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 model contract enforcement as a game with perfect information but probabilistic enforcement and explore the implications of weak enforcement on the design of licensing contracts, the 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. With imperfect enforcement, the licensor lowers variable royalties to reduce cheating. Although imperfect contract enforcement reduces the profits of the licensor, weak enforcement lowers prices, increases downstream innovation, and in some circumstances can increase total economic welfare.

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1 Introduction

A predicate for a strong intellectual property regime is the ability to enforce licensing contracts. Technology licensing contracts commonly require the licensee to pay the licensor a combination of fixed and variable fees. Variable fees, also called "running royaties", promote efficient technology transfer but are vulnerable to under-reporting. 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). 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; Gallini and Lutz, 1992), 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 running royalties allows a licensor to extract more revenue from licensees that differ in their willingness to pay for the technology (Schmalensee, 1981). Royalties that depend on sales also allow a licensor to soften competition for products that employ the licensed technology, potentially increasing the total profits available to the licensor and licensees (Kamien, 1992, Hernández-Murillo and Llobet, 2006).

We study the implications of weak contract enforcement for prices and investment incentives when licenses employ per-unit fees to soften competition, although our analysis is applicable to other licensing arrangements in which the use of variable fees increases joint profits. The form of the intellectual property right is not crucial for the analysis; we assume that it is a patent. 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.

High per-unit royalties maximize joint profits when licensees supply products that are close substitutes, but also reduce incentives for downstream innovation. Weak enforcement constrains the maximum royalty that the licensor can charge without inducing licensees to cheat and, if the constraint is binding, lowers the profit of the licensor. Nonetheless, a central conclusion is that weak enforcement increases incentives for innovation by 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), Aoki and Hu (1999), and Schankerman and Scotchmer (2001). In these papers the purpose of the license is to offer an alternative to infringing conduct and licensing, when it occurs, is enforced perfectly. In the contexts studied by these authors, weak patents encourage licensing, which discourages wasteful efforts to invent around the patent. In our model, the licensed technology is valid and would be infringed without a license. Weak contract enforcement causes the licensor to reduce royalties, which has the beneficial effect of increasing incentives for productive efforts to improve upon the licensed technology.

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 opportunistically in ways that contravene 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 because it 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.[1]

Our analysis is related to the literature on cumulative innovation (Scotchmer, 1991, Green and Scotchmer, 1995) in that a focus is on innovation by technology users. Contract enforcement in our model is similar in some respects to the scope of protection for upstream innovation in Green and Scotchmer (1995). Our results contrast with those in Spulber (2013), who concludes that strong intellectual property rights complement competition in creating incentives for innovation. However, Spulber (2013) does not consider downstream innovation by technology users. 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. Weak contract enforcement promotes downstream 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.

Competition does not have an equivalent salutory effect on upstream innovation in our model as it does in Spulber (2013) because the licensor would use variable royalties to soften competition if contracts are perfectly enforceable. Moreover, we find that perfect contract enforcement is never welfare maximizing. Reduced contract enforcement increases economic welfare by improving downstream innovation and lowering prices.

2 The structure of production and investment

There is a single upstream firm denoted by U and two downstream firms denoted by $j = 1, 2$. To simplify the analysis we assume the downstream firms are symmetric. The upstream firm invests $u > 0$ to develop a new technology that enables production at constant marginal cost

[1] 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).

c. The technology is protected by a valid patent which we assume, for simplicity, has infinite duration. The upstream firm does not produce final goods, but instead licenses the technology to the downstream firms, each of which may invest to increase the value of the technology. Production or sale of the downstream products infringes the upstream technology and cannot lawfully occur without a license. The incremental cost of licensing is zero.

With perfect information the licensor could design a contract that rewards licensees only if they choose the joint-profit-maximizing outputs and investments. We reasonably assume this is not feasible. Such forcing contracts would not be optimal in a practical situation with uncertain demand and imperfect monitoring because joint-profit-maximizing investments would also be uncertain.

Instead, we assume the licensor may charge Firm j a per-unit royalty r_j as well as a fixed fee F_j.[2] 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. Production with the licensed technology repeats indefinitely under stationary conditions.

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.

[2] Our analysis can be extended to more general nonlinear contracts, though with considerable additional complexity.

3 Contracting and Timing

We are concerned with the enforcement of licensing contracts and how imperfect enforcement affects contract design, competition and innovation. 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 given that 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, $F_j^s > 0$ and $r_j^s = 0$ (O'Brien and Shaffer, 1992). We assume that with perfect contract enforcement joint profits are maximized when both firms take a license.

Suppose that Firm U has developed a new technology (invested u) and offers contracts to downstream firms. We begin by assuming upstream investment is fixed and suppress u from the analysis.

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.
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 or other enforcement body 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.

Our contracting game parallels the ex ante negotiation in Green and Scotchmer (1995). There, as here, the upstream and downstream inventors negotiate over contract terms before the downstream firms make irreversible investments. We depart from Green and Scotchmer (1995) in that we give all the bargaining power to the upstream inventor. 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 if they accept the offered contracts, as to do otherwise would result in negative profits. The analysis can be extended to allow a division of profits in a straightforward manner.

We model contract enforcement as a game with perfect information but probabilistic enforcement. The licensor can costlessly audit the outputs of her licensees and determine whether they are in compliance with the licensing contracts. If a licensee under-reports royalties, the licensor can (costlessly) raise this issue with a court or other enforcement agency. The court has imperfect information about compliance and imposes penalties for the underpayment of royalties with probability φ (the "enforcement probability"). This probability depends, for example, on rules of evidence and the competences of court members. If there is insufficient evidence to verify cheating, the licensee will not be forced to pay the correct amount of royalties or be penalized in later periods. We assume there is no litigation risk if the licensee reports truthfully. We further simplify by assuming φ is constant and independent of the licensee.[3]

[3] We simplify the enforcement game because our focus is on the implications of imperfect enforcement of licensing contracts for outputs and investments and not on mechanism design to elicit private information about contract compliance. Examples of auditing games with asymmetric information and costly verification include Reinganum and Wilde (1986), Cremer and Gahvari (1993) and Choe (1998).

4 Perfect contract enforcement

Let (p_1^*, p_2^*) denote the equilibrium downstream prices when both firms report their royalty obligations truthfully and let (e_1^*, e_2^*) and (q_1^*, q_2^*) be the corresponding downstream investments and outputs. With perfect contract enforcement and symmetric but differentiated downstream firms, the upstream firm will offer the same contract (r, F) to both downstream firms. Firms will choose the same equilibrium prices, investments and outputs, however we retain the subscripts when needed for clarity.

