Innovation, Patent Hold-Up, and Equilibrium Effects of RAND Commitments*

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Abstract

Offering users of patented technology access to antitrust courts has been proposed as a remedy for the problem of “patent ambush,” a type of post-investment hold-up. In this paper, we identify a cause of hold-up that has not been previously associated with patent ambush, that incomplete contracts are subject to renegotiation as the future unfolds. Parties who make relationship-specific investments expect to be held up by their trading partners and adjust accordingly, often by under-investing. Our main result is that ex-post litigation is not able to improve upon a simple option-to-license contract even for an idealized court that can compute and enforce prices the parties would have agreed to had they negotiated an option-to-license contract prior to the manufacturer’s investment. One cannot reproduce the effects of ex-ante negotiation when the courts are used only at the discretion of one of the parties. We use random-proposer-bargaining to capture this asymmetry and find that ex-post litigation acts like a “tax” on innovation.

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1 Introduction

A wide variety of governance structures have been used to mediate transactions among parties creating, developing, and using intellectual property, including anonymous spot-market transactions, exclusivity contracts, options contracts, loyalty or market-share contracts, joint ventures, dual sourcing, and vertical integration.\(^1\) Each of these organizational and contractual forms has advantages in the sense that they increase joint surplus by reducing transactions costs or by allocating property rights efficiently, depending on the particular attributes of the trading relationship.\(^2\) At various times in the life cycle of an innovation, some of these organizational forms will be better than others, and we would expect organizational forms and contracts to evolve to address the coordination and contracting problems in the most efficient way.\(^3\)

Whether *ex-post* litigation should be added to this list as another tool that can help mediate transactions between creators and users of intellectual property is a question that has been raised by a string of antitrust cases brought by the FTC\(^4\) and by private parties\(^5\) in both the US and in Europe\(^6\). All of these cases are concerned with “patent ambush,” a type of post-investment hold-up. After a patentee’s technology has been incorporated into a standard, a manufacturer makes relationship-specific investments based on the expectation that the technology will be licensed on RAND (*reasonable and non-discriminatory*) terms. If the patentee then charges above-RAND rates, the manufacturer has been “ambushed” or “held-up.” If the manufacturer anticipates this kind of *ex-post* opportunism, the incentive to make relationship-specific investment is reduced, as is the size of the bargaining surplus.

Courts can restore the incentive of the manufacturer to invest by allowing the manufacturer to sue for damages. Like the gap-filling role played by litigation to resolve contractual disputes arising over unforeseen contingencies, *ex-post* litigation, including cases brought by

\(^1\)See Joskow (2005) for a discussion of the organizational forms that have been used in settings where relationship-specific investments are important.

\(^2\)See Williamson (1979) for a discussion of the former and Grossman and Hart (1986) for the latter.

\(^3\)See Mock (2005) on how Qualcomm evolved from a fully vertically integrated firm designing and manufacturing chipsets, cell phones, and infrastructure into a company that now creates intellectual property and licenses it with options contracts to trading partners around the world.

\(^4\)Dell, 121 F.T.C. 616 (1995); Rambus, FTC Dkt. No. 9302 [thereafter: *Rambus*]; Union Oil Company of California, 2004 FTC LEXIS 115 (FTC 2004); Negotiated Data Solutions LLC, No. 051 (F.T.C. Jan. 23, 2008) [thereafter: *N-Data*].

\(^5\)Broadcom Corp. v. Qualcomm Inc., 501 F. 3d 297 (3d Cir. 2007) [thereafter: *Broadcom*].

\(^6\)See Geradin (2008).
private parties or by the government, can restore the manufacturer’s incentive to undertake relationship-specific investment. In fact, if the court can compute what the parties would have agreed to before the manufacturer made relationship-specific investments, the associated court-awarded damages can offset the effect of the hold-up and lead to a first-best outcome.\footnote{See, e.g., Shavell (1980) and Rogerson (1984) for unilateral investment and, e.g., Edlin and Reichelstein (1996) for bilateral investment. Hermelin, Katz, and Craswell (2007) provide a comprehensive literature review.}

However, in many industries, including the ones in which these antitrust cases have appeared, e.g., telecommunications, it is not only impractical to write complete contracts, but it is impossible for a court to verify compliance or performance and calculate damages. Instead, parties write incomplete contracts that are subject to renegotiation as the future unfolds; and those who make relationship-specific investments expect to be held-up by their trading partners and adjust accordingly, often by under-investing.

This type of hold-up is different from the hold-up that has been previously associated with patent ambush. For example, Shapiro (2006) models hold-up as arising from one of two sources: either (1) the manufacturer does not know about the patent\footnote{Kobayashi and Wright (2009a) refer to this as “unanticipated holdup.”}; or (2) the patent is weak, so the manufacturer rationally starts producing and infringing the patent. In contrast, our hold-up is caused by incomplete contracts and downstream investment decisions which must be made before the production and infringement decisions. So even with strong patents, we see patent hold-up and under-investment. In this environment, the threat of \textit{ex-post} litigation can affect the \textit{ex-ante} bargaining, the terms of trade, and the incentives to invest. It can also supplant other, more efficient solutions to the problem of hold-up. Whether and how it does so is the policy question that motivates our paper.

To answer it, we model the equilibrium bargaining that occurs between innovators and manufacturers over the creation and use of patented technology. We use a model of sequential investment that is tailored to several features of industries in which these cases have appeared. First, we assume that initial investment by the innovator is non-contractible. This implies that innovators must undertake initial R&D without knowing whether the innovation will become valuable. This assumption conforms to anecdotal evidence about the development of the CDMA cellular technology described by Mock (2005), and rules out \textit{ex-ante} mechanisms, like the auctions proposed by Swanson and Baumol (2005), which are held before the innovator has sunk
his development costs. Second, we also assume that initial upstream investment is sensitive to expected returns. In other words, the innovator will not innovate unless the expected returns to innovation are positive. The third—and most significant—feature of our model is the inability of parties to write enforceable contracts that condition on crucial variables, like the level of investment. Instead, parties employ option-to-license contracts that give the manufacturer the option to license a patented technology at a price that is negotiated before the manufacturer decides on the level of relationship-specific investment. Similar options contracts are used in the telecommunications industry and were the subject of a business review letter by the US Department of Justice to the VITA standards setting organization.

In this environment we compare three different institutional settings: (i) no contracts; (ii) ex-post litigation; and (iii) an option-to-license contract. Our court in (ii) uses the option-to-license contract in (iii) to define “reasonable” royalties as the price the parties would have agreed to, had they negotiated a contract prior to the manufacturer’s investment. As opposed to the ex-post RAND interpretation applied in the Broadcom-case, this hypothetical ex-ante contract price solves the manufacturer’s hold-up problem.

In this environment, we find that ex-post litigation can sometimes do better than nothing (no contracts) because court-awarded damages counter the effects of the hold-up on the manufacturer’s decision to invest. In another part of the parameter space, however, ex-post litigation does worse because it serves mainly to replace hold-up by the innovator with hold-up by the

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9 Others, like Farrell, Hayes, Shapiro, and Sullivan (2007), have assumed that upstream innovation is independent of expected returns.

