})/\partial e_j < 0$, and the Hessian matrix of $\Pi^J(\boldsymbol{p}, \boldsymbol{c}, \boldsymbol{e})$ is negative semidefinite. We make similar assumptions for the individual profit functions.

The joint-profit-maximizing prices and investments satisfy for $j = 1, 2$:

$$\frac{d\Pi^J(\boldsymbol{p}, \boldsymbol{c}, \boldsymbol{e})}{dp_j} = 0,$$

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[3]The condition for uniqueness is provided by Friedman (1977, p.71).

$$\frac{d\Pi^J(\boldsymbol{p}, \boldsymbol{c}, \boldsymbol{e})}{de_j} = 0.$$

3 Licensing and enforcement

The upstream Firm U may offer licenses to downstream Firms 1 and 2 or choose to license a single producing firm exclusively. We allow the contract to depend on whether both downstream firms or only one firm licenses the new technology. A licensing contract describes the running royalty paid per unit, r_j, and a fixed fee paid up front, F_j. Let (r_1, F_1) and (r_2, F_2) describe the offered fee structure to Firms 1 and 2 given that both firms accept the contract. Let (r_1^s, F_1^s) and (r_2^s, F_2^s) represent the fee structure if only Firm 1 or Firm 2 accepts the licensing contract. We assume that contracts are observable and the licensor can commit not to renege on a contract with one party. This avoids the problems studied by Rey and Tirole (1986), Katz (1991), O'Brien and Shaffer (1992) and others in which a failure to commit to contracts with downstream firms results in renegotiations that increase output. If the research firm licenses only a single firm, it will charge only a fixed fee, $r_j^s = 0$ and $F_j^s > 0$ (O'Brien and Shaffer, 1992).

3.1 Contracting and timing

Suppose that Firm U has developed a new technology (invested u) and offers contracts to downstream firms.[4] The sequence of offers and actions are as follows:

1. **Contracting**:

   (a) Upstream firm U offers licensing contracts (r_j, F_j) to downstream Firm 1 and Firm 2.

   (b) If only one downstream firm accepts, it is optimal to charge only a fixed fee, $F_j^s > 0$

2. **Investment:**

   (a) Firms 1 and 2 choose investments e_1 and e_2 respectively.

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[4]With perfect contract enforcement and firms that sell differentiated products, it is never optimal to license either Firm 1 or Firm 2 exclusively.

3. **Competition (repeated)**:

   (a) Firms choose prices p_1 and p_2 simultaneously.

   (b) Firms report their sales volumes and pay per-unit royalties.

4. **Enforcement (repeated)**:

   (a) If Firm j under-reports contractual royalties, upstream firm U litigates the firm and a court verifies cheating with probability φ.

   (b) If under-reporting is not verified, the game continues without punishment.
   If under-reporting is verified, the contract is enforced and the under-reporting licensee is penalized in the current period and/or in future periods.

With no uncertainty and perfect foresight the upstream firm can set a fixed fee that extracts all of the downstream firms' profits. Nonetheless, the downstream firms have incentives to invest to maximize their profits conditional on the fees if they accept the offered contracts, as to do otherwise would result in negative profits. We assume that if profits are identical for a range of investments, the firm chooses the smallest investment.

Stage 3 (pricing and reporting decisions) and Stage 4 (enforcement) are repeated indefinitely or until the patent expires. Section 3.3.1 discusses patent expiration while the other parts of the paper assume that the technology is protected in ways that do not expire at a certain date (e.g., the firm may possess complementary assets that are necessary to use the technology and cannot be duplicated by others).

Let (p_1^*, p_2^*) denote the equilibrium downstream prices when both firms report their royalty obligations truthfully. The downstream firms choose these prices simultaneously. If Firm j under-reports contractual royalties, the firm will choose a profit-maximizing price $\hat{p}_j$ that depends on its expected costs, including penalties, and on the price chosen by its rival. We assume that Firm $i \neq j$ does not respond to $\hat{p}_j$ by choosing a price different from p_i^* if Firm i reports truthfully. If firms could observe and respond to their rivals' prices, this would add a further disincentive for under-reporting royalties, as doing so would trigger a price response similar to the responses familiar from the theory of repeated games.

3.2 Perfect contract enforcement

The upstream firm chooses (r_j, F_j) in order to maximze

$$\Pi^U = \sum_{j=1,2} \left[F_j + \frac{1}{1-\delta} r_j q_j^* \right] \tag{3}$$

subject to the participation constraint of the licensees (recall $\rho_j = c_j + r_j$)

$$F_j \leq \frac{1}{1-\delta} \pi_j (\boldsymbol{p}, \rho_j, \boldsymbol{e}) - e_j, \tag{4}$$

the licensees' pricing choices

$$p_j = \arg\max \pi_j (\boldsymbol{p}, \rho_j, \boldsymbol{e}), \tag{5}$$

and the licensees' investment choices

$$e_j = \arg\max \left(\frac{1}{1-\delta} \pi_j (\boldsymbol{p}, \rho_j, \boldsymbol{e}) - e_j \right). \tag{6}$$

Let $\Pi(\cdot)$ be discounted profits and $\pi(\cdot)$ be per-period profits (excluding the cost of investments):

$$\Pi_j^*(\boldsymbol{\rho}, \boldsymbol{e}) = \frac{1}{1-\delta} \pi_j(p_1^*, p_2^*, \rho_j, \boldsymbol{e})$$

and

$$q_j^*(\boldsymbol{e}) = q_j(p_1^*, p_2^*, \boldsymbol{e}),$$

where

$$p_j^* = \arg\max \pi_j (p_j, p_i^*, \rho_j, \boldsymbol{e})$$

and the Nash equilibrium prices with perfect contract enforcement are (p_1^*, p_2^*). To simplify the exposition we suppress the equilibrium prices (stage 3) when we examine optimal investments and contracts (stages 1 and 2).

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Lemma 1. *i) The sign of the effect of r_j on Firm j's investment is given by*

$$sign\left(\frac{de_j}{dr_j}\right) = sign\left(\frac{\partial^2 \pi_j^*}{\partial e_j \partial r_j}\right),$$

ii) the sign of the effect of r_j on Firm i's investment is given by

$$sign\left(\frac{de_i}{dr_j}\right) = sign\left(\frac{\partial^2 \pi_j^*}{\partial e_j \partial r_j} \frac{\partial^2 \pi_i^*}{\partial e_j \partial e_i}\right),$$

iii) and $sign\left(\frac{de_j}{dr_j}\right) = sign\left(\frac{de_i}{dr_j}\right)$ if investments are strategic complements, $\frac{\partial^2 \pi_i^*}{\partial e_j \partial e_i} > 0$.

The proof of this lemma and other results are in Appendix A. Intuitively, Firm j's investment is a non-increasing function of the firm's per-unit royalty if an increase in the royalty lowers Firm j's marginal profit from investing The full information assumptions in the model imply that the licensor's profit is equivalent to

$$\Pi^U(\rho_1, \rho_2) = \sum_{j=1,2}\left[\left(\frac{1}{1-\delta}\right)\left(\pi_j^* + r_j q_j^*\right) - e_j\right].$$

Let (r_1^*, r_2^*) be the licensor's optimal per-unit royalties with perfect contract enforcement and let (e_1^*, e_2^*) be the corresponding profit-maximizing investments by the downstream licensees. Furthermore, let $(\bar{r}_1, \bar{r}_2)$ be the licensor's optimal per-unit royalties if downstream investments are held constant at (e_1^*, e_2^*).

Assumption 3: $\Pi^U(\rho_1, \rho_2)$ is a concave function of (ρ_1, ρ_2).

Assumption 3 follows from Assumption 2 (the Hessian matrix of $\Pi^J(\boldsymbol{p}, \boldsymbol{c}, \boldsymbol{e})$ is negative semidefinite) if the Nash equilibrium prices p_j^* are not too convex functions of r_j for $j = 1, 2$.

The following proposition describes sufficient conditions for which the licensor will lower the per-unit royalty when royalties influence downstream investments.

Proposition 1. *Suppose $\bar{r}_j > 0$ for $j = 1, 2$. Then $r_j^* < \bar{r}_j$ for $j = 1, 2$ if*

   (i)   total royalties collecting from Firm j are a strictly increasing function of e_j,

   (ii) an increase in the royalty lowers Firm j's marginal profit from investing, and

(iii) investments are strategic complements.

Intuitively, the licensor will lower per-unit royalties relative to a situation in which downstream investments are fixed if lower per-unit royalties cause the firms to invest more and if greater investment allows the licensor to collect a higher total royalty. From Lemma 1, a lower per-unit royalty r_j will induce both licensees to invest more if an increase in the royalty lowers Firm j's marginal profit from investing and if investments are strategic complements.

Proposition 1 follows because the upstream licensor cannot directly control the downstream licensees' investments. We will later see that imperfect enforcement may induce the licensor to decrease per-unit royalties further and this may strengthen downstream firms' investment incentives.

Remark 1. *Suppose $\frac{d\pi^*_{\neq k}}{de_k} = 0$. Then a sufficient condition for investment to lower optimal per-unit royalties is that the weighted total output $r_j q^*_j + r_i q^*_i$ is an increasing function of investment by either firm, $\frac{de_j}{dr_j} < 0$ for $j = 1, 2$, and downstream investments are strategic complements.*

The result follows from the proof of Proposition 1. Given the envelope condition for investment by Firm j, on the margin downstream investment by Firm j affects only variable royalties and not fixed fees if $\frac{d\pi^*_i}{de_j} = 0$ for $i \neq j$. Although the condition $\frac{d\pi^*_{\neq k}}{de_k} = 0$ is strong, it is satisfied for some demand functions and in particular for the log-linear demand example in Section 7.

3.3   Enforcement of licensing contracts

We now consider how the enforcement constraint affects the licensor's optimal royalties. As before, let (p^*_1, p^*_2) represent the Nash equilibrium prices conditional on investments (e_1, e_2) when the firms face the per-unit royalties (r_1, r_2) and truthfully report their royalty obligations. Enforcement adds the additional constraint that variable royalties must not be so large that the licensee has incentives to under-report royalty obligations to the licensor's maximization problem with truthful reporting given by the objective function (3) and constraints (4), (6), and (5).

Suppose a license calls for payment of a royalty r_j for each unit of product made or sold

by the licensee that employs the licensed technology. The licensee cheats if he fails to pay a fraction $s > 0$ of the contractually specified royalties. The incentive to cheat depends on the probability that cheating is detected and the resulting consequences. The U.S. Patent Act provides that:[5]

> Upon finding for the claimant [patent holder] the court shall award the claimant damages adequate to compensate for the infringement, but in no event less than a reasonable royalty for the use made of the invention by the infringer, together with interest and costs as fixed by the court.