The upstream firm chooses (r, F) in order to maximize

$$\Pi^U = 2\left[F + \frac{1}{1-\delta} r q_j^*\right]$$

subject to the the licensees' pricing and investment choices. Conditional on (e_1, e_2), define

$$p_j^* = \arg\max_{p_j} \pi_j(\boldsymbol{p}, c+r, \boldsymbol{e}).$$

Downstream firms choose investments

$$e_j^* = \arg\max_{e_j} \left(\frac{1}{1-\delta}\pi_j\left(\boldsymbol{p}^*, c+r, \boldsymbol{e}\right) - e_j\right)$$

and the participation constraint is

$$F \leq \frac{1}{1-\delta}\pi_j\left(\boldsymbol{p}^*, c+r, \boldsymbol{e}^*\right) - e_j^*.$$

Let

$$\pi_j^* = \pi_j\left(\boldsymbol{p}^*, c+r_j, \boldsymbol{e}\right).$$

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

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

The proof of this lemma is in the Appendix. 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 (Edlin and Shannon, 1998). Note that $sign\left(\frac{de_i}{dr_j}\right) = sign\left(\frac{de_j}{dr_j}\right)$ if investments are strategic complements, $\frac{\partial^2 \pi_i^*}{\partial e_j \partial e_i} > 0$.

The licensor's present discounted profit is equivalent to

$$\Pi^U(r) = \sum_{j=1,2}\left[\left(\frac{1}{1-\delta}\right)\left(\pi_j\left(\boldsymbol{p}^*, c + r_j, \boldsymbol{e}^*\right) + rq_j^*\right) - e_j^*\right].$$

Assumption 2 (Uniqueness):

i) To ensure a unique equilibrium in the price setting game we assume that the downstream profit functions have negative semi-definite Hessians conditional on investments.

ii) To ensure that the optimal investments are positive and unique we assume that $\partial \pi_j^* / \partial e_j > 0$ *at* $e_j = 0$ *and* $\lim_{e_j \to \infty} \partial \pi_j^* / \partial e_j < 0$.

iii) To ensure that the licensor's optimal royalty is unique we assume that $\Pi^U(r)$ *is a concave function of* r.

The first two parts of Assumption 2 are standard assumptions. The third part follows from the concavity of the profit functions if the Nash equilibrium prices p_j^* are not too convex functions of r.

Let r_j^* denote the licensor's optimal per-unit royalties with perfect contract enforcement.

5 Enforcement of licensing contracts

We now consider how the enforcement constraint affects the licensor's optimal royalties. We analyze the consequences of failing to pay specified royalties in the context of prevailing patent and contract law.

5.1 Breach penalities and patent damages

Cheating exposes a licensee to damages. Patent law governs the award of damages for infringement of a valid patent. The patent owner is entitled to compensation for past damages and a court may honor a request for a permanent injunction that prevents future infringing conduct. When the patent owner practices the patent, the award may compensate for lost profits.[4] For a non-practicing patent owner, such as the research firm in our model, damages compensate for unpaid royalties.[5]

Courts can impose penalties up to three times the level of a reasonable royalty and award attorney's fees to the prevailing patentee for "willful infringement" of a valid patent.[6] A sufficiently large penalty would deter cheating on a licensing agreement. Although patent owners commonly allege willful infringement in litigation, courts typically do not assess treble damages even in cases where willful infringement has been established (Moore, 2004).[7] Moreover, a licensee that fails to pay royalties could escape a finding of willful infringement by invoking any of several reasons that licensees frequently cite to explain under-payments. Although 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 as differences in contract interpretation.[8] For these reasons,

[4] Schankerman and Scotchmer (2001), Choi (2009), Henry and Turner (2010), and Aoki and Hu (1999) consider the implications of alternative damages rules to compensate a patent owner for lost profits from patent infringement. Lost profits are irrelevant if, as we assume, the technology owner does not make or sell a product in competition with her licensees.

[5] Patent law entitles the patent owner to a "reasonable royalty" as compensation for past infringement. ("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." (35 U.S.C. § 284))

[6] 35 U.S.C. §284 (2000).

[7] In a study of cases alleging patent litigaton in the period 1999-2000, courts established willful infringement in about half of all litigated cases for which there was a finding of liability for patent infringement. However, courts enhanced damages in only about half of these cases and imposed treble damages in less than ten percent of these cases. Moreover, only a small fraction of cases alleging patent infringement end with a decision by the court. (Moore, 2004)

[8] 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

in what follows we assume that courts do not impose damages in excess of unpaid royalties.

Alternatively, patent owners could require licensees to post a bond that would be forfeited if the licensee cheats. With a large enough bond, the licensee would never cheat. However, the intersection of contract and patent law does not accommodate this enforcement strategy. Contract law permits liquidated damages, such as the forfeiture of a bond, as compensation for breach, but the amount cannot exceed a reasonable estimation of the party's expected interest from performance under the contract. If the court can place a monetary value of the party's interest, as would be the case in our situation where damages are unpaid royalties, liquidated damages cannot exceed that monetary value.[9]

For these legal reasons, we assume that a licensee must reimburse the licensor if a court finds that a licensee has failed to pay required royalties. In addition, we assume that cheating, if detected and enforced, would constitute patent infringement and entitle the patent owner to a permanent injunction against future use of the licensed technology.[10] Our base case assumes that the patentee terminates her relationship with the licensee after the award of a permanent injunction. An injunction is consistent with a profit-maximizing licensing program if the licensor can turn to other, equally efficient, licensees. For completeness we also consider the consequences of cheating in licensing arrangements when the patent owner and the licensee would renegotiate a new license following the award of a permanent injunction, as well as infringement penalties that do not involve a permanent injunction.

5.2 Incentive compatible licenses with no downstream investment

Suppose a licensee fails to pay a fraction $s > 0$ of the contractually specified royalties. The licensor can detect this underpayment and (costlessly) sue for damages. We first consider how

not apply after Microsoft acquired Nokia's handset business (Waters, 2014). Under-reporting also can occur from disallowed deductions, misuse of transfer prices, and failure to report sub-licenses.

[9]See Edlin and Schwartz (2003), citing Restatement (Second) of Contracts § 356(1) (1979); U.C.C. § 2-718(1) (1987).

[10]The Supreme Court's 2006 decision in *eBay Inc. v. MercExchange* imposed conditions for the grant of a permanent injunction, but these new requirements did not substantially lower the frequency with which most courts issued injunctions for research firms such as the licensor in our model (Seaman, 2016).

imperfect enforcement affects the design of licensing contracts when investments are fixed and independent of contract terms. We postpone the implications of investment for the next section and drop $\boldsymbol{e}$ from the notation in this section.