10 See Mock (2005).

11 The option-to-license contract is equivalent to the maximum price commitment mentioned in the DOJ’s 1996 VITA letter (26 October 1996 business review letter from Assistant Attorney General Thomas O. Barnett to Robert Skitol on behalf of VITA, saying that the Department of Justice would evaluate VITA’s proposed policy of disclosing maximum royalty rates under a rule of reason analysis).

12 Unlike Shapiro (2006), the litigation threat does not affect the computation of reasonable royalties. Instead, we assume that the option-to-license contract can be enforced perfectly by a court, so there is no “circularity” in computing reasonable royalties.

13 In Georgia-Pacific Corp. v. United States Plywood Corp. (S.D.N.Y. 1970) 318 F.Supp. 1116 [thereafter: Georgia-Pacific], the court has set out a 15-factor test for the determination of reasonable royalties in the context of patent infringement (cf. Epstein and Marcus, 2003; Layne-Farrar, Padilla, and Schmalensee, 2007). The test is designed to echo the outcome of bilateral negotiations over the license price at the time infringement began and bases reasonable royalties on the “established profitability of the product made under the patent” (Factor 8) or the “extent to which the infringer has made use of the invention; and any evidence probative of the value of that use” (Factor 11). See Lemley and Shapiro (2007:note 63) for a list of the factors. Other courts have extended its scope to the question of what a reasonable royalty amounts to in the context of a RAND commitment (Nickson Indus., Inc. v. Rol Mfg. Co. (Fed. Cir. 1988) 847 F.2d 795, or ESS Tech., Inc. v. PC-Tel, Inc. (N.D. Cal. Nov. 28, 2001) No. C-99-20292 RMW, 2001 WL 1891713). In Broadcom the court states that the “success [of the test] persuades us that, given a fully-developed factual record, the same can be done here.”
manufacturer. The tradeoff between no institutions and *ex-post* litigation illustrates the tension between the incentive to create intellectual property (long-run efficiency) and the incentive to use it (short-run efficiency) (Landes and Posner, 2003). While *ex-post* litigation solves the manufacturer’s post-investment hold-up problem and leads to short-run efficiency, it also reduces the returns to innovation which, in long-run equilibrium, can deter the creation of intellectual property.

The most significant finding for policy is that both of these institutional regimes are inferior to a simple option-to-license contract that specifies a maximum royalty rate. The option-to-license contract solves the manufacturer’s hold-up problem, which results in efficient relationship-specific investment by the manufacturer.¹⁴ Efficient downstream investment leads to a more efficient upstream investment, and bigger total surplus.

It is interesting that *ex-post* litigation does worse than a simple option-to-license contract even for an idealized court than can compute and enforce idealized RAND terms, i.e., the prices the parties would have agreed to had they negotiated an option-to-license contract prior to the manufacturer’s investment. Giving only the manufacturer access to the courts raises the hold-up “tax” (Edlin and Reichelstein, 1996) on the innovator’s investment without any offsetting benefit on the manufacturer’s investment. This result highlights the difficulty of restoring the incentives for *ex-ante* investment with *ex-post* litigation. One cannot simply tell the courts to reproduce the effects of *ex-ante* negotiation because the courts are used only at the discretion of one of the parties.

Because so much has been written about the effects of patent ambush in a standard setting organization which brings together multiple innovators and multiple manufacturers, we want to emphasize that ours is a model of unilateral bargaining, between a single innovator and a single manufacturer. Thus, we do not address the collusion issues that joint bargaining raises¹⁵, the problems of patent stacking¹⁶, or internalization of downstream competition among

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¹⁴We show that the option-to-license contract is renegotiation-proof which yields the desired result. For a skeptical view of the ability of contracts to solve the hold-up problem see Maskin and Moore (1999), Hart and Moore (1999), Segal (1999), or Segal and Whinston (2002). For a more optimistic view see, e.g., Nöldeke and Schmidt (1995) or Lyon and Rasmusen (2004). Hoppe and Schmitz (2009) provide a nice discussion of the literature and some experimental results.

¹⁵In fact, the main benefits of the option-to-license contract are not dependent on joint bargaining.

¹⁶See Lemley and Shapiro (2007).
manufacturers caused by high royalty rates\textsuperscript{17}. Our result says only that the option-to-license contract goes a long way towards solving the hold-up problem faced by a single manufacturer and a single innovator. It does this by giving the manufacturer the option of using the technology at an \textit{ex-ante} price, thus taking away the innovator’s ability to increase the price after the manufacturer has made relationship-specific investment.

The paper is structured as follows: In Section 2 we introduce the setup of the model. Section 3 presents the basic results of patent ambush in a scenario without institutional constraints. In Section 4 we consider a simple option-to-license contract which the parties agree to before the manufacturer makes her investment decision. The license price from this contract will serve as “reasonable royalty” in the main analysis in Section 5. We first discuss the details of RAND enforcement and then analyze two scenarios. We first assume that \textit{ex-ante} price commitment (option-to-license) contract is not feasible and derive the equilibrium under RAND enforcement. We then allow for both institutional solutions to be in place and obtain the equilibrium. Section 6 concludes. The formal proofs of the results are relegated to Appendix A.

## 2 The model

We consider a simple sequential decision model with a single innovator of a patented technology and a single manufacturer who uses the technology for her production. Before production can begin, the manufacturer manufacturer must license the technology; otherwise the innovator will successfully sue for patent infringement. We ignore the effects of weak patents and uncertain outcomes of patent infringement suits (Farrell and Shapiro, 2008) and instead examine the effects of \textit{ex-post} litigation on parties’ license negotiations.

The details of the setup are as follows: An innovator (\textit{he}) decides whether or not to develop a technology that is patented and adopted as industrial standard. Both the patent and the fact that this technology is part of a standard are common knowledge.\textsuperscript{18} For the development of the technology the innovator incurs costs $D > 0$. In order to benefit from positive effects of the technology, a downstream manufacturer (\textit{she}) can invest in relationship-specific assets $k \geq 0$

\textsuperscript{17}See Farrell and Shapiro (2008).

\textsuperscript{18}Our model does therefore not capture cases like Rambus where the innovator (fraudulently) does not disclose his patent. See Kobayashi and Wright (2009a).
at constant unit costs. This investment can be viewed as technology-specific costs of product
design. The investment has no value if she decides to discard the technology-specific design
and produce an alternative, which has a constant value \( v_0 > 0 \).\(^{19}\) The value \( j \) of the patented
technology is low \( (j = L) \) with probability \( \pi \) and high \( (j = H) \) with probability \( 1 - \pi \). Note
that this success probability of innovation is independent of the manufacturer’s investment.
We normalize the manufacturer’s revenues from a low-value technology to zero, irrespective of
her investment level. If the value of the technology is high, the manufacturer’s revenues are
increasing in investment and are denoted by \( v(k) \) where \( v(0) = 0, \, v' > 0, \) and \( v'' < 0 \). Moreover,
let \( v(k) \) satisfy the Inada conditions.