Only the royalty is relevant to an inventor who cannot practice the technology described in the patent.[6]

In other contexts, cheating can expose a licensee to different damage rules. A court may treat the failure to pay specified royalties as a breach of contract, in which case contract law would apply, and if the licensed intellectual property is protected by copyright, the copyright owner may be entitled to the licensee's "unjust enrichment", the profits earned by the licensee as a consequence of its infringing conduct (Ben-Shahar, 2011). We assume that a failure to pay royalties exposes the licensee to liability to reimburse the licensor for the unpaid royalties and possible restrictions on the future use of the patented technology. However, because the consequences of a failure to pay required royalties may differ in other circumstances, we explore the implications of alternative damage rules in Appendix B. There we show that none of our qualitative results depend on the alternative rules, although they have different quantitative implications for the ability to enforce particular royalty levels.

We assume that the licensor can costlessly detect an underpayment of royalties by a licensee, but cannot recover damages without establishing underpayment in a legal proceeding. If the licensor sues, the court or other administrative body imposes penalties for the underpayment

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[5]35 U.S.C. §284.

[6]Schankerman and Scotchmer (2001), Choi (2009), Henry and Turner (2010), and Aoki and Hu (1999) consider the implications of alternative damages rules to compensate lost profits from infringement of intellectual property rights. Issues related to damage rules studied in these papers do not arise if the technology owner does not make or sell a product in competition with her licensees.

with probability φ (the "enforcement probability"). We simplify by assuming φ is constant and independent of the licensee.

If the suit results in a finding of liability, the licensee pays the licensor an amount proportional to the unpaid royalties:

$$D_j(s_j) = \beta s_j r_j q_j(\boldsymbol{p}, \boldsymbol{e})$$

where s_j is the underpayment, q_j is the licensee's output conditional on the underpayment, r_j is the per-unit royalty, and β is a multiplier, which does not depend on the identity of the licensee.[7] We ignore litigation costs, which implies that the licensor has sufficient incentives to litigate a licensee who cheats on the contract.

Conditional on a finding of liability, in addition to the penalty for unpaid royalties a licensee may incur a reputation loss that affects its future stream of profits. We model this reputation cost as equal to $\alpha \pi_j(p_i, \rho_j, \boldsymbol{e})$ in every future period with $\alpha \in [0, 1]$. The reputation loss can take different forms. The licensor can demand an injunction that prevents future use of the intellectual property which, if granted, corresponds to $\alpha = 1$. For example, in *Wisconsin Alumni Research Foundation v General Electric*, the court awarded the patent owner a royalty with interest after the defendant ceased to pay required royalties and issued an injunction that prevented further use of the patent.[8] If the licensor chooses (or is required by law) to continue to deal with the licensee, the enforcement probability could increase if the licensee has been found to have cheated in the past. We show below that this would allow the licensor to charge a higher incentive compatible royalty $r' > r$. In this case the licensee's profit in each period following a finding of liability would correspond to $\pi_j(p_i, \rho'_j, \boldsymbol{e}) = (1 - \alpha)\pi_j(p_i, \rho_j, \boldsymbol{e})$ for some $\alpha > 0$, where $\rho'_j = c + r'_j$. In addition, the licensor may impose compliance costs on the licensee or more restrictive license terms, for example by limiting the field of use of the licensed technology. The harm to the licensee also could be realized in other licensing settings.[9]

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[7]A court may impose damages up to three times ($\beta = 3$) the unpaid royalties in the event of willful infringement.

[8]U.S. District Court Eastern District of Wisconsin, 880 F. Supp. 1266; 1995 U.S. Dist. Lexis 4188, March 29, 1995.

[9]The literature on tax evasion and commodity taxation generally assumes that it is costly to conceal true sales from a taxing authority and discusses how these costs change optimal taxes (see e.g., Cremer and Gahvari,

If the licensee cheats, his expected profit in the cheating period is[10]

$$\pi_j^c(s_j, p_i, \rho_j, \boldsymbol{e}) = \max_{p_j}\{(p_j - c - r_j(1 - s_j))q_j(p_j, p_i, \boldsymbol{e}) - \varphi D_j(s_j)\}. \tag{7}$$

Firm j's best response with cheating is

$$\hat{p}_j = \arg\max\{(p_j - c - r_j(1 - s_j))q_j(p_j, p_i, \boldsymbol{e}) - \varphi D_j(s_j)\}.$$

With damages equal to unpaid royalties,

$$\pi_j^c(s_j, p_i, \rho_j, \boldsymbol{e}) = \pi_j(p_i, \rho_j(s_j), \boldsymbol{e}),$$

where

$$\rho_j(s_j) = c + r_j(1 - s_j(1 - \varphi\beta)).$$

To simplify the notation we suppress prices and investments in what follows.

Let δ be the per-period discount factor. If the licensee cheats, his expected discounted future profits are

$$\Pi_j^c = \pi_j^c(s_j, \rho_j) + \varphi\frac{\delta}{1 - \delta}(1 - \alpha)\pi_j(\rho_j) + (1 - \varphi)\delta\Pi_j^c.$$

The first term is the profit from cheating in the period during which the cheating occurs. The second term is the licensee's future profit if the licensee is found liable for cheating weighted by the probability of liability. This term includes the reputation effects from cheating (and is zero if $\alpha = 1$, corresponding to an injunction). The third term is the expected future profit if

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1993). In our model the enforcement probability and threat of punishment (injunction and reputation loss) influence the cost of concealing sales and the incentives for cheating.

[10]An implicit assumption is that cheating occurs in a single period. A straightforward extension would allow for cheating to occur over multiple periods before detection.

the licensee escapes a finding of liability. Re-arranging terms,

$$\Pi_j^c = \frac{1}{1 - \delta(1 - \varphi)} \left[\pi_j^c(s_j, \rho_j) + \frac{\delta}{1 - \delta} \varphi(1 - \alpha) \pi_j(\rho_j) \right].$$

Lemma 2. *The licensee will not cheat if $\varphi\beta \geq 1$ (i.e., will choose $s_j = 0$). If $\varphi\beta < 1$, the licensee will choose $s_j = 1$ if he cheats.*

The proof follows directly from the licensee's profit, equation (7). If $\varphi\beta \geq 1$, the licensee's profit is a maximum when $s_j = 0$ and if $\varphi\beta < 1$, the licensee's profit is a maximum when $s_j = 1$.

We have assumed that the enforcement probability φ is constant. More generally, the enforcement probability is determined by the legal system as well as the evidence of underpayment. Suppose the enforcement probability depends on the amount of under-reporting, s_j. A sufficient condition for $s_j = 1$ if the licensee cheats is

$$\frac{1 - \varphi(s_j)}{\varphi'(s_j)} > s_j$$

for all s_j. Note that $s = 1$ can be interpreted as cheating on all units in a market segment where cheating is feasible (imperfect enforcement). There might be other markets where cheating is infeasible.

We henceforth assume $\beta = 1$ (no enhanced damages).[11] Given Lemma 2, the licensee's total expected present-value profit if he chooses to under-report royalties is

$$\Pi_j^c = \frac{1}{1 - \delta(1 - \varphi)} \left[\pi_j^c(c_j + \varphi r_j) + \frac{\delta}{1 - \delta} \varphi(1 - \alpha) \pi_j(c_j + r_j) \right]. \tag{8}$$

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[11]From Lemma 2, a licensee will cheat if damages are no more than unpaid royalties. Courts award a multiple of unpaid royalties only in exceptional cases, typically involving clear evidence that the infringement is willful. We resolve this dilemma by pointing out that infringement, if enforced, burdens the infringing firm a loss of future profits, in addition to any fixed costs (including the cost of litigation).

A second concern is that damages based on the royalties that a firm reasonably should have paid may be circular if "reasonable" is determined by that royalties that courts typically award successful plaintiffs in infringement actions. We avoid this indeterminacy because we envision a situation in which the plaintiff licensor can establish her profit-maximizing royalty structure and can convince a court that she would have charged and collected these royalties if the contract were enforced.

If he chooses to report royalties truthfully his total expected present-value profit is

$$\Pi_j^* = \frac{1}{1-\delta}\pi_j(c_j + r_j). \tag{9}$$

The following proposition describes the conditions under which a per-unit royalty r_j is incentive compatible.

Proposition 2. *Suppose the penalty for under-reporting royalties is*

$$D_j(s_j) = s_j r_j q_j(\boldsymbol{p}, \boldsymbol{e})$$

and is enforced with probability φ. If enforced, the licensee incurs a reputation loss equal to a fraction α of the profit with truthful reporting. The licensee will not under-report for any per-unit royalty r_j if and only if [12,13]

$$\pi_j(p_i^*, c_j + r_j) \geq \gamma \pi_j(p_i^*, c_j + \varphi r_j), \tag{10}$$

where

$$\gamma = \frac{1}{1 + \frac{\alpha \varphi \delta}{1-\delta}}, \tag{11}$$

δ is the discount factor and $\alpha \in (0,1)$.

Firm j will not under-report royalties if $\Pi_j^* \geq \Pi_j^c$. Substituting equations (8) and (9), rearranging terms, and using equation (11) gives the result in inequality (10).

It is easier to sustain truthful reporting if γ is small. The parameter γ falls if the discount rate (δ), the enforcement probability (φ), or the future loss from being held liable for under-reporting (α) is increased. The licensee has an incentive to cheat for any $r_j > 0$ if either α, δ, or

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[12]We assume the licensee reports truthfully if he is indifferent to truthful reporting and under-reporting.

[13]The analysis is little changed if royalties are assessed on an ad valorem basis rather than per unit of the licensed product. If the royalty is a percentage λ of Firm j's revenues, the incentive compatibility constraint becomes

$$\pi_j\left(p_i^*, \frac{c}{1-\lambda}, e_j\right) \geq \gamma\left(\frac{1-\varphi\lambda}{1-\lambda}\right)\pi_j\left(p_i^*\frac{c}{1-\varphi\lambda}, e_j\right).$$

φ is zero.

Let $r_j^c(\gamma)$ be the maximum per-unit royalty that satisfies the incentive compatibility constraint (10) for $j = 1, 2$ and define

$$\hat{r}_j(\gamma) = \min(r_j^*, r_j^c(\gamma)),$$

where r_j^* is the optimal royalty with perfect contract enforcement. The incentive-compatibility constraint is binding for Firm j if $\hat{r}_j(\gamma) = r_j^c(\gamma)$. Otherwise, $\hat{r}_j(\gamma) = r_j^*$.

Proposition 3. $\hat{r}_j(\gamma)$ *is weakly increasing in* γ.

The proof follows from Assumption 3. The licensor's profit is increasing in r_j when $r_j < r_j^*$ for $j = 1, 2$. Furthermore, increasing γ allows the licensor to increase her profits by choosing a larger value of r_j without inducing cheating.