A licensee that under-reports royalties by s_j in the current period must pay damages if the licensor brings suit for underpayment of the royalty and the suit results in a finding of liability. The damages are[11,12]

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

where s_j is the underpayment and r_j is the per-unit royalty. In addition, we assume that a determination of liability entitles the licensor to a permanent injunction that prevents future use of the patented technology. We first assume that the licensor invokes this injunction and terminates its relationship with the licensee if the licensee is found liable for cheating.

The licensee's current period expected profit from under-payment of royalties is

$$\pi_j^c(p_i, s_j, \varphi) = \max_{p_j} \left[(p_j - (c + (1 - s_j)r_j)q_j(\boldsymbol{p}) - \varphi D(s_j, \boldsymbol{p})\right] \tag{1}$$

where φ is the enforcement parameter, the probability that a court confirms cheating given that it occurs.[13]

Let δ be the per-period discount factor. If the licensee cheats, his expected present-value profits are[14]

$$\Pi_j^c = \pi_j^c(p_i, s_j, \varphi) + (1 - \varphi)\delta\Pi_j^c. \tag{2}$$

[11] As noted above, courts typically do not require monetary compensation in excess of a reasonable royalty for patent infringement.

[12] Damages based on the royalties that a firm reasonably should have paid are circular if "reasonable" is determined by the 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 and can convince a court that she would have charged and collected this royalty if the contract were enforced perfectly.

[13] The expected value of the enforcement parameter is typically much less than one. Courts find no liability in about half of litigated cases, either because the patent was not infringed, was invalid, or otherwise not enforceable. See Moore (2004) and Allison and Lemley (1998).

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

The first term in (2) is the profit from cheating in the period during which the cheating occurs. The second term is the expected present-value profit if the licensee escapes a finding of liability. The licensee earns nothing if found liable for cheating.

Re-arranging terms,

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

Lemma 2. *The licensee will choose* $s_j = 1$ *if he cheats.*

The proof follows directly from the licensee's profit, equation (1). Given the envelope condition for prices, the licensee's profit is a maximum when $s_j = 1$ if $\varphi < 1$.

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 due to imperfect contract enforcement and there might be other markets where cheating is infeasible.

From equation (1) with $s_j = 1$, cheating exposes the licensee to an effective per-unit royalty

$$\rho_j = c + \varphi r_j.$$

The corresponding profit-maximizing price and expected present-value profit if the licensee cheats is

$$\hat{p}_j = \arg\max_{p_j} \pi_j(p_j, p_i, c + \varphi r_j)$$

and

$$\Pi_j^c = \frac{\pi_j(\hat{p}_j, p_i^*, c + \varphi r_j)}{1 - \delta(1-\varphi)}. \quad (3)$$

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

$$\Pi_j^* = \frac{\pi_j\left(p_j^*, p_i^*, c + r_j\right)}{1-\delta}. \tag{4}$$

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

Proposition 1. *Suppose the penalty for under-reporting royalties is a monetary payment*

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

followed by termination of the license. Furthermore, suppose cheating is enforced with probability $\varphi \in [0, 1)$. *Given* r_j, *the licensee will not under-report if and only if* [15,16]

$$\pi_j\left(p_j^*, p_i^*, c + r_j\right) \geq \gamma \pi_j(\hat{p}_j, p_i^*, c + \varphi r_j), \tag{5}$$

where

$$\begin{aligned} p_j^* &= \arg\max_{p_j} \left[(p_j - c - r_j) q_j(p_j, p_i^*)\right], \\ \hat{p}_j &= \arg\max_{p_j} \left[(p_j - c - \varphi r_j) q_j(p_j, p_i^*)\right], \end{aligned}$$

$$\gamma = \frac{1}{1 + \frac{\varphi\delta}{1-\delta}} \tag{6}$$

and δ *is the discount factor* $\in [0, 1)$.

Firm j will not under-report royalties if $\Pi_j^* \geq \Pi_j^c$. Substituting equations (3) and (4), rearranging terms, and using equation (6) gives the inequality (5).

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

[16] 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

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

We sometimes replace inequality (5) with the more economical expression

$$\pi_j^*(p_i^*) \geq \gamma \pi_j^c(p_i^*, \varphi).$$

The contracting game assumes that downstream firms choose prices simultaneously. This implies that Firm $i \neq j$ does not respond to $\hat{p}_j$ by choosing a price different from the price p_i^* that it would have chosen if Firm j had reported 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 competitive price response.

Our interest is in the relationship between the parameter γ, and particularly the enforcement parameter φ, and the maximum per-unit royalty that the licensor can charge without inducing the licensee to cheat. It is easier to sustain truthful reporting if γ is small. The parameter γ falls if the discount rate δ or the enforcement probability φ is increased. The licensee has an incentive to cheat for any $r_j > 0$ if either δ or φ is zero.

Write the incentive compatibility constraint (5) as

$$\Psi_j(r_j) = \pi_j\left(p_j^*, p_i^*, c + r_j\right) - \gamma \pi_j(\hat{p}_j, p_i^*, c + \varphi r_j) \geq 0. \tag{7}$$

Given the discount factor δ, let $r(\varphi)$ be the (symmetric) maximum per-unit royalty that satisfies $\Psi_j(r) \geq 0$ and define the profit-maximizing royalty

$$\hat{r}(\varphi) = \min(r(\varphi), r^*), \tag{8}$$

where r^* is the optimal royalty with perfect contract enforcement. The incentive-compatibility constraint is binding if $\hat{r}(\varphi) = r(\varphi)$. Otherwise, $\hat{r}(\varphi) = r^*$.

To obtain unambiguous results, we strengthen Assumption 2 and require

Assumption 3. $\eta_j = -d \log q_j(\boldsymbol{p})/d \log p_j$ *is weakly increasing in* p_j.

This assumption assures that downstream prices are increasing functions of the per-unit royalty. The Appendix shows that Assumption 3 is sufficient (but not necessary) to prove that

$\Psi_j(r_j)$ is weakly decreasing in r_j. This result is useful to prove the following proposition.

Proposition 2. *$\hat{r}(\varphi)$ exists and is unique. Furthermore, $r(\varphi)$ is increasing in φ.*

The proof is in the Appendix. Note that when $\varphi = 0$, condition (7) is satisfied with equality at $r(0) = 0$.

Corollary 1. *Stronger enforcement ($\varphi' > \varphi$) implies weakly lower downstream output.*

Given Assumption 3, each downstream firm's output is a weakly declining function of the firm's per-unit royalty, which is non-decreasing in φ if $r(\varphi) < r^*$. Stronger enforcement has no effect if the enforcement constraint is not binding, corresponding to $r(\varphi) \geq r^*$.

In our licensing model the licensor chooses a per-unit royalty such that licensees have no incentive to cheat on the licensing contract. We could extend our model to allow for 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.[17] 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.