The value of the next-best alternative, \( v_0 \), and probability \( \pi \) characterize the potential of
technology innovation. A low value of the next-best alternative implies a high relative impact
of the patented technology with a higher social value. Moreover, a small \( \pi \) implies a high
probability of success of innovation.

**DEFINITION 1.** *Innovation is defined as high potential if \( \pi \) and \( v_0 \) are relatively small.*

The sequence of events of actions and information are as follows: the innovator makes his
innovation decision and then, following innovation, the manufacturer invests \( k \). Next, the value
of the technology is realized. Finally, the manufacturer observes this value and decides whether
to adopt the patented technology with valuation \( v(k) \) (or zero) or the next-best alternative with
valuation \( v_0 \). We compute the subgame-perfect equilibrium.

We assume that the value \( j \) of the technology, investment \( k \), and innovator’s costs of devel-
opment are not verifiable ex-post, yet are known to both the innovator and the manufacturer.
Moreover, we assume that \( \pi \) and \( v_0 \) are common knowledge *ex ante* and verifiable by third
parties *ex post*.

Suppose the innovator and the manufacturer could coordinate on strategies at the outset of
the game, i.e., before the innovator develops, and fully commit to these strategies. In that case,
they would agree on a first-best strategy vector that maximizes their joint expected surplus net

\(^{19}\)We assume the direct costs of redesign to be equal to zero, as in Farrell and Shapiro (2008) and unlike in
of opportunity costs $v_0$. The benchmark maximization problem is then defined as

$$\max_{k \geq 0, a_j \in \{0, 1\}} (a_L \pi [0 - v_0] + a_H (1 - \pi) [v(k) - v_0] - k)$$  \hspace{1cm} (1)

where the manufacturer’s ex-post adoption decision is $a_j = 1$ if and only if $j = H$ and $v(k) \geq v_0$, and the innovator optimally innovates if and only if the expression in (1) is not smaller than his development costs $D$. Let an ex-ante efficient investment level $k^* := k^* (\pi)$ exist so that ex-post efficient adoption decisions are $a_L (k^*) = 0$ and $a_H (k^*) = 1$. Moreover, let

$$w(k) := (1 - \pi) (v(k) - v_0) - k$$  \hspace{1cm} (2)

denote the expected social value added of the technology, net of the next-best alternative, for a given investment level $k$. Note, the highest level of $D$ for which innovation is ex-ante efficient is equal to $w(k^*)$. Let the innovator’s costs be uniformly distributed between 0 and $\bar{D}$ where $\bar{D} \geq w(k^*)$. Innovation is said to be excessive if the innovator develops the technology for $w(k^*) < D$, and insufficient otherwise. We restrict the parameter space to potentials that give rise to strictly positive social value added so that innovation is efficient with strictly positive probability.

**ASSUMPTION 1.** The potential $(\pi, v_0)$ of innovation is such that $w(k^*) > 0$.

The expected social value added of the technology is a short-run measure as it is conditional on innovation. Endogenizing the innovator’s development decision allows us to consider a long-run measure of expected welfare. Let $I$ denote the innovator’s expected returns from royalty payments for licensing the technology. By the time the innovator develops the technology, he knows his costs $D$ and will develop only if the expected profits $I - D$ are nonnegative. Given this innovation decision, i.e., the technology is developed for all $D \leq I$, the expected welfare can be defined as

$$W(k, I) := \int_0^I \frac{(w(k) - D)}{D} dD.$$  \hspace{1cm} (3)

Arguing that a given enforcement regime solves the manufacturer’s patent hold-up problem ignores the long-run effects of such a regime. The long-run expected welfare measure $W$ allows us
to understand how certain enforcement regimes affect the market in equilibrium, i.e., accounting for both the manufacturer’s investment decision and the innovator’s development decision.

3 Patent ambush

In what follows we first derive the benchmark outcome of post-investment hold-up or patent ambush. For this case, we assume that there are no institutions regulating the economy other than protection of the innovator’s intellectual property rights. The manufacturer must make her investment decision before she learns whether the innovation is of any value, but decides ex-post, i.e., after the value has been realized, whether or not to adopt the technology. At that stage, the parties bargain over the price of the license.20 The innovator forms expectations over these expected royalty payments and will decide to develop if his net payoffs are nonnegative. We solve for the subgame-perfect Nash equilibrium of this patent-ambush scenario by backward induction. The sequence of events is depicted in Figure 1.

For the ex-post license negotiations, we assume random-proposer-bargaining, meaning that the manufacturer [innovator] makes a take-it-or-leave-it price offer with probability $\beta$ [probability $1 - \beta$] which the innovator [manufacturer] can either accept or reject.21 We refer to this $\beta$ as the manufacturer’s bargaining power.22 The equilibrium price offers $p_{iH}$ will render the offeree indifferent between accepting and rejecting23 so that the manufacturer will offer $p_{M,H} = 0$ with

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20We do not model the downstream market for the manufacturer’s products and will there use royalties and (fixed) license fees interchangeably.

21Farrell and Shapiro (2008), with the innovator making license contract offers with probability one ($\beta = 0$), are a special case of our approach. Note that random-proposer-bargaining is equivalent to an ultimatum game where the roles are assigned with probabilities $\beta$ and $(1 - \beta)$.

22Ma (1994) suggests this simple bargaining game in a moral hazard framework. With symmetric information and risk-neutral parties it leads to the generalized Nash-bargaining solution (Schmitz, 2006) with proposal probability $\beta$ equal to the manufacturer’s Nash bargaining power. See Bajari and Tadelis (2001), Hart and Moore (1999), or Schmitz (2008) for related applications.

23We assume acceptance as tie-breaking rule.
probability $\beta$ and the innovator $p_{I,H} = v(k) - v_0$ with probability $1 - \beta$. At the investment stage, the manufacturer’s expectations over the ex-post price are equal to

$$
p^{PA} = (1 - \beta)(v(k) - v_0)
$$

if $v(k) \geq v_0$. If $v(k) < v_0$ or $j = L$ the manufacturer will not adopt the technology ex post.

Before the value of the technology is realized, the manufacturer takes her investment decision, $k^{PA}$. At this point, her expected payoff is

$$
\pi v_0 + (1 - \pi)[v(k) - (1 - \beta)(v(k) - v_0)] - k
$$

She chooses the level of investment $k^{PA} \equiv k^{PA}(\pi, v_0, \beta)$ to maximize the expected net payoff,

$$
\max_k (v_0 + a_H(k)\{(1 - \pi)\beta(v(k) - v_0)\} - k).
$$

Note that she will invest only if her ex-ante participation constraint is satisfied, i.e., if the maximand of (5), denoted by $k^0$ and increasing in $\beta$, is such that

$$
(1 - \pi)\beta(v(k^0) - v_0) - k^0 \geq 0.
$$

Also, if equation (6) holds, Assumption 1 is not binding. Let $\underline{\beta} \equiv \underline{\beta}(\pi, v_0)$ be such that (6) holds with strict equality and is satisfied for all $\beta \geq \underline{\beta}$. This cutoff value $\underline{\beta}$ is increasing both in $\pi$ and $v_0$. If the ex-ante participation constraint does not hold true, that means, if the manufacturer can not recoup her costs of investment, she will not invest but use the next-best alternative irrespective of the value of the patented technology. To summarize, the manufacturer will always under-invest relative to the first-best benchmark, $k^{PA} \in \{0, k^0\} < k^*$, if $\beta < 1$ to protect herself against the innovator’s ex-post opportunism.