Corollary 1. *Holding* α *and* δ *constant,* $\hat{r}_j$ *is weakly increasing in* φ. *Holding* φ *constant,* $\hat{r}_j$ *is weakly increasing in* α *and* δ.

Corollary 1 follows directly from Proposition 3 given the dependence of γ on α, δ, and φ.

Note that by constraining variable royalty payments to be less than a level that would induce under-reporting by the licensee, the constraint also prevents the licensor from raising royalties in a multi-period setting without commitment. In this respect imperfect contract enforcement can be a safeguard against hold-up by the licensor when the licensee has to make irreversible investments early on.

Suppose a new technology can obsolete the licensor's technology. The discount rate δ can represent a combination of a continuation probability θ and the discounting of future gains, δ_0 so that $\delta = \theta \delta_0$. The continuation probability is the probability that the existing licensed technology is not dominated by a novel and better technology in the next period.

Corollary 2. *Suppose that Industry A and Industry B have two symmetric licensees with the same demand and costs, but the probability for introduction of a new and dominating technology is higher in Industry A: $\theta_A > \theta_B$. Then*

i) if the enforcement constraint is not binding, the running royalties are constant and equal to the profit maximizing level, $\hat{r}_k = r^*$ in both industries, $k = A, B$.

ii) if the enforcement constraint is binding, running royalties are lower in Industry A than in Industry B, $\hat{r}_A < \hat{r}_B$.

The proof is immediate from Proposition 3 and the effect of θ on the discount factor and γ.

Running royalties depend on the likelihood of a new innovation only if the enforcement constraint is binding, provided that alternative technologies have identical demands and costs. Other analyses of licensing such as Gallini (1984, 1992), Gallini and Winter (1985), and Aoki and Hu (1999) have focused on the incentives of downstream firms to innovate around the existing technology to avoid licensing costs and showed how this will influence the royalty structure. Our model suggests an alternative reason for lower royalties in innovative industries.

In what follows, unless stated otherwise we hold constant the future loss from being held liable for under-reporting, α, and the discount rate, δ, and focus on the enforcement probability, φ, replacing $r_j^c(\gamma)$ with $r_j^c(\varphi)$ and $\hat{r}_j(\gamma) = \min(r_j^c(\gamma), r_j^*)$ with $\hat{r}_j(\varphi)$.

Corollary 3. *Stronger enforcement ($\varphi' > \varphi$) implies weakly lower downstream output.*

Stronger enforcement has no effect if the enforcement constraint is not binding, corresponding to $r_j^c(\varphi) \geq r_j^*$. If $r_j^c(\varphi) < r_j^*$, each downstream firm's output is a declining function of the firm's per-unit royalty, which is non-decreasing in φ.

In our licensing model, the licensor chooses per-unit royalties such that the licensee has no incentive to cheat on the licensing contract. As noted in the Introduction, audits of licensing contracts have found that under-reporting is common. However, under-reporting typically is the result of differences in contract interpretation rather than failure to comply with agreed upon contract terms. We could extend our model to allow for this type of under-reporting in equilibrium by including a stochastic component that affects the value of the licensing contract

and therefore the incentive to under-report royalties. This stochastic component can reflect differences in the interpretation of the scope of the contract. Alternatively, we could assume that there is uncertainty regarding the enforcement probability or the penalty. Yet another approach is to allow for uncertain future profits, which can affect the incentive to under-report royalties and sustain some under-reporting in equilibrium. We do not further develop these extensions in this paper.

3.3.1 Licensing royalties and patent expiration

Suppose the licensed technology is protected by a patent that expires at date T. Following the expiration of the patent, competition prevents the technology owner from charging a positive per-unit royalty. The remaining patent term may affect the incentives for cheating on the licensing contract and the licensor's profit-maximizing royalties.

Proposition 4. *Suppose licensees are symmetric with market demand and costs that are constant over time. The patent on the licensed technology expires at date T.*

i) If enforcement of licensing contracts is perfect, the optimal running royalty is the same over the life of the patent.

ii) If the enforcement constraint is binding, the running royalty is weakly decreasing until the patent expires, at which time the royalty is zero.

$$\hat{r}_{t_0} \geq \hat{r}_{t_1} \quad \text{if } t_0 < t_1 \leq T$$

3.4 Competition and optimal royalties

How does downstream competition influence the enforcement constraint and thereby the maximum sustainable per-unit royalties? Products are more competitive if they are closer substitutes. All else equal, the larger the cross-elasticity of demand, the greater the change in a firm's profit in response to a change in its price. Suppose demand for the two downstream products is symmetric and the firms have equal marginal cost, c. Let ζ denote the degree of downstream

competition as indexed by the cross-elasticity of demand.

In general, the cross-elasticity of demand and therefore the measure of downstream competition depend on downstream prices. Let $\hat{p}_j(\varphi)$ be Firm j's profit-maximizing price if it under-reports royalties. Furthermore, suppose $\zeta_A > \zeta_B$ for all prices $(p_i^*, \hat{p}_j(\varphi))$. This restriction permits a characterization of the conditions under which an increase in downstream competition affects the enforcement constraint.

Proposition 5. *Assume that market A is more competitive than market B in the sense that $\zeta_A > \zeta_B$ for all prices $(p_i^*, \hat{p}_j(\varphi))$. The maximum sustainable per-unit royalty is weakly lower for market A than for market B if, for all $\varphi \in \langle 0, 1 \rangle$,*

$$\frac{\pi_j^A(p_i^{A*}, c + \varphi r)}{\pi_j^A(p_i^{A*}, c + r)} > \frac{\pi_j^B(p_i^{B*}, c + \varphi r)}{\pi_j^B(p_i^{B*}, c + r)}, \tag{12}$$

where p_i^{k*} is Firm i's equilibrium price with truthful reporting for $k = A, B$.

The proof follows directly from the incentive compatibility constraint (10).

Proposition 5 offers a way to test whether a more competitive market has a lower sustainable royalty. One might expect that in a more competitive downstream market the percentage increase in per-period profit from under-reporting is larger than in a less competive market. However, this is not generally correct. The result depends on the measure of competition and is different for alternative specifications of demand. Consider the Hotelling and log-linear demand specifications. In the Hotelling model of spatial competition with uniform demand on a unit line,

$$q_j = \frac{p_i - p_j + t}{2t},$$

where t is the marginal disutility of distance from either supplier. The cross-elasticity of demand is

$$\zeta = \frac{p_j}{p_j - p_i + t}.$$

At prices p_i^* and $\hat{p}_j$, the cross-elasticity of demand is[14]

$$\zeta = \frac{c + t + \frac{1}{2}r(1+\varphi)}{t - \frac{1}{2}r(1-\varphi)}.$$

This is decreasing in t. It is easily verified that condition (12) is satisfied for Hotelling demand with the degree of competition indexed by the cross-elasticity of demand, which in turn depends on t.

Next consider log-linear demand with constant own and cross-price elasticities,

$$q_j = A p_j^{-\eta} p_i^{\zeta}.$$

The incentive compatibility condition is independent of ζ for log-linear demand. An increase in the cross-elasticity of demand changes the licensee's profit proportionally with and without under-reporting and hence the ratios in inequality (12) are independent of the degree of competition. A more competitive downstream market does not satisfy inequality (12) if downstream demand is log-linear.

In markets for which an increase in competition satifies the ratio condition (12), the licensor must reduce the per-unit royalty in order to prevent under-reporting in equilibrium. This is exactly the opposite of the prediction from common models with perfect contract enforcement for which it is profit-maximizing to increase per-unit royalties to soften competition in more competitive markets.

3.5   Investment with imperfect contract enforcement

The preceding results allow us to characterize the effects of imperfect contract enforcement on investment. To simplify the notation, suppress the dependence of r_j^c on the enforcement probability, φ. Weak contract enforcement changes investment incentives only to the extent that lower per-unit royalties change the marginal effects of investments on downstream profits.

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[14]Recall that $\hat{p}_j$ is the best response given that Firm j is under-reporting while Firm i chooses p_i^* and reports truthfully. In the Hotellling model, $p_i^* = t + c + r$ and $\hat{p}_j = t + c + \frac{1}{2}r(1+\varphi)$.

Proposition 6.

(i) If $\hat{r}_j(\varphi) = r_j^c(\varphi) < r_j^*$ for $j = 1, 2$, an increase in the strength of contract enforcement φ weakly decreases Firm j's investment if and only if $\partial^2 \pi_j^*(\boldsymbol{\rho}, \boldsymbol{e})/\partial e_j \partial r_j \leq 0$.

(ii) If $\hat{r}_j(\varphi) = r_j^*$ for $j = 1, 2$, an increase in φ has no effect on downstream investment.

Conversely, weaker contract enforcement (weakly) lowers the per-unit royalties, which (weakly) increases licensees' outputs, profits, and investments when $\partial^2 \pi_j^*(\boldsymbol{\rho}, \boldsymbol{e})/\partial e_j \partial r_j \leq 0$ and the constraint is binding. Note that the familiar condition $\partial \pi_j^*/\partial r_j = -q_j^*$ does not generally hold in this model. The reason is that the licensor's choice of r_j in the first stage affects the rival's downstream investment and its equilibrium price, which have first-order effects on Firm j's profit. Absent these effects, weaker contract enforcement weakly increases downstream investments if and only if $\partial q_j^*/\partial e_j \geq 0$.

Innovation can occur at any level in the value chain that supplies a product to a customer. Spulber (2013) explores a model in which upstream inventors compete to license their inventions to a downstream industry. As in our model, inventors offer fixed and per-unit royalties to maximize their profits. He finds that greater downstream competition – as measured by the number of downstream firms or the elasticity of substitution – increases incentives for upstream invention. Our focus is on downstream innovation to improve upon a licensed technology. In our model it does not generally follow that an increase in competition – as measured by the degree of downstream substitution – promotes downstream innovation. An increase in downstream competition can lead the licensor to charge higher per-unit royalties when licensing contracts can be enforced perfectly. Higher royalties lower downstream profits and lead to less investment to improve the products. We explore this result further in Section 7 below for a particular functional form for downstream demand.

With perfect contract enforcement, whether competition reinforces incentives for innovation depends on whether the activity occurs upstream by the developers of a new technology or downstream by the firms that implement the new technology. Competition increases incentives for upstream invention but may reduce incentives for downstream innovation. Factors that limit the ability to appropriate the value of an invention or innovation such as weak con-

tract enforcement have different implications for investment incentives and competitive effects. Weak appropriability in our model corresponds to weak enforcement of licensing contracts, which leads to relatively lower per-unit royalties and greater investment by licensees when $\partial^2 \pi_j^*(\boldsymbol{\rho}, \boldsymbol{e})/\partial e_j \partial r_j \leq 0$. The effects are particularly significant when downstream competition would otherwise lead the licensor to choose high per-unit royalties to soften downstream competition if contracts could be enforced perfectly.[15]

Our model is not inconsistent with the conclusions in Spulber (2013) if the focus is on invention by the upstream licensor. Weak contract enforcement can force the upstream licensor to choose a low per-unit royalty, which lowers her profits. The reduction in profit can be a disincentive for the licensor to invest to create the technology in the first place or to improve her invention to make it more useful for licensees.