5.2.1 Post-injunction renegotiation

At the time an injunction is awarded the licensee has made investments in developing the product. Hence there are gains from negotiating a new license contact instead of signing a contract with a new licensee. We have assumed that the licensor has all the bargaining power and, consequently, the new contract (F^n, r^n) will extract all profit from the licensee, excluding the licensee's sunk cost. If the enforcement probability is unchanged, the running royalty will be the same as before the injunction and the fixed fee F^n will extract all future downstream profits.

[17] Schuett (2012) considers the probabilistic enforcement of contract terms for patent licenses that contain a field-of-use restriction.

Under these assumptions, post-injunction renegotiation does not change the right-hand side of inequality (5). Consequently, the incentive compatibility condition and the profit-maximizing royalty $\hat{r}(\varphi)$ are unaffected by the potential for post-injunction renegotiation.

Alternatively, if a court finds liability for cheating, the licensor and licensee could agree to a new contract with conditions that penalize the licensee and facilitate enforcement, such as restrictions that limit the licensee to particular fields of use. The expectation of lower profits if a court rules that a licensee has violated the terms of the contract can discourage cheating even if a court would not impose an injunction on further use of the licensed technology.

5.2.2 Competition and incentive compatible royalties

How does downstream competition influence the enforcement constraint and the maximum sustainable per-unit royalty? 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. Let ζ denote the degree of downstream competition as indexed by the cross-elasticity of demand.

Proposition 3. *Assume that market A is more competitive than market B in the sense that $\zeta_A > \zeta_B$ for all prices in the interval $[\hat{p}_j^k, p_j^{*k}]$ for $j = 1, 2$ and $k = A, B$. The maximum sustainable per-unit royalty is weakly lower for market A than for market B if, for all $\varphi \in [0, 1)$,*

$$\frac{\pi_j^{cA}(p_i^{*A}, \varphi)}{\pi_j^{*A}(p_i^{*A})} > \frac{\pi_j^{cB}(p_i^{*B}, \varphi)}{\pi_j^{*B}(p_i^{*B})}, \tag{9}$$

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

The proof follows directly from the incentive compatibility constraint (5).

In response to an increase in competition in markets that satisfy the ratio condition (9), the licensor must reduce the per-unit royalty in order to prevent under-reporting in equilibrium. Under-reporting is more attractive in a market with higher cross-price elasticity because a price cut would attract more buyers from the competing licensee and increase the ratio of the cheating profit to the no-cheating profit (condition (9)). This result in 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.

Proposition 3 offers a way to test whether a more competitive market has a lower sustainable royalty. It is easily verified that condition (9) is satisfied for symmetric Hotelling demand on the unit interval with values $v - \frac{1}{\tau}x_j$ for consumption of one unit sold by Firm j to a customer located at a distance x_j from the point of sale and with $v\tau > 1$ so the market is fully covered at equilibrium prices. The market share of Firm j is

$$x_j = \frac{\tau}{2}(p_i - p_j + \frac{1}{\tau})$$

and the degree of competition is indexed by τ. The joint-profit-maximizing per-unit royalty is

$$r^* = v - \frac{3}{2\tau}.$$

The maximum royalty that does not induce cheating is

$$r(\varphi) = \left(\frac{2}{\tau(1-\varphi)}\right)\left(\frac{1-\sqrt{\gamma}}{\sqrt{\gamma}}\right).$$

With symmetric Hotelling demand, the optimal royalty with perfect contract enforcement is an increasing function of the competition parameter, τ. The constrained royalty $r(\varphi)$ has the opposite dependence on the competition parameter. Holding φ and δ constant, greater competition makes cheating more attractive and lowers the incentive compatible royalty. See Figure 1.

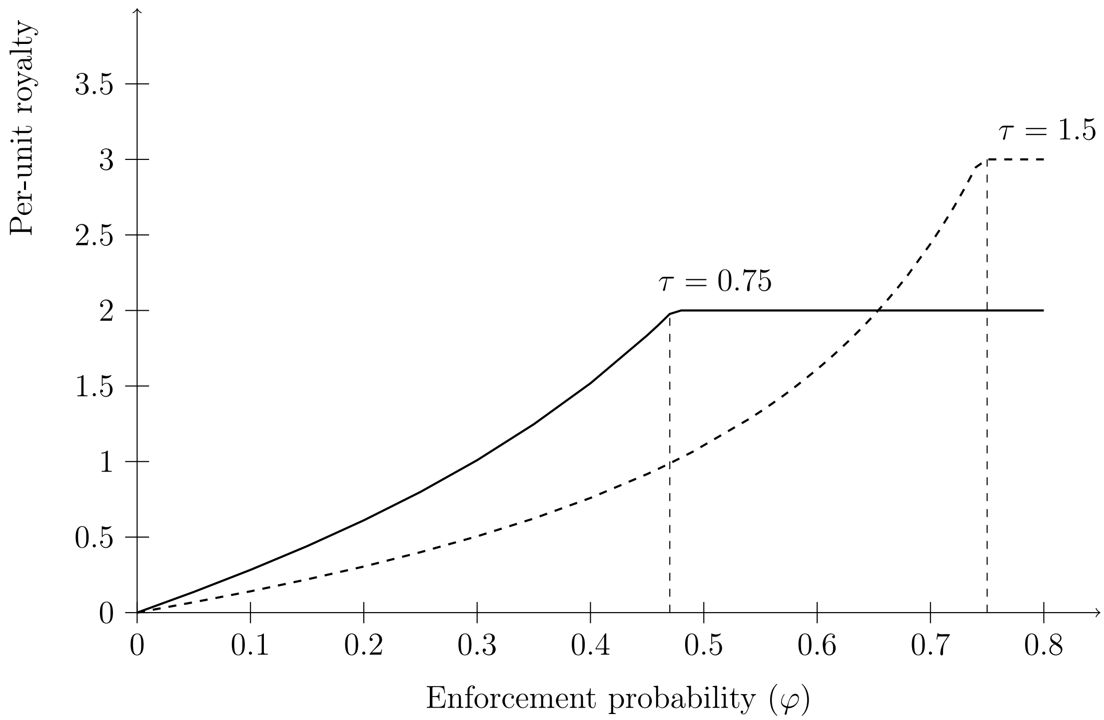

Figure 1: Profit-maximizing royalty with symmetric Hotelling demand ($v = 4$).

In contrast, with symmetric log-linear demand

$$q_j(\boldsymbol{p}) = Ap_j^{-\eta}p_i^{\zeta},$$

the incentive compatibility condition is independent of the level of competition, indexed by the cross-price elasticity ζ. An increase in ζ changes the licensee's profit proportionally with and without under-reporting and hence the ratios in inequality (5) are independent of the level of competition.