If $\beta \geq \underline{\beta}$ so that (6) holds, the manufacturer will ex post adopt for the high-value realization of the technology so that the innovator’s returns are $p^{PA} \equiv p^{PA}(\pi, v_0, \beta)$. If $\beta < \underline{\beta}$, they are equal to zero. At the innovation stage, the innovator’s expected royalties are a piecewise
function of $\beta$ and equal to

$$I^{PA}(\beta) = \begin{cases} (1 - \pi)(1 - \beta)(v(k^0) - v_0) & \text{if } \beta \geq \beta_0, \\ 0 & \text{if } \beta < \beta_0. \end{cases} \quad (7)$$

Note that (7) is equal to zero for $\beta = 1$ and $\beta < \beta_0$ but strictly positive for all $\beta \in [\beta_0, 1)$. The manufacturer’s expected private gains from innovation are

$$M^{PA}(\beta) = \begin{cases} (1 - \pi)\beta(v(k^0) - v_0) - k^0 & \text{if } \beta \geq \beta_0, \\ 0 & \text{if } \beta < \beta_0. \end{cases} \quad (8)$$

We show in Proposition 1 that the first best cannot be attained for any $\beta$. More specifically, in order for the innovator to develop the patented technology for some values of $D$ so that the expected welfare $W$ is strictly positive, the parties must share the ex-post gains from innovation which will distort the manufacturer’s investment incentives. Put differently, if either party makes the license price offer with sufficiently high probability, we will observe a collapse of R&D.

**PROPOSITION 1.** *As the manufacturer efficiently invests only if $\beta = 1$ and the innovator develops the technology only if $\beta$ is of intermediate value, the first best can never be attained in the patent-ambush scenario.*

*Proof.* See Appendix A. Q.E.D.

Proposition 1 illustrates the problems of a one-sided solution to the short-run hold-up problem without accounting for its long-run effects. Any institutional arrangement that solves the manufacturer’s hold-up problem by granting her a larger share of the ex-post surplus will destroy the innovator’s incentives to develop the technology. More bargaining power works only if parties have aligned interests and favor higher bargaining power for the manufacturer ex ante. This reduces the innovator’s share ex post but has a positive effect on the manufacturer’s incentives and thus on the value of $w(k)$. The innovator will ultimately receive a smaller share of a much larger pie. Figure 2 provides a graphical illustration. It depicts the short-run social gains from innovation as well as the parties’ private gains against $\beta \in [0, 1]$ for $v(k) = 10\sqrt{k}$, $\pi = 1/2$.

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24We will return to this issue in a related context when we discuss Georgia-Pacific in Section 5.
and $v_0 = 3$. The lowest $\beta$ for which the manufacturer will invest is $\beta = .24$, the innovator’s expected returns are maximized for $\beta^I = .56$, and, given $D = 2$, the innovator will develop the technology for all $\beta \in [.38, .76]$ (shaded region). Given $D = 1$, he will develop the technology for all $\beta \in [.22, .90]$ but will never develop if $D = 3$. Notice that in none of these cases innovation is excessive as $w(k^*) > w(k^{PA}) = M + I > I$.

4 Option-to-license contracts

In this section, we consider price negotiations before the manufacturer has incurred the costs of specific investment and the value of the patented technology is realized.\footnote{Such an \textit{ex-ante} contract is related to the discussion of “early negotiations” in Lemley and Shapiro (2007).} We show that a simple option-to-license contract can solve the manufacturer’s hold-up problem.\footnote{For the advantages and disadvantages of different approaches to patent licensing see Kamien (1992).} In the previous section, we assumed that the value of the patented technology and the manufacturer’s investment level were not verifiable \textit{ex post} so that the \textit{ex-ante} commitment to a fully contingent first-best strategy vector was not feasible. In other words, any \textit{ex-ante} agreement would be incomplete. The literature on simple or incomplete contracts has identified a wide array of possible solutions to double-sided hold-up problems involving long-term contracts that parties can commit to before they invest (e.g., Aghion, Dewatripont, and Rey, 1994; Edlin and Reichelstein, 1996; Nöldeke and Schmidt, 1995). For the purpose of this paper, however, we rule
Figure 3: Sequence of events with simple option-to-license contracts

- $t_1$: Innovator: innovation at cost $D$; standard setting
- $t_2$: Contract: license price is $\bar{p}_i$
- $t_3$: Manufacturer: investment $k$ at cost $k$
- $t_4$: value $v(k)$ with probability $1 - \pi$
- $t_5$: Renegotiation: effective license price is $p_e$
- $t_6$: Manufacturer: adoption if $v(k) - p_e \geq v_0$

out any pre-innovation commitment or contractual arrangements such as R&D joint ventures or work-made-for-hire contracts. Innovation is often very hard to plan and contract for because future commercial uses are often unforeseeable, and their expected value is difficult to calculate. Suppose, for instance, that innovation is a discovery process and both the innovator and manufacturer learn about possible commercial uses only after the costs of development have been sunk. In such a case, pre-innovation license negotiations would not be feasible. Our focus on post-innovation option-to-license contracts is meant to capture this feature.

The sequence of events is depicted in Figure 3. We refer to an *ex-ante* contract as one that is entered at stage $t_2$, i.e., post-innovation yet pre-investment. The parties will reach this stage only if the innovator anticipates sufficiently high returns, denoted by $I^C$, from this contract. In order to characterize the contract and quantify the respective license price we make a number of assumptions with respect to the bargaining structure:

First, we assume random-proposer-bargaining for both *ex-ante* and *ex-post* negotiations where the assignment of roles is independent over time. Again, let $\beta [1-\beta]$ denote the probability with which the manufacturer [the innovator] makes either the *ex-ante* or *ex-post* license price offer. This means that with a probability of $\beta \cdot \beta$ the manufacturer will make both the *ex-ante* and the *ex-post* offer; with a probability of $\beta \cdot (1 - \beta)$ the manufacturer makes the *ex-ante* offer but the innovator the *ex-post* offer; and so forth.

Second, we restrict attention to simple and noncontingent option-to-license contracts. We do so because option contracts have been shown to be a quite robust solution to the (manufacturer’s) hold-up problem (Lyon and Rasmusen, 2004; Nöldeke and Schmidt, 1995). Moreover, we account only for noncontingent contracts to stress the point that even with very simple contracts we get fairly close to first-best implementation. Also, as we will argue in the next section, the license price $\bar{p}$ which the parties will agree to *ex ante* is what courts will use to fill
contractual gaps once they ask the hypothetical of ‘what would the price have been had the parties had a chance to bargain over it.’ Note that if the parties do not agree on a contract, they can always negotiate the contract \textit{ex post} so that their outside options are equal to the net payoffs $M^{PA}(\beta)$ and $I^{PA}(\beta)$ in the patent-ambush scenario from equations (7) and (8).