For example, suppose downstream firms are symmetric and demand for the technology depends on investment in upstream innovation, u. Holding downstream investment constant, the upstream firm invests to maximize

$$\Pi(\rho, u) - u$$

where $\rho = c + r$ and r is the per-unit royalty charged to both symmetric downstream licensees. With perfect contract enforcement, the upstream firm charges a per-unit royalty r^* and invests $u^* = \arg\max(\Pi(\rho^*, u) - u)$. A reduction in the per-unit royalty resulting from weak contract enforcement causes the upstream firm to invest less if

$$\frac{du}{dr} = -\frac{\frac{\partial^2 \Pi(\rho, u)}{\partial u \partial r}}{\frac{\partial^2 \Pi(\rho, u)}{\partial u^2}} > 0,$$

or if $\frac{\partial^2 \Pi(\rho, u)}{\partial u \partial r} > 0$. This condition is satisfied, for example, if demand is log-linear: $q_j = A(u) p_j^{-\eta} p_i^\zeta$ with $A'(u) > 0$, $\zeta > 0$, and $\eta > \zeta + 1$.

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[15]See also Vives (2008). Relatedly, López and Vives (2014) explore the relationship between competition and cost-reducing R&D investment when firms have limited ability to appropriate the benefits from their investments.

Recall that φ^c is the smallest value of φ for which $r^c(\varphi) \geq r^*$. Although weak enforcement can lower welfare by lowering the upstream firm's profit and incentive to invent, a marginal reduction in the enforcement strength φ increases total economic welfare.

Proposition 7. *Suppose downstream firms are symmetric and demand for the technology depends on investment in upstream and downstream innovation. Suppose further that $r^c(\varphi)$ is strictly increasing in φ and downstream profit is strictly decreasing in φ in the neighborhood of φ^c. Then there exists a $\delta > 0$ for which total economic welfare is higher when $\varphi = \varphi^c - \delta$ than when $\varphi \geq \varphi^c$.*

By definition, $\frac{d\Pi^U(\rho^*, u^*)}{dr} = 0$ when the per-unit royalty $r = r^*$. A small reduction in φ to $\varphi^c - \delta$ results in a small reduction in r below r^*. This small reduction in the per-unit royalty has no first-order effect on the licensor's profit and therefore no adverse first-order effect on upstream investment, u. However, the reduction in r has a first-order effect on lower downstream prices. Thus the net effect of a small reduction in φ below φ^c is an increase in investment and economic welfare.[16]

We have assumed throughout that the enforcement probability is exogenous. With this assumption Proposition 7 implies that under some conditions weaker enforcement can increase total welfare, but it does not increase the profits of the licensor (and licensee profits are zero with profit-maximzing fixed fees). If the enforcement probability depends on efforts by the licensor, it is possible that the licensor as well as consumers may benefit from weaker enforcement. Suppose we ignore upstream investment but make the enforcement probability an endogenous decision by the licensor that is observed by the licensees. The technology owner can increase φ by exerting more effort to detect cheating. Let $k(\varphi)$ be the cost of this effort, with $k(0) = 0$, $k'(\varphi) > 0$, and $k''(\varphi) > 0$. Allowing for asymmetric licensees, the licensor chooses φ to maximize

$$\Pi(\rho_1(\varphi), \rho_2(\varphi)) - k(\varphi)$$

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[16]This result is similar in some respects to Ayres and Klemperer (1999). Takeyama (1994) finds that copying can increase the profits of a licensor when the licensed product benefits from positive network externalities.

where $\rho_k(\varphi) = c_k + r_k(\varphi)$ for $k = 1, 2$. Without loss of generality, suppose $\varphi_1^c \leq \varphi_2^c$.

Proposition 8. *Given the above assumptions, if $\frac{d\Pi(\rho_1(\varphi), \rho_2(\varphi))}{d\varphi} < \frac{dk(\varphi)}{d\varphi}$ at $\varphi = \varphi_2^c$, then the technology owner maximizes profit by choosing an enforcement level $\varphi^* < \varphi_2^c$ and royalties $\hat{r}_1(\varphi^*) \leq r_1^*$ and $\hat{r}_2(\varphi^*) < r_2^*$.*

The proof follows immediately from the slopes of the profit and enforcement cost functions. Under these assumptions, the technology owner chooses an enforcement level that is too weak to sustain the optimal royalties with perfect contract enforcement for both licensees, although the level may be sufficient to charge the royalty corresponding to perfect enforcement for one of the licensees. By choosing a slightly an enforcement level slightly lower than the level that would allow r_j^* for both licensees, the licensor saves more in enforcement cost than she sacrifices in profits.

Figure 1 illustrates this tradeoff for an example with symmetric licensees and log-linear demand. In this example the licensor can choose the unconstrained royalty if the enforcement level exceeds about 0.62. However, given the effort required to monitor contracts at this intensity, the licensor optimally chooses a weaker enforcement level of about 0.50 and a correspondingly lower per-unit royalty. Although the licensor's profit excluding monitoring costs is lower at the weaker enforcement level, consumers benefit from lower prices and downstream firms have greater incentive to invest to improve their products.
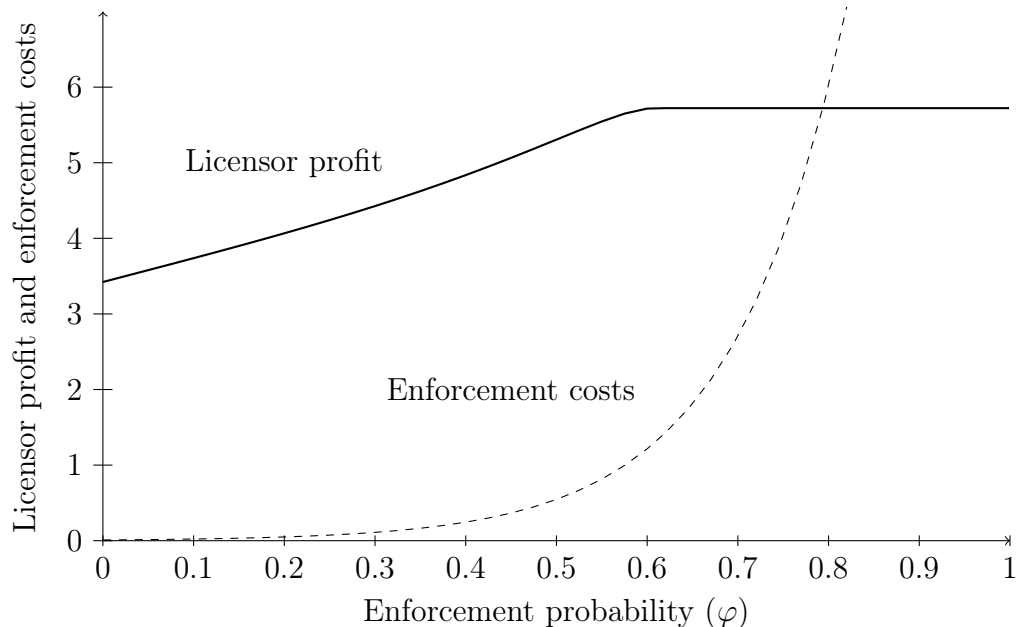
Figure 1: Licensor profit and cost of enforcement

This result complements the literature on digital rights management (DRM). If enforcement is costly to the licensor, both the licensor and society can prefer weaker protection from misuse of licensed intellectual property even if perfect protection is feasible. Both the technology rights owner and economic welfare can benefit from imperfection contract enforcement when enforcement is costly.

Although we share a central conclusion with the DRM literature that there is a trade-off between the benefits of protection provided by DRM technologies and the costs of these technologies, the mechanism differs from what others have examined. For example, Scotchmer and Park (2006) show that, by lowering the prices of the protected products, increased competition makes it less attractive for users to defeat DRM protections and correspondingly lowers incentives for rights holders to invest in these DRM technologies. We show that increased competition increases profit-maximizing per-unit royalties with perfect contract enforcement and therefore makes it more difficult for rights holders to sustain these desired royalties when contract enforcement is imperfect. As a result, if greater enforcement is increasingly costly,

all else equal, rights holders will choose (weakly) less perfect enforcement (corresponding to weaker DRM) when downstream markets are more competitive.

4   Incentives for exclusive licensing

The upstream firm may choose to deal exclusively with one licensee. In a sample of 1612 licensing deals over the period 1990-93, 37% granted exclusive rights to the licensee either worldwide or in a geographic region (Anand and Khanna, 2000). The Association of University Technology Managers reported that 41% of technology licenses in its 2007 survey were exclusive (AUTM, 2007). Exclusivity entails an efficiency loss when potential licensees sell differentiated products, but it has advantages such as committing the licensor to make the licensee the residual claimant for investment in the licensed technology. Of particular relevance to the focus of this paper, exclusive licensing avoids the cost of cheating when contract enforcement is imperfect because the optimal per-unit royalty is zero with a single licensee. With an exclusive license, the downstream firm pays only a fixed fee for the technology.[17]

Proposition 9. *Suppose: (i) it is profit-maximizing to license both firms when contract enforcement is perfect; (ii) $r_j^* > 0$ for $j = 1, 2$; and (iii) for some firm k, the firm's monopoly profit with a zero royalty exceeds the total profit earned by both licensees with a zero royalty. Then there exists an enforcement level $\hat{\varphi}$ for which it is optimal for the licensor to license Firm k exclusively if $\varphi < \hat{\varphi}$.*

Exclusive licensing solves the licensor's enforcement problem by replacing the per-unit royalty with a simple fixed fee. In addition, exclusive licensing can benefit the licensor by promoting downstream investment. Suppose the two potential licensees are symmetric and sell products that are partial substitutes. There are two reasons why investments can make exclusive licensing more attractive for the licensor. First, because the downstream firms are substitutes, the profit and output of an exclusive licensee are likely to be greater than the profit and output

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[17]Of course the licensor could have reasons other than softening competition to have non-zero running royalties for an exclusive licensee (e.g., risk-sharing).

of any single non-exclusive licensee. If the return to investment increases with demand, each non-exclusive licensee will invest less than the exclusive licensee. If downstream investments are not too complementary, this increases the incentive for exclusive licensing.[18] Second, the exclusive licensee has a marginal cost c, while each non-exclusive licensee has a marginal cost $c + r$. If $r > 0$, the greater marginal cost of non-exclusive licensees further reduces output and incentives for investment.