With symmetric log-linear demand and perfect contract enforcement, the optimal per-unit royalty is

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

where $D = \zeta/\eta$ is the diversion ratio defined by

$$D = -\frac{dq_i/dp_j}{dq_j/dp_j}.$$

The optimal royalty with perfect contract enforcement is an increasing function of the diversion ratio given the stability condition $\eta(1 - D) > 1$.

The maximum per-unit royalty that satisfies the incentive compatibility constraint (5) is

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

which is independent of the diversion ratio.

Define the critical level of the enforcement parameter φ^c by the smallest value of φ for which enforcement is not a binding constraint on the licensor's profit-maximizing per-unit royalty:

$$r(\varphi^c) = r^*.$$

Although the constrained royalty $r(\varphi)$ is independent of demand when demand is log-linear, the critical value of the enforcement parameter φ^c increases with the level of competition. See Figure 2.

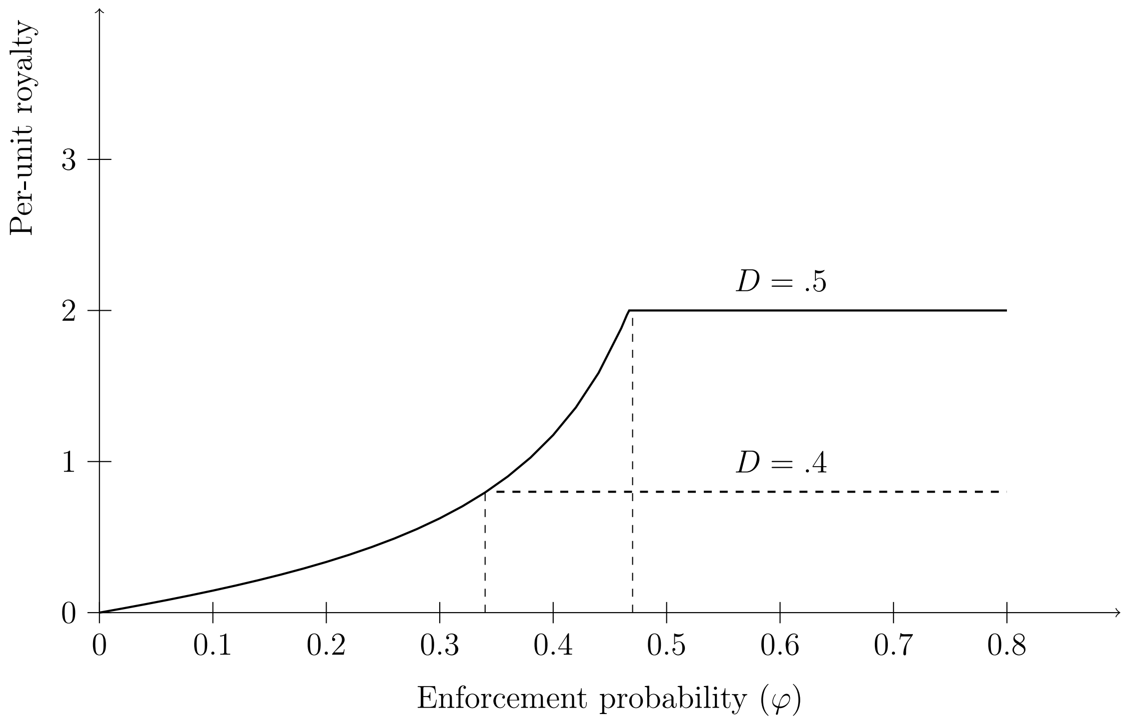

Figure 2: Profit-maximizing royalty with symmetric log-linear demand ($c = 1$, $\eta = 2.5$).

5.3 Incentive compatible licenses with downstream investment

Downstream investment adds an additional complication to the licensor's problem of optimal contract design. It is no longer sufficient to focus solely on the incentive compatibility condition at the third stage of the game. It is also necessary to consider the licensee's investment incentives at the second stage of the game and how they influence the licensee's incentives to cheat at the third stage.

Adding downstream investment, the incentive compatibility condition for honest reporting at the third stage of the contracting game becomes

$$\Psi_j(r_j, \boldsymbol{e}) = \pi_j \left(p_j^*, p_i^*, c + r_j, \boldsymbol{e}\right) - \gamma \pi_j(\hat{p}_j, p_i^*, c + \varphi r_j, \boldsymbol{e}) \geq 0. \tag{10}$$

Proposition 4.

(i) Downstream investment does not affect the licensor's profit-maximizing royalty if demand

is a separable function of investment: $q_j(\boldsymbol{p}, \boldsymbol{e}) = f(\boldsymbol{e})\tilde{q}(\boldsymbol{p})$*. The licensor's optimal royalty is* $\hat{r}_j(\varphi)$*, the largest per-unit royalty for which* $\Psi_j(r_j, \boldsymbol{e}) \geq 0$.

(ii) If demand is not a separable function of investment, the licensor's optimal royalty is $\hat{r}^e_j(\varphi) \leq \hat{r}_j(\varphi)$*. Downstream investment forces the licensor to choose a weakly lower royalty when contract enforcement is imperfect.*

Part (i) of Proposition 4 follows immediately because the sign of the incentive compatibility condition (10) is independent of downstream investment if demand is a separable function of investment.

For part (ii), note that a licensee that reports honestly at stage 3 will choose an investment level at stage 2 that solves

$$e^*_j = \arg\max \left[\frac{1}{1-\delta}\pi_j\left(p^*_j, p^*_i, c + r_j, \boldsymbol{e}\right) - e_j\right], \tag{11}$$

while a licensee that plans to cheat at stage 3 will choose an investment level at stage 2 that solves

$$\hat{e}_j = \arg\max \left[\frac{1}{1-\delta(1-\varphi)}\pi_j(\hat{p}_j, p^*_i, c + \varphi r_j, \boldsymbol{e}) - e_j\right]. \tag{12}$$

When $\Psi_j(r_j, \boldsymbol{e}) = 0$, there is generally an investment level $\hat{e}_j \neq e^*_j$ for which the licensee would earn more by choosing $\hat{e}_j$ and under-reporting at stage 3 if $r_j = r_j(\varphi)$, because the licensee's marginal product of investment differs when the licensee cheats compared to honest reporting. The licensor must prevent cheating to earn royalty income. The licensor's optimal strategy is to choose a weakly lower royalty $\hat{r}^e_j(\varphi)$ for which $\Psi_j(r_j, \hat{e}_j, e^*_i) \geq 0$. The ability to cheat at stage 3 determines the licensee's investment at stage 2, $\hat{e}_j$. The licensor's optimal royalty is the largest royalty for which the licensee will report honestly at stage 3 given the investment level $\hat{e}_j$, knowing that any larger royalty will induce the license to cheat at stage 3. Assumption 3 guarantees the existence of an optimal royalty $\hat{r}^e_j(\varphi) \leq \hat{r}_j(\varphi)$, because $\Psi_j(r_j, \boldsymbol{e})$ is decreasing in r_j.