**DEFINITION 2.** An admissible option-to-license contract specifies a noncontingent license fee $\bar{p}_i$, $i = M, I$ to be paid by the manufacturer in case of adoption of the patented technology. If she decides to use the next-best alternative, the payment to the innovator is equal to zero.

Third, \textit{ex-ante} commitment applies only to the possibility of enforcement of such an option-to-license contract before a court of law.\footnote{We assume costless third-party enforcement of contracts. For a comprehensive review of the economic analysis of remedies for breach of contract see Hermalin, Katz, and Craswell (2007) and the work cited therein.} We assume, however, that the parties cannot commit to not renegotiate the contract \textit{ex post} at stage $t_5$. Again, renegotiation of $\bar{p}_i$ is by random-proposer-bargaining.

The equilibrium license price $\bar{p}_i$ which the manufacturer [innovator] will offer makes the innovator [manufacturer] just indifferent between accepting and rejecting. Rejection implies that the parties materialize their outside option payoffs $I^{PA}(\beta)$ [$M^{PA}(\beta)$] from the game without any institutional commitment. In the following Lemma, we show that the equilibrium prices are equal to the \textit{ex-ante} prices, or that our simply option-to-license contract is renegotiation-proof. In this context renegotiation-proof means that after having observed the manufacturer’s investment $k$ and the realization of the value of the patented technology, the parties cannot both agree on a new price $p_e \neq \bar{p}_i$. The option-to-license contract gives the manufacturer the option to license the technology at the price $\bar{p}_i$, so she does not have to accept any price $p_I > \bar{p}_i$. Likewise, the innovator will not accept any offer $p_M < \bar{p}_i$ because the manufacturer’s threat of otherwise not adopting the patented technology is not credible. As a consequence, the manufacturer becomes residual claimant and will efficiently invest.

**LEMMA 1.** The renegotiation-proof license prices $\bar{p}_i$, $i = M, I$, are

\[
\bar{p}_M = \frac{I^{PA}(\beta)}{1 - \pi} \quad \text{and} \quad \bar{p}_I = \frac{w(k^*) - M^{PA}(\beta)}{1 - \pi}.
\]
Because the effective price $p_e = \bar{p}_i$, $e = M, I$, is independent of $k$, the manufacturer will invest efficiently for all $\beta$.

Proof. See Appendix A. \(\text{Q.E.D.}\)

The manufacturer makes her investment decisions at stage $t_3$ given the prices $\bar{p}_M$ or $\bar{p}_I$ agreed to at stage $t_2$. When deciding whether or not to develop at stage $t_1$, the innovator computes his expected royalties as

$$IC(\beta) = (1 - \pi) [\beta \bar{p}_M + (1 - \beta) \bar{p}_I] = IPA(\beta) + (1 - \beta) (w(k^*) - w(k^{PA})).$$

Royalties are strictly positive for all $\beta < 1$. Again, the innovator will develop the technology if the costs of development are covered by the expected royalty payments, $D \leq IC(\beta)$. The equilibrium results for the case with \textit{ex-ante} price commitment through an option-to-license contract are summarized in Proposition 2.

**PROPOSITION 2.** Price commitment through a renegotiation-proof option-to-license contract improves expected welfare relative to the patent-ambush case, i.e., $W^C(\pi, v_0, \beta) > W^{PA}(\pi, v_0, \beta)$, for all $\beta < 1$. The contract makes the manufacturer residual claimant, thus inducing efficient investment $k^*$ for all $\beta$, and increases the likelihood of innovation for all $\beta \in [0, 1)$. Moreover, it prevents a collapse of R&D for all $\beta < \frac{1}{2}$.

Proof. See Appendix A. \(\text{Q.E.D.}\)
Both parties are strictly better off *ex ante* for any $\beta \in (0, 1)$. Figure 4 depicts the innovator’s and manufacturer’s expected payoffs for $\pi = \frac{1}{2}$ and $v_0 = 3$. Recall that in the scenario of patent ambush, the innovator decides to develop the technology only for intermediate values of $\beta$ (dark shaded area). Once we allow for *ex-ante* contracts, the manufacturer’s investment incentives are not affected by $\beta$ and the expected value added from innovation, $w(k^*)$, is a constant. Giving the innovator more bargaining power therefore strictly increases his expected royalty payments and results in more innovation in the long run.

Notice, the first-best outcome, i.e., efficient investment $k^*$ and innovation if and only if $D \leq w(k^*)$, is attained for $\beta = 0$. This is not a necessary condition, however. Suppose for a moment that the *ex-ante* proposal probabilities are $\alpha [1 - \alpha]$ and the *ex-post* probabilities are $\beta [1 - \beta]$. If $\alpha = 0$ so that the innovator receive the entire negotiation surplus $w(k^*) - w(k_{PA})$, then $\beta < \beta$ is sufficient for first-best implementation as $w(k^*) - w(k_{PA}) = w(k^*)$. If, for instance as in Farrell and Shapiro (2008), the innovator sets the (ex-ante) license price and the manufacturer’s proposal probability in *ex-post* bargaining is sufficiently low, the first best can be attained through *ex-ante* price commitment.

5 RAND commitments and *ex-post* litigation

When the innovator’s patented technology is added to an industrial standard by a standard setting organization, he commits to licensing under reasonable and non-discriminatory (RAND) terms.\(^{28}\) This commitment, and subsequent litigation, is one-sided as only the manufacturer is entitled to RAND terms and can sue the innovator for a violation, i.e., if the innovator makes an above-reasonable price offer. The innovator, however, may not sue the manufacturer for offering only below-reasonable price. In this section, we study how the enforcement of this (one-sided) RAND commitment—assumed to be common knowledge at the outset of the game\(^{29}\)—affects the equilibrium of our model. More specifically, we show that it will have


\(^{29}\)Because we assume common knowledge of the patent, deception as in the *Rambus* case cannot be captured by our model. Notice, however, that a promise to charge RAND terms is cheap talk as long as the RAND commitment is not enforced. The *Broadcom* case is thus within the scope of our analysis.
positive effect on short-run efficiency, by solving the manufacturer’s post-investment hold-up problem, but an ambiguous long-run effect, by deterring innovation for sufficiently high values of the manufacturer’s bargaining power, $\beta$.