5 The choice of innovation projects

Investment decisions involve the types of technologies that firms may pursue as well as how much to invest in each technology. In this section we explore the implications of weak contract enforcement for technology choice by both the licensor and her licensees. We simplify by assuming the licensees are symmetric. First we consider technology choice by the licensor.

5.1 Technology choice by the licensor

Suppose the licensor can choose technologies from a set $I = \{\sigma_1, ..., \sigma_N\}$ and it is cost-efficient to develop only one of the possible technologies, which the licensor offers to both licensees. We assume all technologies when employed provide the downstream firms with symmetric demand and constant and equal marginal production costs. With perfect contract enforcement and with no risk of infringement by unlicensed firms, the licensor would choose to license the technology that maximizes the joint profit of the licensor and licensees. For a given technology, m, the licensor's profit is

$$\Pi^U(\boldsymbol{\rho}_m^*, \sigma_m) = 2 \max_{e_j} [\frac{1}{1-\delta} \left(\pi_j(\boldsymbol{\rho}_m^*, \boldsymbol{e}, \sigma_m) + r_m^* q_j(\boldsymbol{\rho}_m^*, \boldsymbol{e}, \sigma_m)\right) - e_j],$$

where $\boldsymbol{\rho}_m^* = (c + r_m^*, c + r_m^*)$ and r_m^* is the licensor's optimal per-unit royalty with perfect contract enforcement for technology σ_m.

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[18]Dasgupta and Stiglitz (1980) provide an example with investments that lower production costs in which downstream investments are not complementary.

Let the subscript p denote the technology that maximizes the licensor's expected profit with perfectly enforced contracts. The licensor's profit-maximizing technology may differ from σ_p if contract enforcement is imperfect. Let $\hat{r}_p$ be the profit-maximizing per-unit royalty with imperfect contract enforcement for technology σ_p and $\hat{r}_k$ the profit-maximizing per-unit royalty with imperfect contract enforcement for technology σ_k. Furthermore, let $\hat{\rho}_k = c + \hat{r}_k$ and $\hat{\rho}_p = c + \hat{r}_p$. The licensor will choose σ_k if

$$\Pi^U(\hat{\boldsymbol{\rho}}_k, \sigma_k) > \Pi^U(\hat{\boldsymbol{\rho}}_p, \sigma_p).$$

For example, the licensor may choose a project that enables greater product differentiation by the licensed firms, allowing $\hat{r}_k$ to be closer to the unconstrained profit-maximizing level, r_k^*. Given Assumption 3, $\Pi^U(\boldsymbol{\rho}, \sigma_k)$ is weakly increasing in r for $r < r_k^*$. Therefore, with imperfect enforcement, the licensor's expected profit from σ_k can exceed her expected profit from σ_p even though project σ_p would be more profitable if contract enforcement were perfect.

5.2 Technology choice by licensees

Suppose the licensees can choose between investing in Project A and Project B, both of which employ the licensed technology. Project A maximizes joint profits under perfect enforcement. Under imperfect enforcement a licensee can deviate by not paying running royalties and by choosing an alternative innovation project, Project B. For comparison assume that the enforcement probability is the same for both technologies and cheating incurs the same reputation costs. The opportunity to deviate in two ways makes the no-cheating constraint more demanding to satisfy,

$$\pi_A(c_A + r) \geq \gamma \max \left\{ \pi_A(c_A + \varphi r), \pi_B(c_B + \varphi r) \right\}. \tag{13}$$

If $\pi_B(c_B + \varphi r) > \pi_A(c_A + \varphi r)$, then the royalty r must be lower than in the case where innovation Project B is not available.

Weak enforcement has two detrimental effects for the licensor. Weak enforcement reduces

r as before. In addition, weak enforcement induces the downstream firm to choose a project that does not maximize the licensor's profit. Consequently, the licensor may have incentives to choose licensees who are unable to do Project B, which would allow the licensor to charge a higher running royalty. This can be optimal for the licensor even if the technology-constrained licensee has a slightly higher production cost than another licensee that can invest in either project.

These choices illustrate a tension between technology choice by the licensor and the licensee with contrasting implications for strong and weak contract enforcement. With perfect contract enforcement, the licensor will choose the technology that maximizes joint profits, regardless of its implications for downstream differentiation. Licensees will favor technologies that imply greater downstream product differentiation, as the corresponding lower per-unit royalty allows them to earn more and increases the return from investment holding fixed fees constant.[19] With imperfect contract enforcement, the licensor will favor technologies that imply greater downstream product differentiation, because such technologies make it easier to support optimal per-unit royalties when contract enforcement is weak. However, all else equal, licensees may favor technologies that lower downstream product differentiation, notwithstanding the fact that such technologies imply greater downstream competition, if low differentiation forces the licensor to charge a low per-unit royalty when contract enforcement is weak. Conditional on the fixed fees, the low per-unit royalty increases incentives for investment by the licensees and may allow greater downstream profit.

6   Incentives for vertical integration

We have assumed that the upstream firm acts only as a licensor, licensing the technology to downstream firms producing heterogenous but competing final goods. Alternatively, the licensor may sell final goods, which it can do by integrating with one or more downstream firms. With perfect contract enforcement the technology owner would not integrate with a potential

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[19]Layne-Farrar and Llobet (2014) show that licensees' competitive circumstances may affect the values they can obtain with different technologies and influence technology choice.

licensee if the result is a loss of productive efficiency. However, if contract enforcement is imperfect, vertical integration may allow the technology owner to choose prices that are closer to the prices that maximize joint profits, which can counteract a loss of productive efficiency.

6.1   Full vertical integration

Suppose that the upstream technology owner enters into the final goods market and produces both products on its own. If there is no loss of efficiency from vertical integration, the resulting prices maximize joint profits. This is no better than what the unintegrated technology owner can accomplish through licensing if contract enforcement is perfect and there is no downstream investment. If there is investment, vertical integration is weakly superior to licensing even if contract enforcement is perfect.

The vertically integrated firm earns

$$\Pi^V(\boldsymbol{e}) = \sum_{j=1,2} \frac{1}{1-\delta} \left(\max_{p_j} (p_j - c_j) \; q_j(p_j, p_i, \boldsymbol{e}) \right) - e_j$$

with $i \neq j$. Let $\hat{p}_j$ be the vertically integrated firm's optimal prices. The integrated firm's investments satisfy

$$\hat{e}_j = \arg\max_{e_j} [\frac{1}{1-\delta} (\hat{p}_j - c_j) \; q_j(\hat{p}_j, \hat{p}_i, \boldsymbol{e}) - e_j].$$

With perfect contract enforcement, the unintegrated licensor can choose per-unit royalties r_j^* such that $p_j^* = \hat{p}_j$. However, investments satisfy

$$e_j^* = \arg\max_{e_j} \left[\frac{1}{1-\delta} \left((p_j^* - c_j - r_j^*) \; q_j(p_j^*, p_i^*, \boldsymbol{e}) \right) - e_j \right].$$

Even if the unintegrated licensor can maximize joint profits without investments, the double-marginalization from positive per-unit royalties implies that she cannot generally maximize joint profits with investments. Therefore, if downstream firms can invest to improve their products, vertical integration is superior to licensing if there is no loss of productive efficiency, even if contract enforcement is perfect.

Imperfect contract enforcement strengthens the case for vertical integration. The fully integrated firm can maximize joint profits, with or without investment. Weak contract enforcement lowers the licensor's joint profit and therefore makes vertical integration more attractive relative to licensing with perfect contract enforcement.[20]

6.2 Partial vertical integration

Suppose the licensor can merge with one, and only one, of the downstream producing firms. There are two symmetric downstream firms and the licensor merges with downstream Firm i. The joint-profit-maximizing prices and investments are unchanged. We explore how this partial vertical integration affects prices and investments with and without enforceable licensing contracts. Having already noted that vertical integration affects incentives for investment even if contract enforcement is perfect, we ignore investment in this analysis.

If the upstream firm acquires one of the downstream firms, it acts to maximize the sum of its downstream profit and its license revenue collected from the unintegrated firm.[21] The vertically integrated firm's profit is

$$\Pi_i^V = \max_{r_j, F_j, p_i} \left[\frac{1}{1-\delta} \left((p_i - c)q_i(p_i, p_j) + r_j q_j(p_i, p_j) \right) + F_j \right]$$

where F_j is the fixed licensing fee charged to downstream Firm j and r_j is the per-unit royalty. The non-integrated downstream firm chooses

$$p_j^* = \arg\max (p_j - c - r_j) q_j(p_i, p_j).$$

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[20]Ignoring investment effects, Chen (2013) and others have questioned why a firm that controls an input may refuse to sell the input to firms that are rivals in downstream markets. We show that weak contract enforcement is an explanation for refusals to deal.

[21]Alternatively, the upstream technology owner could sell the technology to one of the downstream firms. The acquiring firm then becomes both a producer in the downstream market and collects licensing revenue from the unintegrated firm.

Assuming the fixed fee extracts all of the non-integrated firm's surplus,

$$\Pi_i^V = \max_{r_j, p_i} \left[(p_i - c) q_i(p_i, p_j^*) + (p_j^* - c) q_j(p_j^*, p_i) \right].$$

There is nothing to be gained from partial vertical integration if contracts can be enforced perfectly, there are no investments, and no efficiency benefits from integration. The partially integrated firm maximizes profit by charging $p_i^{VI} = p_i^J$ for its downstream product and offering a contract (F_j, r_j) to the unintegrated firm with $r_j = r_j^*$ and $F_j^* = \pi_j(c + r_j^*)$. In particular, there is no incentive for the integrated producer to act strategically by charging a royalty that raises its rival's cost. The integrated firm should charge a downstream price and royalty to maximize the joint profit of the integrated firm and its licensee.

However, partial integration introduces an additional strategic concern. We have assumed throughout that the licensor commits to its royalty terms. That is not a sufficient commitment condition for profit-maximization by a partially integrated firm. Suppose the non-integrated firm accepts the contract (F_j^*, r_j^*). The integrated firm would then choose its downstream price to maximize

$$(p_i - c) q_i(p_i, p_j^*) + r_j^* q_j(p_i, p_j^*).$$

Suppose the integrated firm promised, but did not commit, to a price p_i^J when it offered the licensing contract (F_j^*, r_j^*) to the unintegrated firm. After the licensee accepts the contract, the integrated firm would choose a profit-maximizing price below p_i^J if the downstream products are substitutes. This follows because $r_j^* < p_i^J - c$. By lowering its price, the integrated firm captures more demand, which earns the firm a higher margin $(p_i - c)$ than it earns on its licensing revenues (r_j^*). If the licensee anticipates this lower price, the licensee would not accept the offered contract without a reduction in the fixed fee. The inability of the integrated firm to commit to its downstream price thus can be a deterrent to partial vertical integration, even if the licensing contract can be enforced perfectly.