Figure 3 illustrates this outcome. The figure assumes that the per-unit royalty is the value $r(\varphi)$ that maximizes the licensor's profit when the licensee chooses e^*_j, corresponding to truthful reporting, so that $\Psi_j(r(\varphi), \boldsymbol{e}^*) = 0$. The horizontal axis is the licensee's investment, e_j, as is the dashed line. The thick line is the licensee's (gross) profit with honest reporting, $\pi_j\left(p_j^*, p_i^*, c + r_j, \boldsymbol{e}\right)/(1-\delta)$. The thin line is the licensee's (gross) profit with under-reporting reporting, $\pi_j(\hat{p}_j, p_i^*, c+\varphi r_j, \boldsymbol{e})/(1-\delta(1-\varphi))$. The incentive compatibility condition is satisfied with equality at $e_j = e_j^*$: the two upper lines intersect at this level of investment.[18] However, the licensee is strictly better off by choosing $\hat{e}_j < e_j^*$ and under-reporting. The licensor must choose a lower royalty to avoid cheating. The licensor chooses the largest royalty for which $\Psi_j(r_j, e_j, e_i^*) \geq 0$ when $e_j = \hat{e}_j$. This defines $r_j^e(\varphi) \leq r(\varphi)$. The licensee reports honestly in equilibrium, but the royalty is determined by the potential for the licensee to invest and cheat off the equilibrium path.[19]

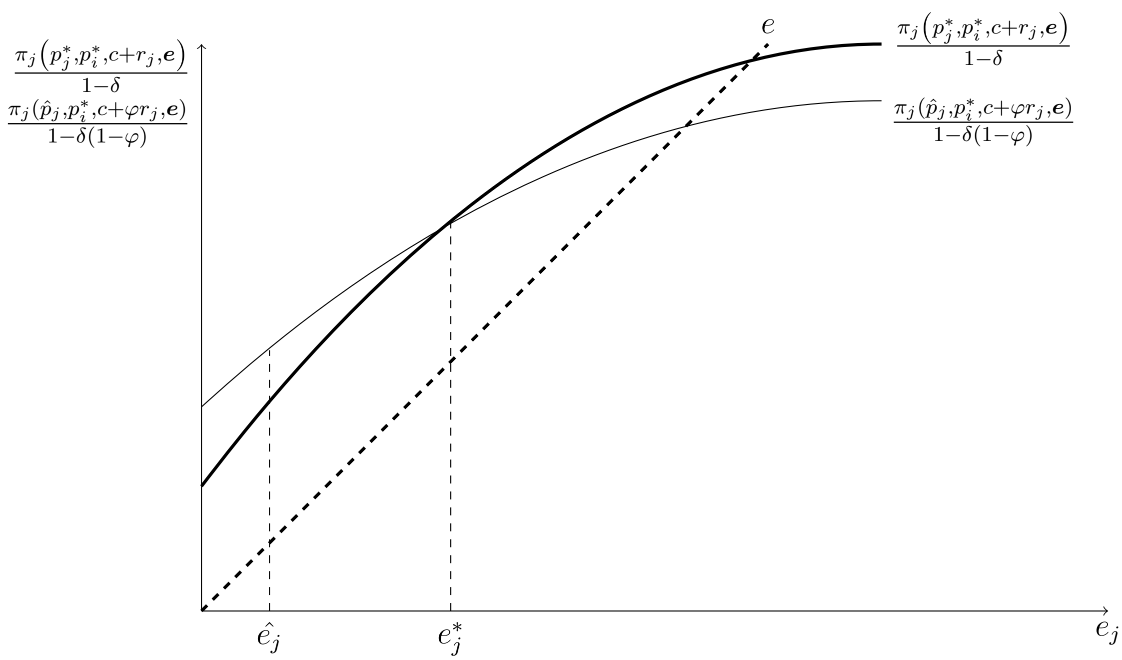

Figure 3: Profit-maximizing downstream investments with and without misreporting.

It is useful to contrast our model with Green and Scotchmer (1995) and Spulber (2013). In Green and Scotchmer (1995), innovation occurs both upstream and downstream and firms

[18]Firm i's investment is kept fixed at $e_i = e_i^*$.

[19]In Figure 3 the licensee's expected profit from cheating intersects the licensee's profit with honest reporting at e_j^* from above. The profit could intersect from below, in which case $\hat{e}_j > e_j^*$. The result would be the same: the licensor would have to lower r_j to prevent cheating.

have equal bargaining power. In their model the downstream firms' incentives to innovate depends on the breadth of the upstream firm's patent. This is analogous in some respects to the enforcement constraint in our model. A narrow patent breadth increases incentives for innovation downstream at the expense of incentives for upstream innovation.

Spulber (2013) explores a model in which inventions only occur upstream. As in our model, production occurs downstream and inventors license their technologies using fixed and per-unit royalties. 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 and utilize a licensed invention. In our model it does not generally follow that an increase in competition promotes downstream innovation. An increase in competition can lead the licensor to charge higher per-unit royalties when licensing contracts can be enforced perfectly. Higher royalties lower downstream profits and discourage investment to improve the products.[20]

Spulber (2013) concludes that competition and strong intellectual property rights are complements in that they both increase incentives for (upstream) innovation. In our model, strong intellectual property rights correspond to strong contract enforcement (a high value of φ). Suppose we expand our analysis and consider incentives for invention by the upstream research firm as well as for innovation by downstream firms. We show below that weak enforcement can undermine incentives for upstream invention, but the welfare consequences from weak enforcement are not uniformly negative.

Consider two licensees with (symmetric) demand

$$q_j(\boldsymbol{p}, u, \boldsymbol{e}, \zeta) \quad \text{for } j = 1, 2,$$

where u is upstream investment in the technology, $\boldsymbol{e}$ is downstream investment and ζ is the cross-elasticity of demand between the two downstream producers and is an index for downstream

[20]In Spulber (2013), competition among upstream technologies constrains the royalties that a licensor can charge. This limits the use of variable royalties to soften downstream competition. Contract enforcement may not be a binding constraint if upstream competition imposes a cap on the level of variable royalties.

competition. The licensor's profit is

$$\Pi^U(\zeta) = \max_{r,u} \sum_{j=1,2} \left[\frac{1}{1-\delta} z_j(\boldsymbol{e}, u, \zeta) - e_j \right] - u,$$

where $z_j = \pi_j^*(\boldsymbol{e}, u, \zeta) + r q_j(\boldsymbol{p}, u, \boldsymbol{e}, \zeta)$.