What RAND terms comprise is often left unanswered by standard setting organizations. In particular, reasonability of license prices—the condition we focus on in our analysis—has been the subject of a contentious debate.\textsuperscript{30} Reasonable royalties have been viewed as the price the parties would have agreed to, had they negotiated one \textit{ex ante}.\textsuperscript{31} We follow this approach by defining the hypothetical license price to be the license price in the option-to-license contract from the previous section. There, parties bargained over the price as to split the expected gains from innovation, $w(k)$. Accordant to the literature, reasonable royalties are the expected price the innovator expects from these negotiations, $R = \beta \bar{p}_M + (1 - \beta) \bar{p}_I$.\textsuperscript{32}

**DEFINITION 3** (Reasonable royalties). Reasonable royalties $R$ are equal to the hypothetical license price,

$$R := \frac{I^P_A(\beta)}{1 - \pi} + (1 - \beta) \frac{w(k^*) - w(k^{PA})}{1 - \pi}. \quad (9)$$

The RAND commitment prescribes a price not exceeding $R$. At this point, the applied non-cooperative bargaining game allows us to model a take-it-or-leave-it price proposal $p_{Ij} > R$ by the innovator as a violation of his RAND commitment.\textsuperscript{33} Definition 4 defines the rules of litigation, i.e., (1) the conditions for a violation of the RAND commitment, (2) the probability of a conviction in court, and (3) the damages in case the innovator is found guilty of a violation.

**DEFINITION 4.** Enforcement of a RAND commitment comprises three factors:

\textsuperscript{30}Swanson and Baumol (2005) discuss how the question of “reasonable” royalties in the context of a RAND commitment ought to be related to the determination of a patent holder’s compensation for reasonable royalties in cases of patent infringement by a manufacturer.

\textsuperscript{31}Blair and Cotter (2005), Elhauge (2008), Lemley and Shapiro (2007), or Shapiro (2006). Cotter (2009) states that reasonable royalties are to be applied “in the sense of awarding the patentee only the share of the expected gains from innovation that the patentee would have bargained for \textit{ex ante} under a bilateral monopoly scenario.”

\textsuperscript{32}Our notion of reasonable is thus market-based rather than driven by what is considered as “fair.”

\textsuperscript{33}Note that we do not need to assume that courts observe who has made the contract offer. The reasonable price in equation (9) is nonnegative, and it is therefore not an optimal strategy for the manufacturer to offer a price $p_{Mj}$ that violates the innovator’s RAND term and subsequently have the reasonable price $R$ enforced by the court. When making her offer, the manufacturer will make the innovator indifferent between acceptance and rejection of the offer, which is achieved by a price strictly lower than $R$. Consequentially, if the manufacturer brings legal action against the innovator for a violation of his RAND commitment, it is indeed the innovator who will have made the violating price offer.
1. The innovator violates his RAND commitment by demanding a license fee that exceeds the hypothetical license price so that $p_{IJ} > R$.

2. In case of a violation, the court sides with the manufacturer with probability $0 < \gamma < 1$; $\gamma = 0$ otherwise.

3. If found guilty, the innovator is compelled to pay damages $\tau (p_{IJ} - R)$ with $\tau \geq 1$.

The reasonable price $R$ as well as parameters $\gamma$ and $\tau$ are common knowledge. Notice, we assume that the plaintiff manufacturer does not receive what the defendant innovator pays. More specifically, we assume that the manufacturer receives single damages ($\tau = 1$) so that her payoffs will be just as if the innovator had offered $R$. The innovator, on the other hand, pays at least single damages ($\tau \geq 1$). We remain agnostic about who receives the net transfer and show below that this “decoupling approach” (Polinsky, 1986) is without loss of generality. For the equilibrium, the size of the transfer the manufacturer receives is irrelevant as long as she is at least as well off as she would have been, had the innovator offered the reasonable royalty $R$. Moreover, for the timing of decisions, we assume that the manufacturer is not bound by the court’s decision with respect to her own adoption decision. This means that once the court has taken a decision, the manufacturer gets to decide whether or not to adopt given the court-induced price (equal to $R$ if the manufacturer wins her case, and $p_{IJ}$ if she loses). Litigation—or rather the threat of litigation—enters the timeline in Figure 3 between stages $t_5$ and $t_6$. The reduced extensive form of the subgame for the innovator’s ex-post price offer is depicted in Appendix B.

5.1 Without ex-ante price commitment

We first assume that ex-ante price commitment is not available, i.e., the parties cannot write an option-to-license contract but have access to courts to enforce the innovator’s RAND commitment. The timing is as depicted in Figure 3 without contract negotiations at stage $t_2$. The parties will negotiate the license prices at stage $t_5$ after the manufacturer has invested ($t_3$) and the value of the patented technology has been realized ($t_4$). Again, we solve for the subgame-perfect Nash equilibrium by backward induction.
At $t_6$ the manufacturer will adopt the technology if her net payoffs are nonnegative, that means if $v(k) - p_i \geq v_0$ (unsuccessful litigation) or $v(k) - R \geq v_0$ (successful litigation) where $p_i$ is the respective price offer. Notice that for $j = L$, the parties will not be able to agree on a price and the manufacturer will not adopt the innovator’s technology. We simplify notation so that $p_I \equiv p_{I,H}$ and $p_M \equiv p_{M,H}$. When making his price offer at stage $t_5$, the innovator anticipates the effects an excessive offer will have in court. If he loses, his payoffs will be $p_I - \tau (p_I - R)$; if he wins, his payoffs are $p_I$. Lemma 2 presents the parties’ equilibrium price offers at stage $t_5$.

**Lemma 2.** The manufacturer’s and innovator’s equilibrium price offers for $j = H$ are $p_M = 0$ and
\[
p_I = \begin{cases} 
\max \{ v(k) - v_0, 0 \} & \text{if } \gamma \tau < 1. \\
\min \{ R, \max \{ v(k) - v_0, 0 \} \} & \text{if } \gamma \tau \geq 1. 
\end{cases} 
\]  

(10)

**Proof.** See Appendix A. Q.E.D.

Two important observations can be made. First, note that RAND enforcement is ineffective if $\gamma \tau < 1$. In that case, the innovator’s benefits from charging an excessive royalty more than offset the expected costs from losing the law suit. Ineffective enforcement takes us back to the results for patent ambush in Section 3. In order for RAND enforcement to be effective, $\tau > 1$ has to hold. This is by the assumption of $\gamma < 1$, i.e., the manufacturer will not win her case with certainty. As a result, single damages—an injunction without penalties for the innovator—are without effect in our model, whereas, for instance, treble damages—an injunction with strictly positive penalties—constrain the innovator’s price setting.\(^{34}\)

Second, we can see that by introducing effective RAND enforcement we replace the manufacturer’s hold-up by the innovator with the innovator’s hold-up by the manufacturer. The former is characterized by an innovator’s price offer that extracts the manufacturer’s entire ex-post surplus. If the reasonable price is binding, i.e. if $R \leq v(k) - v_0$, with RAND enforcement the innovator is now deprived of this possibility of expropriation. While the manufacturer (when making an offer) can still extract the entire ex-post surplus, the innovator is constrained in his pricing strategy through the manufacturer’s entitlement of reasonable royalties. The manufac-

\(^{34}\)For more general analyses of treble damages and private antitrust enforcement see, for instance, Besanko and Spulber (1990), Breit and Elzinga (1974, 1985), or Briggs, Huryn, and McBride (1996).
turer’s threat of taking the innovator to court for excessive pricing is thus one-sided, allowing the manufacturer to “hold up” the innovator. The value of this restriction can be viewed as a “tax” on being the innovator, and ultimately on innovation itself.