6.3 Partial vertical integration with imperfect contract enforcement

A key question is whether partial vertical integration allows the technology owner to charge a higher royalty when contract enforcement is imperfect without inducing one or more licensees to cheat. If that is the case, partial vertical integration may allow the technology owner to obtain a larger total profit than she could earn as an unintegrated licensor.

Let $\hat{p}_i$ be the vertically integrated firm's profit-maximizing downstream price and r_j the per-unit royalty charged to the unintegrated licensee. Suppose that the integrated firm can commit to $\hat{p}_i$ as well as to the offered contract terms. The licensee will not cheat if

$$\pi_j(c_j + r_j, \hat{p}_i) \geq \gamma \pi_j(c_j + \varphi r_j, \hat{p}_i).$$

Holding p_i constant, weak enforcement lowers the integrated firm's maximum royalty, r_j^c, and this is a binding constraint if $r_j^c < r_j^*$. Whether partial vertical integration allows the integrated firm to charge a higher royalty than an unintegrated licensor with imperfect contract enforcement depends on the interaction, if any, between r_j^c and the integrated firm's downstream price, $\hat{p}_i$. Therefore, it is not possible to make a general statement about the effect of partial vertical integration on r_j^c, the maximum per-unit royalty that the licensor can charge without inducing cheating.

To obtain additional results, we consider an example that imposes a particular structure of demand and explore the implications for licensing terms offered by an unintegrated technology owner, incentives for exclusive licensing, vertical integration, and competition and investment.

7 Log-Linear Demand

Suppose demand is log-linear and symmetric. Potential licensees face constant own and cross-price elasticities and downsteam investment affects the magnitude of demand

$$q_j(p_j, p_i, e_j) = A(e_j) p_j^{-\eta} p_i^{\zeta}.$$

The demand parameter $A(e_j)$ depends on investment by the licensee:

$$A(e_j) = A_0(e_j)^\sigma, \tag{14}$$

with $0 < \sigma < 1$.

Downstream production has a constant marginal cost, $c_1 = c_2 = c$, in addition to any per-unit royalty. To assure solutions, we impose the condition:

Assumption 4: $\eta > \zeta + 1$.

7.1   Joint-profit maximizing outputs and investments

Joint profits are

$$\Pi^U = \max_{p_j, e_j} \left[\sum_{j=1,2} \frac{1}{1-\delta}(p_j - c)q_j(p_1, p_2, e_j) - e_j \right].$$

Given the assumed symmetry, the prices that maximize joint profits are equal and given by

$$p_1^J = p_2^J = p^J = \frac{c\eta(1-D)}{\eta(1-D)-1},$$

where D is the diversion ratio:

$$D = -\frac{dq_2/dp_1}{dq_1/dp_1} = \frac{q_i}{q_j}\frac{\zeta}{\eta}.$$

The diversion ratio is the fraction of sales lost by firm j in response to a price increase that is gained by its rival and is a measure of the strength of downstream competition. With symmetric demand,

$$D = \zeta/\eta < 1.$$

The larger the diversion ratio, the greater the extent to which the licensees' products are substitutes for each other. Note that the joint-profit-maximizing prices are increasing in the diversion ratio.

Given p_j^J, conditional on the diversion ratio each firm's per-period downstream profit ex-

cluding investment cost is

$$\pi^J(c, e) = \frac{A_0}{\eta(1-D)}(e)^\sigma \left[\left(\frac{\eta(1-D)}{\eta(1-D)-1} \right) c \right]^{-\eta(1-D)+1}.$$

Investments solve

$$\frac{1}{1-\delta} \frac{d\pi^J(c, e)}{de} = 1,$$

which implies

$$e^J = \frac{\sigma}{1-\delta} \pi^J(c, e^J)$$

and

$$\Pi^U = \frac{2(1-\sigma)}{1-\delta} \pi^J(c, e^J).$$

7.2   Licensing with perfect contract enforcement

As before, let q_j^* and π_j^* denote the Nash equilibrium outputs and profits with truthful reporting. With perfect contract enforcement the licensor will choose $r_1^* = r_2^* = r^*$ to maximize joint profits

$$\Pi^U = \sum_{j=1,2} \frac{1}{1-\delta} \left(\pi_j^* + r_j q_j^* \right) - e_j. \tag{15}$$

First consider the case with fixed investment. Each firm's Nash equilibrium price is

$$p_j^* = \left(\frac{\eta}{\eta-1} \right) (c + r_j). \tag{16}$$

Given the assumed symmetry, at an interior solution the licensor's optimal royalty satisfies

$$r^* = \frac{cD}{\eta(1-D)-1}, \tag{17}$$

which supports the joint-profit maximizing prices p_j^J. The per-unit royalty is increasing in the diversion ratio with perfect contract enforcement.

Next suppose that the downstream firms invest to improve their products and maximize

their profits. Each downstream firm invests so that

$$\frac{1}{1-\delta}\frac{d\pi_j^*(\rho_j, e_j)}{de_j} = 1,$$

which implies

$$e_j^* = \frac{\sigma}{1-\delta}\pi_j^*(\rho_j, e_j^*).$$

After solving for e_j^* and substituting the result in equation (15), the licensor's optimal royalty is

$$r^*(\sigma) = \frac{\eta(1-\sigma)}{\eta-\sigma}r^*. \tag{18}$$

This is strictly less than the optimal royalty with no investment when $\sigma > 0$. The licensor lowers the per-unit royalty to encourage investment by downstream firms.

Remark 2. *Relative to the joint-profit maximizing investment, there is under-investment when contracts are enforced perfectly: $e_j^* < e_j^J$.*

This follows because $r^*(\sigma) > 0$ and $\pi_j^*(c+r, e) < \pi^J(c, e)$. Double-marginalization lowers downstream profits, which lowers incentives to invest.

7.3   Imperfect contract enforcement

Assume that it is optimal for the upstream firm to offer licenses to both firms even if contract enforcement is imperfect. The licensor's optimal per-unit royalty is

$$\hat{r} = \min(r^*(\sigma), r^c),$$

where $r^*(\sigma)$ is the licensor's optimal per-unit royalty with perfect contract enforcement and r^c is the maximum per-unit royalty for which the licensee will report his royalty obligations truthfully when contract enforcement is imperfect.

From the incentive compatibility condition (10),

$$r^c(\varphi) = c \left[\frac{1 - \gamma^{\frac{1}{\eta-1}}}{\gamma^{\frac{1}{\eta-1}} - \varphi} \right] \tag{19}$$

provided that $\varphi < \gamma^{\frac{1}{\eta-1}}$. If $\varphi \geq \gamma^{\frac{1}{\eta-1}}$, then any royalty satisfies the incentive compatibility condition.

Note that an increase in the enforcement probability φ increases the critical royalty r^c provided that $\varphi < \gamma^{\frac{1}{\eta-1}}$. Furthermore, γ is decreasing in both α and δ and therefore an increase in either of these two parameters also raises r^c. This comes about because an increase in α or δ increases the cost imposed on the licensee if he is found liable for cheating, in addition to the damages for unpaid royalties. Observe that as $\varphi \to 0$, $\gamma \to 1$ and $r^c \to 0$. There is no enforcement in this case and the maximum sustainable per-unit royalty is zero. As $\varphi \to 1$, the converse is true, as cheating never pays in this case.

7.4 The effect of competition on optimal royalties

With log-linear demand, as the diversion ratio increases holding the own elasticity η constant, the licensor desires a higher royalty to mitigate the adverse effects of downstream competition on joint profits. With perfect contract enforcement, the per-unit royalty is an increasing function of D. An increase in the diversion ratio has a symmetric effect on the licensee's profit if he cheats and the profit if he reports royalties truthfully. Therefore, when the enforcement constraint is binding, the maximum per-unit royalty that the licensor can charge without inducing the licensee to cheat is independent of the diversion ratio.[22] Summarizing:

Proposition 10. *Suppose demand is given by the log-linear example. Let D be the diversion ratio and hold η constant:*

(i) If $\hat{r} = r^*$, the licensor's optimal per-unit royalty is increasing in D.

(ii) If $\hat{r} = r^c$, the licensor's optimal per-unit royalty is independent of D.

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[22]Log-linear demand is a special case in this respect. See Section 3.4.

(iii) The critical value φ^c for which enforcement is a binding constraint is increasing in D.

Figure 2 shows r^* and r^c as a function of the enforcement probability φ for different values of the diversion ratio. Holding η constant, it is more difficult to sustain the joint-profit maximizing solution when the downstream market is more competitive in the sense that for a given value of the enforcement probability it is more likely that the incentive compatibility constraint limits the per-unit royalty when D is large.
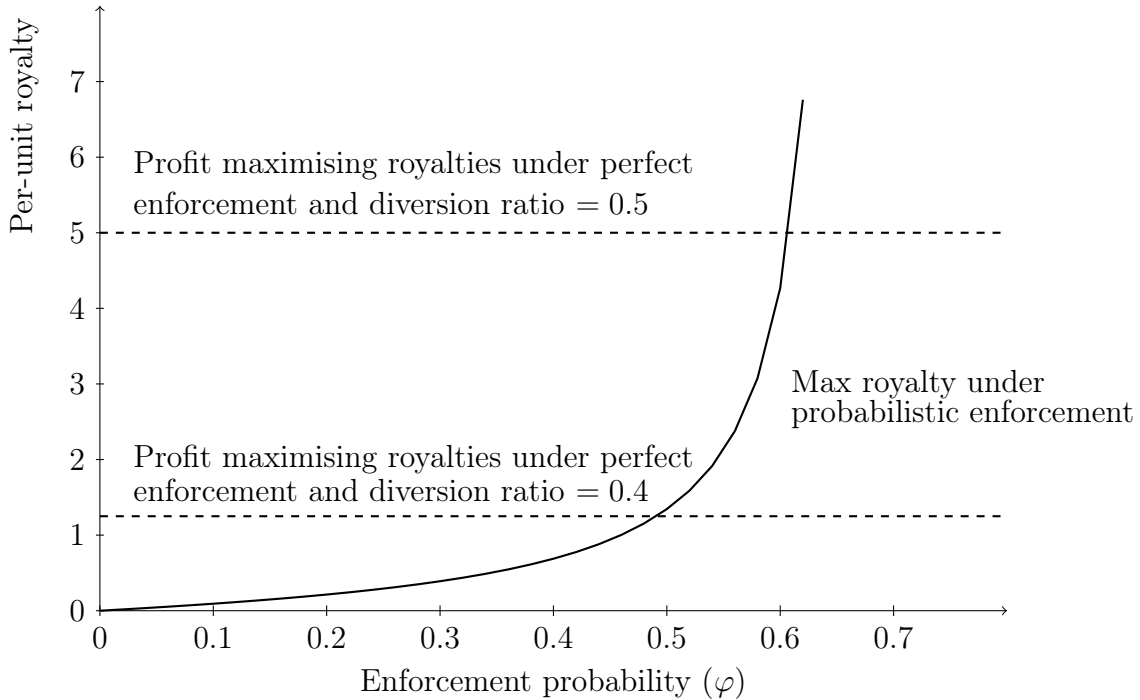

Figure 2. Per-unit royalties with perfect and imperfect enforcement (η=2)

An increase in the diversion ration D holding the own-elasticity η constant increases the per-unit royalty when licensing contracts can be enforced perfectly and reduces downstream profits and investment. In contrast to Spulber (2013), greater competition in this sense does not lead to greater (downstream) innovation when contracts are enforced perfectly.