An increase in downstream competition increases the incentive to invent upstream if and only if

$$\frac{du}{d\zeta} = -\frac{\sum_{j=1,2} \frac{\partial^2 z_j(u,\boldsymbol{e},\zeta)}{\partial u \partial \zeta}}{\sum_{j=1,2} \frac{\partial^2 z_j(u,\boldsymbol{e},\zeta)}{\partial u^2}} > 0,$$

or if

$$\sum_{j=1,2} \frac{\partial^2 z_j(u, \boldsymbol{e}, \zeta)}{\partial u \partial \zeta} > 0. \tag{13}$$

With perfect contract enforcement, this condition is satisfied for some demand functions, such as log-linear demand $q_j = A(u, \boldsymbol{e}) p_j^{-\eta} p_i^{\zeta}$ with $\partial A(u, \boldsymbol{e})/\partial u > 0$ and $\eta > \zeta + 1$. It is not satisfied for Hotelling demand with symmetric values $v(u, \boldsymbol{e}) - \frac{1}{\tau} x$, with x an index of distance from a preferred supplier. In this case an increase in competition, measured by τ, has no effect on the marginal downstream profit when contracts can be enforced perfectly.[21]

With imperfect contract enforcement, it follows from Assumption 2 and Proposition 2 that stronger enforcement (larger φ) weakly raises the licensor's profit, which increases the incentive for upstream invention if the marginal return from invention also increases. However, an increase in competition may lower incentives for upstream invention if it requires the licensor to lower the per-unit royalty to avoid cheating. Thus, if demand is such that inequality (13) is satisfied, an increase in competition coupled with strong contract enforcement increases incentives for upstream invention. However, weaker contract enforcement can reduce incentives for upstream invention by lowering joint profits. Furthermore, it does not necessarily follow that an increase in competition – holding enforcement constant – also increases upstream invention incentives if greater competition lowers joint profits by forcing the licensor to choose a lower

[21] In the case of Hotelling demand, an increase in τ increases the joint profit-maximizing price, but has no effect on the marginal profit from the upstream invention.

per-unit royalty.[22]

Up to this point we have implicitly assumed that courts determine the enforcement level φ and bear any enforcement-related costs. The cost of enforcement can be internalized by the licensor under some circumstances. For example, φ depends on evidence supplied by the licensor, which is costly to collect and communicate. Suppose that enforcement has a cost $k(\varphi)$, which is borne by the licensor, with $k'(\varphi) > 0$. Consider the critical level of the enforcement parameter, φ^c, the smallest value of φ for which $r(\varphi) \geq r^*$, where r^* is the per-unit royalty that supports the joint-profit-maximizing profits. In our formulation perfect contract enforcement can be interpreted as $\varphi \geq \varphi^c$, which enables the licensor to charge the unconstrained profit-maximizing per-unit royalty, r^*. Given Assumption 2, $r(\varphi)$ is increasing in φ. Under these conditions, weak enforcement can lower the licensor's profit and incentive to invent, but it does not follow that the licensor would always prefer strong enforcement when enforcement is costly.

Proposition 5. *Suppose enforcement has a cost $k(\varphi)$ with $k'(\varphi) > 0$. The licensor will choose an enforcement level φ^m that is strictly less than φ^c.*

Ignoring enforcement costs, the licensor's profit is a maximum when $r = r^*$, corresponding to $\varphi \geq \varphi^c$. A small reduction in φ to $\varphi^c - \epsilon$ 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 (excluding enforcement costs) and therefore no adverse first-order effect on upstream investment. However, the reduction in φ has a first-order reduction in enforcement cost when $k'(\varphi) > 0$. Therefore, if φ is increasingly costly in the neighborhood of φ^c, the licensor will choose an enforcement parameter $\varphi^m < \varphi^c$.

Proposition 5 demonstrates that a licensor would not desire an outcome in which contracts are perfectly enforced if the licensor bears a marginal cost of enforcement. The next result shows that perfect contract enforcement does not maximize total economic welfare even if it has no cost.

[22] 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.

Proposition 6. *There exists a $\psi > 0$ for which total economic welfare is higher when $\varphi = \varphi^c - \psi$ than when $\varphi \geq \varphi^c$.*

Ignoring enforcement costs, there is no first order effect on the licensor's profit or investment when ψ is sufficiently small. However, the per-unit royalty r has a first-order effect on downstream prices and downstream investment. Prices are lower and downstream investment is higher with $\varphi < \varphi^c$. Costly enforcement only increases the benefit from a slight reduction in the level of enforcement. Thus the net effect of a small reduction in φ below φ^c is an increase in investment and economic welfare.[23]

A reduction in φ to a level below φ^c can come about because enforcement is costly, as Proposition 5 demonstrates. Alternatively, an enforcement level below φ^c may be the result of policies imposed by the courts that adjudicate contract compliance. For example, courts may require evidence of malfeasance by licensees to satisfy a high standard of proof, or they may permit a small amount of activity to occur without compensation to the licensor, such as fair use in copyright. Proposition 6 demonstrates that enforcement costs and legal standards that may appear to weaken intellectual property rights can increase total economic welfare.

6 Further implications of imperfect enforcement

In this section we explore the implications of imperfect contract enforcement for the decision to license exclusively, technology choices by licensees, and the interdependence between contract enforcement and vertical integration.

6.1 Exclusive licensing

Exclusive licensing avoids the cost of cheating when contract enforcement is imperfect because the optimal per-unit royalty is zero with a single 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

[23]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.

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 can also benefit the licensor by promoting downstream investment in the licensed technology, provided that downstream investments are not too complementary.[24] Furthermore, exclusive licensing promotes downstream investments by eliminating the incentive to charge royalties to soften competition.

6.2 Technology choice

Investment decisions involve the types of technologies that firms may pursue as well as how much to invest in each technology. The licensor may not choose to license the most efficient technology if it calls for a profit-maximizing royalty that cannot be sustained with imperfect contract enforcement. For example, the licensor may choose a project that enables greater product differentiation by the licensed firms, allowing the maximum sustainable per-unit royalty to be closer to the unconstrained profit-maximizing level.

Similarly, licensees may have the option to invest in different projects that utilize the licensed technology. Although licensees earn zero profits in our model, more generally, 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.