For the characterization of the subgame-perfect equilibrium in this model, the following two Lemmas are important. In Lemma 3 we show that the reasonable price $R$ is indeed binding so that the innovator, when making his offer, will propose a price $R$. Recall that this $R$ is not a function of the true investment level but arises from a hypothetical equilibrium. Because at her investment stage $t_3$ the manufacturer expects a license price

$$\beta p_M + (1 - \beta) p_I = (1 - \beta) R$$

which is independent of actual investment $k$, effective RAND enforcement makes her residual claimant and induces efficient ex-ante investment, $k^R = k^*$. The effect of RAND enforcement on the manufacturer’s incentives is therefore equivalent to the effect of ex-ante price commitment: It solves her post-investment hold-up problem.

**Lemma 3.** The manufacturer will efficiently invest so that $k^R = k^*$ if and only if $\gamma \tau \geq 1$.

*Proof.* See Appendix A. Q.E.D.

RAND enforcement indeed solves the manufacturer’s patent hold-up problem as intended by those who have proposed enforcement of RAND terms as a remedy for this very problem. Notice, however, that this result hinges on the interpretation of RAND applied in this paper. An ex-post view of reasonableness that is based on the “established profitability” of the technology and the manufactured product, i.e., also on the true level of investment $k$, as suggested in the 15-factor test in Georgia-Pacific and taken on by the court in Broadcom, will render the expected license price a function of investment. It will therefore not solve the manufacturer’s hold-up problem because the manufacturer can manipulate the ex-post price by investing accordingly. For the remainder of the paper, we assume effective RAND enforcement given the ex-ante interpretation in Definition 3.

**Assumption 2.** $\gamma \tau \geq 1$. 

20
The efficient-investment result implies that the reasonable price $R$ is indeed binding because by $p_M < R < p_I < v(k^*) - v_0$ the innovator’s ex-post price offer (for effective enforcement) will be equal to

$$p_I = R < v(k^*) - v_0.$$  

A binding reasonable price, however, does not necessarily mean that RAND enforcement results in lower expected payoffs $I^R$ for the innovator, with

$$I^R = (1 - \pi)(1 - \beta) R. \quad (11)$$

RAND enforcement will reduce the innovator’s expected payoffs only if $R$ is lower than the price the innovator can offer in the patent-ambush case,

$$R < v(k^{PA}) - v_0. \quad (12)$$

Whether or not equation (12) holds true depends on the potential of innovation and the bargaining parameter $\beta$. Suppose $\beta = 0$, then $R = w(k^*) > 0$ but $k^{PA} = 0$ and the innovator will not have developed the technology so that (12) does not hold irrespective of potential (by Assumption 1). Alternatively, if $\beta = 1$, then $R = 0$ and $k^{PA} = k^*$ so that the condition does hold irrespective of potential. In the following Lemma we show that RAND enforcement facilitates innovation only if $\beta$ is of sufficiently low value.

**Lemma 4.** RAND enforcement facilitates long-run innovation relative to the patent-ambush case only if $\beta$ is sufficiently low. More specifically, there is cutoff value $\beta^R \equiv \beta^R(\pi, v_0)$ with $\underline{\beta} \leq \beta^R < 1$ such that the innovator’s expected royalty returns under $R$ are strictly larger than in the patent-ambush case for all $\beta < \beta^R$.

**Proof.** See Appendix A. Q.E.D.

Figure 5 plots the innovator’s expected returns for the case of RAND enforcement (solid line) and the patent-ambush case (dashed line). The shaded area characterizes the region in which the returns from the latter are higher than from the former, i.e., for the values of $\beta > \beta^R$ for which RAND enforcement deters innovation. Recall that RAND enforcement simply replaces the
Figure 5: Innovator’s expected returns $I^{PA}(\beta)$, $I^{C}(\beta)$, and $I^{R}(\beta)$

manufacturer’s (short-run) hold-up problem with the innovator’s (long-run) hold-up problem. As the innovator’s exposure under the latter is more severe the weaker his bargaining power, the innovator’s hold-up problem becomes relatively more detrimental the higher the value of $\beta$. From a long-run efficiency perspective—balancing short-run and long-run incentives—we should therefore expose the parties to their respective hold-up problem whenever their bargaining power is strong, i.e., when the impact of hold-up is relatively weak.

We know from Lemma 3 that in the short run the RAND-enforcement regime is superior as $R$ induces efficient investment for all $\beta$, whereas the patent-ambush case gives rise to underinvestment for all $\beta < 1$ (or no investment with R&D breakdown for all $\beta < \beta_R$). Yet, byLemma 4, the RAND-enforcement regime deters innovation for all $\beta > \beta_R$. Expected welfare in equation (3) accounts for both short-run and long-run effects. We have shown that investment $k$ and expected royalties $I$ depend on both the potential of innovation and the manufacturer’s bargaining power $\beta$. Equation (3) can thus be rewritten as

$$W(\pi, v_0, \beta) := \int_0^{I(\pi,v_0,\beta)} \frac{w(k(\pi,v_0,\beta)) - D}{D} dD$$  \hspace{1cm} (13)

to characterize the expected welfare in equilibrium for either the case of patent ambush or the
case of RAND enforcement. It is straightforward from Lemma (4) that
\[
\int_0^{I^R} \frac{w(k^*) - D}{D} dD > \int_0^{I^{PA}} \frac{w(k^{PA}) - D}{D} dD
\]
holds for all \( \beta \leq \beta^R \) so that the case of RAND enforcement yields better welfare results than no institutions in the patent-ambush case. The same will hold true for some \( \beta > \beta^R \) as the positive short-run effects on the manufacturer’s investment and thus on the realized value-added from the patented technology will more than offset the negative effects from innovation deterrence. The statement in the previous paragraph suggests that there exists a cutoff value \( \beta^W \equiv \beta^W(\pi, v_0) \) such that RAND enforcement and the patent-ambush case yield identical long-run results,
\[
W^R(\pi, v_0, \beta^W) = W^{PA}(\pi, v_0, \beta^W), \quad (14)
\]
but the innovation deterrence more than offsets the short-run efficiency gains from RAND enforcement for all \( \beta > \beta^W \). Figure 6 illustrates this relation in the \((\pi, v_0)\)-space for showcase parameterizations with different values of \( \beta \) and \( v(k) = 10\sqrt{k} \). Consider the center picture for \( \beta = \frac{1}{2} \). The dotted line gives all potentials such that \( w(k^*) = 0 \) and Assumption 1 is satisfied for all potentials to the southwest. The dashed line depicts all \((\pi, v_0)\)-tuples (i.e., potentials) for which the manufacturer’s ex-ante participation constraint in equation (6) is binding so that \( \beta = \beta(\pi, v_0) \) and \( k^{PA} = 0 \) for all potentials to the northeast. The light-shaded area thus represents all potentials, given \( \beta \), for which we observe an R&D breakdown in the patent-ambush case so that expected welfare \( W \) is equal to zero. Because \( R \) yields efficient investment for all \( \beta \) irrespective of potential so that \( W > 0 \), RAND enforcement is superior over the patent-ambush case for all these low potentials.