7.5 Investment incentives with imperfect enforcement

When the no-cheating constraint is binding, optimal investments satisfy

$$e^* = \frac{\sigma}{1-\delta} \pi_j^*(c + \hat{r}(\varphi), e^*).$$

where

$$\pi_j^*(c + \hat{r}(\varphi), e) = A(e) \left[\left(\frac{\eta}{\eta - 1} \right) (c + \hat{r}(\varphi)) \right]^{-\eta(1-D)+1}.$$

When the no-cheating constraint is binding, the strength of downstream competition as measured by the diversion ratio has no effect on per-unit royalties in the log-linear example. Downstream profit, however, is increasing in the diversion ratio for a given value of the per-unit royalty provided that $\left(\frac{\eta}{\eta-1} \right) (c + \hat{r}(\varphi)) > 1$. Investment is increasing in the diversion ratio when the no-cheating constraint is binding. Greater competition in this case leads to more innovation as in Spulber (2013), but only when contract enforcement is weak so that the no-cheating constraint is binding.

8 Conclusions

Kenneth Arrow (2012) posed a "licensing puzzle." He wrote, "It is generally accepted that the main source of profits to the innovator are those derived from temporary monopoly. Why is it that royalties are not an equivalent source of revenues? In simple theory, the two should be equivalent. Indeed, if there is heterogeneity in productive efficiency, in the use of the innovation in production, then it should generally be more profitable to the innovator to grant a licence... [But] I have the impression that licensing is a minor source of revenues."[23] We show that imperfect enforcement of licensing contracts can cause a technology rights owner to limit the transfer of technology, either by licensing exclusively or by integrating vertically and substituting own production for licensing.

However, imperfect enforcement is not without benefits. Imperfect enforcement can require

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[23]Arrow (2012), p.47.

a licensor to choose lower royalties that vary with output than the licensor would choose if the contracts could be enforced perfectly. These lower variable royalties increase the profits of downstream firms and encourage these firms to invest to improve their products or lower costs even if a licensor can charge fixed fees that extract downstream profits.

Exclusive licensing and vertical integration eliminate enforcement constraints when the function of a per-unit royalty is to soften downstream competition and increase incentives for downstream investment, although at the risk of other distortions. Exclusive licensing compromises the benefits from downstream differentiation. Vertical integration introduces an additional hazard if the integrated firm also contracts with nonintegrated licensees. After licenses have been accepted, the integrated firm' profit-maximizing downstream price may differ from the price that maximizes the joint profit of the integrated firm and its licensees. This reduces the maximum fixed fees that licensees would pay for a license.

The potential for cheating can have negative consequences for licensing and technology transfer. However, cheating does not occur in an equilibrium outcome in our model and the threat of cheating can cause a rights owner to structure contract terms in ways that promote innovation and welfare. If the cheating threat is not so great as to cause the licensor to forego non-exclusive licensing, the threat of cheating raises downstream profits (excluding fixed fees), promotes innovation by downstream producers, lowers consumer prices and, by constraining variable royalty payments to be less than a level that would induce under-reporting by the licensee, can help a licensor to commit to license terms. The dark cloud of irresponsible licensee conduct is not without some silver linings.

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Appendix A: Proofs

Proof of Lemma 1: The first-order condition for downstream investment is

$$\frac{\partial \Pi_j^*(\boldsymbol{\rho}, \boldsymbol{e})}{\partial e_j} - 1 = 0 \qquad \text{for } j = 1, 2.$$

To examine the effects of an increased running royalty to Firm j, differentiate the first-order conditions to obtain the following system of equations in matrix form.

$$\begin{pmatrix} \frac{\partial^2 \Pi_j^*}{\partial (e_j)^2} & \frac{\partial^2 \Pi_j^*}{\partial e_j \partial e_i} \\ \frac{\partial^2 \Pi_i^*}{\partial e_j \partial e_i} & \frac{\partial^2 \Pi_i^*}{\partial (e_i)^2} \end{pmatrix} \begin{pmatrix} \frac{de_j}{dr_j} \\ \frac{de_i}{dr_j} \end{pmatrix} = \begin{pmatrix} -\frac{\partial^2 \Pi_j^*}{\partial e_j \partial r_j} \\ 0 \end{pmatrix}. \tag{20}$$

Solving for de_j/dr_j and de_i/dr_j,

$$\frac{de_j}{dr_j} = \frac{-\frac{\partial^2 \Pi_j^*}{\partial e_j \partial r_j} \frac{\partial^2 \Pi_i^*}{\partial (e_i)^2}}{|M|}$$

$$\frac{de_i}{dr_j} = \frac{\frac{\partial^2 \Pi_j^*}{\partial e_j \partial r_j} \frac{\partial^2 \Pi_i^*}{\partial e_j \partial e_i}}{|M|}$$

where $|M|$ is the deteriminant of the matrix in eq. (20), which is positive given an assumed stable equilibrium. By the second order condition $\frac{\partial^2 \Pi_i^*}{\partial (e_i)^2} < 0$, and since $\Pi_j^*(\boldsymbol{\rho}, \boldsymbol{e}) = \frac{1}{1-\delta} \pi_j^*(\boldsymbol{\rho}, \boldsymbol{e})$ it follows that

$$sign\left(\frac{de_j}{dr_j}\right) = sign\left(\frac{\partial^2 \pi_j^*}{\partial e_j \partial r_j}\right)$$

and

$$sign\left(\frac{de_i}{dr_j}\right) = sign\left(\frac{\partial^2 \pi_j^*}{\partial e_j \partial r_j} \frac{\partial^2 \pi_i^*}{\partial e_j \partial e_i}\right).$$

Furthermore, $\frac{\partial^2 \pi_i^*}{\partial e_j \partial e_i} > 0$ if investments are strategic complements and $\frac{\partial^2 \pi_i^*}{\partial e_j \partial e_i} < 0$ if investments are strategic substitutes.

Proof of Proposition 1: The licensor's profit is

$$\Pi^U(\rho_1, \rho_2) = \sum_{j=1,2} \left[\frac{1}{1-\delta} \left(\pi_j^* + r_j q_j^* \right) - e_j \right].$$

The licensor's choice of the per-unit royalty r_j^* solves

$$\frac{d\Pi^U(\rho_1^*, \rho_2^*)}{dr_j}\Big|_{e^*}$$

$$+ \left(\frac{1}{1-\delta} \left(\underbrace{\frac{d\pi_i^*}{de_j}}_{\text{Effect on fixed fee from Firm i}} + \underbrace{r_j \frac{dq_j^*}{de_j} + r_i \frac{dq_i^*}{de_j}}_{\text{Effect on running royalties}} + \frac{\partial \pi_j^*}{\partial e_j} \right) - 1 \right) \frac{de_j}{dr_j}$$

$$+ \left(\frac{1}{1-\delta} \left(\underbrace{\frac{d\pi_j^*}{de_i}}_{\text{Effect on fixed fee from Firm j}} + \underbrace{r_j \frac{dq_j^*}{de_i} + r_i \frac{dq_i^*}{de_i}}_{\text{Effect on running royalties}} + \frac{\partial \pi_i^*}{\partial e_i} \right) - 1 \right) \frac{de_i}{dr_j}$$

$$= 0.$$

The first term accounts for the effect of the per-unit royalty on joint profits holding investment constant. The second term accounts for the indirect effect on total royalties from an increase in the per-unit royalty that affects investment by Firm j while the third term accounts for the indirect effect on total royalties from an increase in the per-unit royalty that affects investment by Firm i.

From the first order condition for the downstream firms, $\frac{1}{1-\delta}\partial \pi_k^*/\partial e_k - 1 = 0$ for $k = 1, 2$,

we have

$$\frac{d\Pi^U(\rho_1^*, \rho_2^*)}{dr_j}\Big|_{e^*}$$

$$+\frac{1}{1-\delta}\left(\underbrace{\frac{d\pi_i^*}{de_j}}_{\text{Effect on fixed fee from firm i}} + \underbrace{\frac{d(r_j q_j^* + r_i q_i^*)}{de_j}}_{\text{Effect on running royalties}}\right)\frac{de_j}{dr_j}$$

$$+\frac{1}{1-\delta}\left(\underbrace{\frac{d\pi_j^*}{de_i}}_{\text{Effect on fixed fee from firm j}} + \underbrace{\frac{d(r_j q_j^* + r_i q_i^*)}{de_i}}_{\text{Effect on running royalties}}\right)\frac{de_i}{dr_j}$$

$$= 0.$$

From Lemma 1, the term de_j/dr_j has the same sign as $\partial^2 \pi_j^*(\boldsymbol{\rho}, \boldsymbol{e})/\partial e_j \partial r_j$. Therefore, if an increase in downstream investment increases the total license payment, the licensor maximizes her profit by choosing $r_j^* < \bar{r}_j$ if $\partial^2 \pi_j^*(\boldsymbol{\rho}, \boldsymbol{e})/\partial e_j \partial r_j < 0$ and investments are strategic complements.