6.3 Vertical integration

We have assumed that the upstream firm only licenses the technology to downstream firms producing differentiated final goods. Alternatively, the licensor may sell final goods, which it

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

can do by integrating with one or more downstream firms.[25] Weak contract enforcement lowers the licensor's joint profit and therefore makes vertical integration more attractive relative to licensing with perfect contract enforcement.[26]

Suppose the licensor can merge with only one of the downstream producing firms. 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 licensor integrates with firm i and offers the non-integrated firm the contract (F_j^*, r_j^*) along with a promise to charge a downstream price p_i^J. 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. Whether partial vertical integration allows the technology owner to obtain a larger total profit than she could earn as an unintegrated licensor depends on the interaction, if any, between the maximum sustainable royalty and the integrated firm's downstream price.

7 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

[25] Vertical integration has the additional benefit that it eliminates the disincentive effects for downstream investment from double-marginalization.

[26] 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. An explanation is weak contracting enforcement, which makes an input supplier prefer vertical integration to sales or licensing.

a licence... [But] I have the impression that licensing is a minor source of revenues."[27] 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 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 encourage the firm's licensees to invest to improve their products or lower their costs.

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 forces a licensor to commit to license terms that lower consumer prices and promote innovation by downstream producers. The dark cloud of irresponsible licensee conduct is not without some silver linings.

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

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Appendix

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

$$\frac{\partial \pi_j \left(\boldsymbol{p}^*, c + r_j, \boldsymbol{e}\right)}{\partial e_j} - 1 = 0 \qquad \text{for } j = 1, 2.$$

Let $\pi_j^* = \pi_j \left(\boldsymbol{p}^*, c + r_j, \boldsymbol{e}\right)$.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.

$$\begin{pmatrix} \frac{\partial^2 \pi_j^*}{\partial (e_j)^2} & \frac{\partial^2 \pi_j^*}{\partial e_j \partial e_i} \\ \frac{\partial^2 \pi_i^*}{\partial e_j \partial e_i} & \frac{\partial^2 \pi_i^*}{\partial (e_i)^2} \end{pmatrix} \begin{pmatrix} \frac{de_j}{dr_j} \\ \frac{de_i}{dr_j} \end{pmatrix} = \begin{pmatrix} -\frac{\partial^2 \pi_j^*}{\partial e_j \partial r_j} \\ 0 \end{pmatrix}. \tag{14}$$

Solving for de_j/dr_j and de_i/dr_j,

$$\begin{aligned} \frac{de_j}{dr_j} &= \frac{-\frac{\partial^2 \pi_j^*}{\partial e_j \partial r_j} \frac{\partial^2 \pi_i^*}{\partial (e_i)^2}}{|M|} \\ \frac{de_i}{dr_j} &= \frac{\frac{\partial^2 \pi_j^*}{\partial e_j \partial r_j} \frac{\partial^2 \pi_i^*}{\partial e_j \partial e_i}}{|M|} \end{aligned}$$

where $|M|$ is the deteriminant of the matrix in eq. (14), which is positive given an assumed stable equilibrium. By the second order condition $\frac{\partial^2 \pi_j^*}{\partial (e_j)^2} < 0$, and 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 2:

First we show that $\hat{r}(\varphi)$ exists. The incentive compatibility condition is

$$\Psi_j(r_j) = \pi_j\left(p_j^*, p_i^*, c + r_j\right) - \gamma\pi_j(\hat{p}_j, p_i^*, c + \varphi r_j) \geq 0.$$

Note that $\Psi_j(0) > 0$ if $\gamma < 1$. Furthermore, at r_j^*, either $\Psi_j(r_j^*) \geq 0$, in which case $\hat{r}(\varphi) = r_j^*$, or $\Psi_j(r_j^*) < 0$. We show below that $\Psi_j(r_j)$ is decreasing in r_j. It follows that there exists a $r(\varphi)$ at which $\Psi_j(r_j^*) = 0$, in which case $\hat{r}(\varphi) = r(\varphi)$, or $\hat{r}(\varphi) = r_j^*$.

To show that $\hat{r}(\varphi)$ is unique, first note that

$$\frac{d\Psi_j(r_j)}{dr_j} = -q_j(p_j^*, p_i^*) + \gamma\varphi q_j(\hat{p}_j, p_i^*). \tag{15}$$

By definition, at $r_j = r_j(\varphi)$,

$$(p_j^* - c - r_j)q_j(p_j^*, p_i^*) = \gamma(\hat{p}_j - c - \varphi r)q_j(\hat{p}_j, p_i^*). \tag{16}$$

Substituting (16) into (15) gives, at $r_j = r_j(\varphi)$,

$$\frac{d\Psi_j(r_j)}{dr_j} = -\gamma q_j(\hat{p}_j, p_i^*)\left[\frac{\hat{p}_j - c - \varphi r}{p_j^* - c - r} - \varphi\right].$$

Thus $\Psi_j(r_j)$ is decreasing in r_j in the neighborhood of $r_j(\varphi)$ if

$$Z(\varphi) = \hat{p}_j - \varphi p_j^* - c(1 - \varphi) \geq 0 \;\text{ for all } \varphi.$$

Now

$$\hat{p}_j = h_j(\hat{p}_j)(c + r\varphi)$$

and

$$p_j^* = h_j(p_j^*)(c + r),$$

where

$$h_j(p_j) = \frac{\eta_j(p_j)}{\eta_j(p_j) - 1} \geq 1$$

and $\eta_j(p_j)$ is the magnitude of the firm-specific elasticity of demand for Firm j at price p_j.

Thus

$$Z(\varphi) = h_j(\hat{p}_j)(c + r\varphi) - \varphi h_j(p_j^*)(c + r) - c(1 - \varphi)$$

and $Z(\varphi) \geq 0$ if

$$\left[h_j(\hat{p}_j) - h_j(p_j^*)\right](c + \varphi r) \geq -c(1 - \varphi)(h_j(p_j^*) - 1).$$

This condition is satisfied if $h_j(p_j)$ is weakly decreasing in p_j, which follows if $\eta_j(p_j)$ is weakly increasing in p_j (Assumption 3). Note that this result holds whenever $\Psi_j(r_j) = 0$. It follows that $r_j(\varphi)$ is unique.

To show that $r_j(\varphi)$ is increasing in φ, differentiate the condition $\Psi_j(r_j) = 0$ with respect to the enforcement parameter φ. This gives

$$\frac{dr_j(\varphi)}{d\varphi} = \frac{\delta\gamma^2}{1 - \delta}\left(\frac{\pi_j(\hat{p}_j, p_i^*, c + \varphi r_j)}{q_j(p_j^*, p_i^*) - \gamma\varphi q_j(\hat{p}_j, p_i^*)}\right), \tag{17}$$

and $r_j(\varphi)$ is increasing if

$$q_j(p_j^*, p_i^*) - \gamma\varphi q_j(\hat{p}_j, p_i^*) \geq 0, \tag{18}$$

which follows for all φ given Assumption 3.