Proof of Proposition 4: Let $\tau = T - t$, the number of periods remaining before the patent expires. Assume $\pi_j = \pi_j(c)$ for all $\tau \leq 0$. Firm j's profit from truthful reporting is for $\tau = 1$,

$$\Pi_j^*(1) = \pi_j(c + r) + \frac{\delta}{1-\delta}\pi_j(c)$$

Firm j's profit if he cheats is for $\tau = 1$

$$\Pi_j^c(1) = \pi_j(c + \varphi r) + \frac{\delta}{1-\delta}\pi_j(c).$$

When $\tau = 1$, the only incentive compatible royalty is $\hat{r}(1) = 0$. Furthermore, $\Pi_j^c(1) =$

$\frac{1}{1-\delta}\pi_j(c) = \Pi_j^*(1)$. Suppose $\tau \geq 2$. Firm j's profit with truthful reporting is

$$\Pi_j^*(\tau) = \frac{1-\delta^\tau}{1-\delta}\pi_j(c+r) + \frac{\delta^\tau}{1-\delta}\pi_j(c)$$

Firm j's profit if he cheats is for $\tau \geq 2$

$$\Pi_j^c(\tau) = \pi_j(c+\varphi r) + \varphi\delta(1-\alpha)\left[\frac{1-\delta^{\tau-1}}{1-\delta}\pi_j(c+r)\right] + \frac{\delta^\tau}{1-\delta}\pi_j(c) + (1-\varphi)\delta\Pi_j^c(\tau-1).$$

The largest incentive compatible royalty satisfies

$$\pi_j(c+\hat{r}(\tau)) = K(\tau)\left[\pi_j(c+\varphi\hat{r}(\tau)) + (1-\varphi)\delta\Pi_j^c(\tau-1)\right], \tag{21}$$

where

$$K(\tau) = \frac{1-\delta}{1-\varphi(1-\alpha)\delta - \delta^\tau(1-\varphi(1-\alpha))}.$$

Note that $K(\tau)$ is decreasing in τ. Furthermore, holding r constant

$$\Pi_j^c(\tau) - \Pi_j^c(\tau-1) = \frac{\delta^\tau}{1-\delta}\left[\varphi(1-\alpha)\pi_j(c+r) - \pi_j(c)\right] < 0.$$

Therefore, holding r constant, the RHS of (21) is decreasing in τ. It follows that

$$\pi_j(c+\hat{r}(\tau)) < \pi_j(c+\hat{r}(\tau-1))$$

and therefore $\hat{r}(\tau) \geq \hat{r}(\tau-1)$.

Proof of Proposition 6: Part (i) follows from Proposition 3 and Lemma 1. Since r_j^c is non-decreasing in φ, an increase in the strength of contract enforcement weakly reduces the licensee's profit-maximizing investment when $\partial^2\pi_j^*(\boldsymbol{\rho}, \boldsymbol{e})/\partial e_j\partial r_j \leq 0$. Part (ii) is immediate as the enforcement probability has no effect on r_j^*.

Proof of Proposition 9: The licensor is better off with an exclusive licensee if for some k

$$\max_{e_k} \left[\frac{1}{1-\delta} \pi_k^s(c_k, e_k) - e_k \right] > \max_{e_j} \sum_{j=1,2} \left[\frac{1}{1-\delta} \left(\pi_j(\hat{\boldsymbol{\rho}}(\varphi), \boldsymbol{e}) + r_j^c q_j(\hat{\boldsymbol{\rho}}(\varphi), \boldsymbol{e}) \right) - e_j \right]. \quad (22)$$

where $\frac{1}{1-\delta} \pi_k^s(c, e_k) - e_k$ is the net profit earned by Firm k when it is the exclusive licensee with a zero per-unit royalty and $\hat{\boldsymbol{\rho}}(\varphi) = (c_1 + \hat{r}_1(\varphi), c_2 + \hat{r}_2(\varphi))$. If $\hat{r}_j(\varphi) = r_j^*$ for $j \in N$, this inequality cannot be satisfied if there are efficiencies from licensing both firms. If $\hat{r}_j(\varphi) = 0$, this inequality is satisfied if Firm k's monopoly profit with a zero royalty exceeds the total profit earned by both licensees with a zero royalty. Furthermore, the right-hand side of (22) is a continuous function of $\hat{r}_j$ for $j = 1, 2$. Therefore there exist per-unit royalties $\hat{r}_j$ for which the inequality is satisfied. Moreover, $\hat{r}_j = 0$ when $\varphi = 0$, $\hat{r}_j = r_j^*$ when $\varphi = 1$, and is non-decreasing in φ for $\varphi \in (0, 1)$. Therefore there exists an enforcement level $\hat{\varphi}$ for which it is optimal for the licensor to license a single firm exclusively if $\varphi < \hat{\varphi}$.

Proof of Proposition 10: Part (i) follows directly from equation (18) and part (ii) from equation (19). Part (iii) follows by solving for the critical value of the enforcement probability for which $r^c(\varphi) = r^*$.

Appendix B: Alternative damage rules

1. Unjust enrichment

Suppose that damages for cheating on a licensing contract by failing to report royalties are proportional to the profit that the licensee unjustly earns with the licensor's technology. As in the main text we assume the licensor chooses a per unit royalty r and the licensee uses the licensed technology to produce a product with constant marginal cost c and demand $q(p)$. If the licensor detects underpayment, she can sue for damages, which incurs a litigation cost K_p. A court verifes infringement with probability φ and if $s > 0$ assesses damages

$$D^\pi = \tilde\pi - \pi,$$

where

$$\tilde\pi = \max_q(p - c - r(1 - s))q$$

is the licensee's profit when it under-reports royalties and

$$\pi = \max_q(p - c - r)q$$

is the licensee's profit when it reports royalties truthfully. The difference $\tilde\pi - \pi$ measures the amount by which the licensee has profited by failing to report royalties. This is the licensee's unjust enrichment.

Licensee j's expected profit in the period during which cheating occurs is

$$\begin{aligned}
\pi_j^c &= \tilde\pi_j - \varphi D^\pi \\
&= \varphi\pi_j(p_i^*, c + r(1 - s), \boldsymbol{e}) + (1 - \varphi)\pi(p_i^*, c, \boldsymbol{e})
\end{aligned}$$

Lemma A2.1: *Given $\varphi < 1$, the licensee will choose $s = 1$ if he cheats.*

Proof. Follows from $\frac{d}{ds}\pi_j(p_i^*, c + r(1 - s), \boldsymbol{e}) > 0$. ∎

The licencee's expected profit from cheating is

$$\Pi_j^c = \pi_j^c + \varphi \frac{\delta}{1-\delta} \varphi(1-\alpha)\pi_j(p_i^*, c+r, \boldsymbol{e}) + (1-\varphi)\delta\Pi_j^c,$$

where δ is the discount factor. Re-arranging terms,

$$\Pi_j^c = \frac{1}{1-\delta(1-\varphi)}\left[\pi_j^c + \frac{\delta}{1-\delta}\varphi(1-\alpha)\pi_j(p_i^*, c+r, \boldsymbol{e})\right]$$

and the licensee will not cheat if

$$\frac{1}{1-\delta}\pi_j(p_i^*, c+r, \boldsymbol{e}) \geq \Pi_j^c.$$

This condition is

$$\pi_j(p_i^*, c+r, \boldsymbol{e}) \geq (\gamma^\pi)\pi(p_i^*, c, \boldsymbol{e}) \tag{23}$$

where

$$\gamma^\pi = \frac{1}{1+\alpha\left(\frac{\delta}{1-\delta}\right)\left(\frac{\varphi}{1-\varphi}\right)}. \tag{24}$$

For the log-linear example, the critical royalty for which truthful reporting is incentive compatible is

$$r^c(\varphi) = c\left[\left(\frac{1}{\gamma^\pi}\right)^{\frac{1}{\eta-1}} - 1\right]$$

Note that $\gamma^\pi < \gamma$ if $\varphi > 0$. Compared to damages equal to unpaid royalties, unjust enrichment damages allow the licensor to charge a higher per-unit royalty without inducing the licensee to cheat on his royalty obligations.

All of the propositions in the main text continue to hold when damages equal unjust enrichment. The analogy to Proposition 4 holds because when damages are equal to unjust enrichment,

$$\frac{dr_j}{d\varphi} = -\left(\frac{d\gamma^\pi}{d\varphi}\right)\frac{\pi(p_i^*, c, \boldsymbol{e})}{q(p_i^*, c+r, \boldsymbol{e})} \geq 0.$$

2. Termination of the licensing contract

Suppose the licensor detects cheating with probability φ and revokes the license in the next period if cheating is detected. There are no damages other than the revocation of the license. This scenario may apply if the licensor cannot appeal to a court or other authority to enforce the licensing agreement and if the licensor has no collateral. If the licensee cheats, he should fail to report all contractually specified royalties ($s = 1$) as this maximizes his profit from cheating. The probability φ is a unilateral choice by the rights owner.

To facilitate comparison with other damage rules, we continue to assume that the licensee can renegotiate the contract following an episode of under-reporting and that renegotiation costs the licensee a fraction α of the royalties that the licensee would earn if he had not cheated. Under these assumption, and given that the licensee earns zero profit without the licensed technology, the licensee's expected profit from cheating for the period in which the cheating occurs is

$$\pi_j^c = \pi_j(p_i^*, c, \boldsymbol{e})$$

The licencee's expected profit from cheating is

$$\Pi_j^c = \pi_j^c + \varphi \frac{\delta}{1-\delta} \varphi(1-\alpha)\pi_j(p_i^*, c+r, \boldsymbol{e}) + (1-\varphi)\delta\Pi_j^c,$$

where δ is the discount factor. Hence,

$$\Pi_j^c = \frac{1}{1-\delta(1-\varphi)}\left[\pi_j(p_i^*, c, \boldsymbol{e}) + \frac{\delta}{1-\delta}\varphi(1-\alpha)\pi_j(p_i^*, c+r, \boldsymbol{e})\right]$$

and the licensee will not cheat if

$$\frac{1}{1-\delta}\pi_j(p_i^*, c+r, \boldsymbol{e}) \geq \Pi_j^c.$$

This condition is

$$\pi_j(p_i^*, c+r, \boldsymbol{e}) \geq (\gamma^x)\pi(p_i^*, c, \boldsymbol{e}) \tag{25}$$

where

$$\gamma^x = \frac{1}{1 + \alpha\varphi\left(\frac{\delta}{1-\delta}\right)}. \tag{26}$$

For the log-linear example, the critical royalty for which truthful reporting is incentive compatible is

$$r^c(\varphi) = c\left[\left(\frac{1}{\gamma^x}\right)^{\frac{1}{\eta-1}} - 1\right].$$

Note that $\gamma^x = \gamma$. Compared to damages equal to unpaid royalties, the maximum per-unit royalty for which truthful reporting is incentive compatible is lower when damages for under-reporting results in termination of the licensing contract. The difference between the two damage regimes is that a licensee who is found liable for cheating does not have to pay back under-reported royalties when damages result only in the termination of the contract (assuming the same α in both regimes). Consequently, the licensee has a greater incentive to cheat and the royalty required to prevent cheating is lower. However, the threat of termination can allow a higher incentive compatible royalty if $\alpha = 1$ with termination (no future benefits to the licensee) but $\alpha < 1$ when damages for under-reporting are proportional to unpaid royalties.

All of the propositions in the main text continue to hold in this scenario. The analogy to Proposition 4 holds because when the penalty is revocation of the license,

$$\frac{dr_j}{d\varphi} = -\left(\frac{d\gamma^x}{d\varphi}\right)\frac{\pi(p_i^*, c, \boldsymbol{e})}{q(p_i^*, c+r, \boldsymbol{e})} \geq 0.$$

Observation: Observe that the highest incentive compatible running royalty can be ranked in the following way

$$r(\text{unjust enrichment}) \geq r(\text{reasonable royalty}) \geq r(\text{termination of contract})$$

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