For all potentials to the southwest of the dashed line, satisfying equation (6), RAND enforcement increases the manufacturer’s incentive to invest. The solid lines in Figure 6 depict all potentials such that equation (14) is satisfied for the given values of \( \beta \). For potentials in between the solid lines, \( W^R > W^{PA} \) holds true. The dark-shaded area depicts all potentials for which RAND enforcement solves the manufacturer’s hold-up problem without overly deterring innovation so that the long-run expected welfare under \( R \) is larger than in the patent-ambush case. To summarize, for all shaded potentials RAND enforcement is a “good” solution to the
Figure 6: RAND enforcement is a desirable policy only for shaded potentials \((\pi, v_0)\)

manufacturer’s hold-up problem as the deterrence effect (if present) is limited. We can now return to the claim made earlier, namely that parties should be exposed to their respective hold-up problems if their bargaining power is high and the detrimental effects of hold-up are limited. The first picture in Figure 6 illustrates that for relatively high bargaining power for the innovator \((\beta = 1/4)\), RAND enforcement is the preferred solution. If, on the other hand, the innovator has relatively low bargaining power \((\beta = 3/4)\), RAND enforcement is a good solution only for low potentials. For high potentials the long-run losses from innovation deterrence through \(R\) more than offset the short-run gains from efficient investment. In these cases, not interfering with market forces is the optimal policy.

**PROPOSITION 3.** **RAND enforcement is an optimal policy only if the potential \((\pi, v_0)\) of innovation and the manufacturer’s bargaining power \(\beta\) are sufficiently low.**

*Proof.* See the discussion above. Q.E.D.

For the analysis in the previous section we have assumed that *ex-ante* price commitment was not available. The question we ask is whether or not enforcement of the innovator’s RAND commitment as laid out in Definition 4 has beneficial welfare effects in the long run when no other bilateral solution is available. In the final part of the paper we allow for both bilateral bargaining *ex ante* and RAND enforcement *ex post.*
5.2 With *ex-ante* price commitment

The first result is straightforward from the discussion above. It states that, if considered in isolation, *ex-ante* price commitment has better long-run properties than RAND enforcement. While both an option-to-license contract and RAND enforcement maximize short-run efficiency by solving the manufacturer’s hold-up problem, the two solutions yield different long-run results because RAND enforcement generates lower expected royalties for the innovator due to one-sided litigation. We have given a showcase illustration in Figure 5 and provide a formal proof in Proposition 4 below.

**PROPOSITION 4.** Let $\beta \in (0, 1)$, then price commitment is superior to RAND enforcement.

*Proof.* See Appendix A. Q.E.D.

Proposition 4 tells us that if *one* institution could be chosen at the outset of the game, i.e., before the innovation stage $t_1$, bilateral bargaining would give us the better long-run outcome. Suppose for the remainder of this section that *both* institutions are in place. This means that parties can at stage $t_2$ agree on an option-to-license contract and the manufacturer can after stage $t_5$ sue the innovator for a violation of his RAND commitment. Note that the claim of *unfair competition* (as in Section 5 of the FTC Act; see *N-Data*) ought to be much weaker for price offers before the manufacturer has sunk her investment costs than for offers after this investment stage. As a result, *ex-ante* pricing is to be less likely to come under antitrust scrutiny, as means of RAND enforcement, than *ex-post* pricing. We show in Proposition 5 that such a distinction has no effect in our model. This is because the threat of innovator’s hold-up through *ex-post* RAND enforcement will induce the innovator to make an *ex-ante* price offer that does not violate his RAND commitment. Moreover, the threat of RAND enforcement in case parties bargain over but cannot agree on a license contract, limits the range of *ex-ante* price offers either party is willing to accept. The manufacturer’s price offer will make the innovator indifferent between accepting and rejecting (with expected returns of $I^R(\beta)$ as in the case of RAND enforcement); similarly for the innovator’s offer. It turns out that if *ex-post* RAND enforcement is available, the results for the option-to-license contracts in Proposition 2 are displaced by the results for RAND enforcement in Proposition 3.
PROPOSITION 5. Ex-post enforcement of RAND terms distorts the parties’ ex-ante license negotiations and deters innovation as it shifts bargaining rents from the innovator to the manufacturer.

Proof. See Appendix A. Q.E.D.

Proposition 5 extends the implications from Proposition 4 but presents a much stronger case: Price commitment is not only superior to RAND enforcement when compared in isolation, but social welfare is lower when innovation is deterred by allowing for RAND enforcement (and innovator’s hold-up by the manufacturer) once an enforceable option-to-license contract has been agreed to. If the case of RAND enforcement without ex-ante price commitment is the reference case, then adding price commitment does not have an impact on overall welfare because RAND enforcement simply displaces the contract. Ex-post enforcement of RAND terms with an without ex-ante price commitment yields identical results. Yet, if price commitment through an option-to-license contract is the reference case, adding RAND enforcement has a negative effect on overall welfare because an option-to-license contract creates better innovation incentives than enforcement of the RAND commitment.

For Proposition 5 we have implicitly assumed that the manufacturer—through the contract—waives her right to sue the innovator for a violation of the RAND commitment. If RAND enforcement is by antitrust law, such a waiver will be invalid because antitrust law is mandatory and parties cannot simply opt out. Alternatively, if enforcement is by contract law, it may not be possible for the manufacturer and innovator to opt out of a binding commitment the innovator has made vis-à-vis a third party, i.e., the standard setting organization. However, even if the manufacturer could waive her right to sue the innovator, the latter will ex ante have to pay for such a waiver. As a result, his expected payoffs from an option-to-license contract with a waived RAND-enforcement option are lower than from an option-to-license contract without such an option, as in Section 4. Proposition 5 continues to hold.

6 Concluding remarks

The fact that innovators and manufacturers use option-to-license contracts suggests that complete contingent contracts are too costly and difficult to write and enforce. It follows that crit-
icism of existing practice should take this into account. When we do this, we identify a cause of hold-up that has not been previously associated with patent ambush, that incomplete contracts are subject to renegotiation as the future unfolds. Parties who make relationship-specific investments expect to be held up by their trading partners and adjust accordingly, often by under-investing. A simple bilateral option-to-license contract restores a manufacturer’s incentive to invest by giving the manufacturer the option to obtain the license at a price negotiated before the manufacturer makes the relationship-specific investment.

Our main result is that ex-post litigation is not able to improve upon a simple option-to-license contract even for an idealized court that can compute and enforce idealized RAND terms, i.e., the prices the parties would have agreed to had they negotiated an option-to-license contract prior to the manufacturer’s investment. This result highlights the difficulty of restoring the incentives for ex-ante investment using ex-post litigation. One cannot reproduce the effects of ex-ante negotiation when the courts are used only at the discretion of one of the parties.

Our approach breaks some new theoretical ground by using random-proposer-bargaining to capture this asymmetry. Unlike standard models of pre-trial negotiation where the threat of litigation affects the alternative to agreement and thus the terms of agreement, we model litigation as being triggered by the parties’ price offers. While the manufacturer can propose a license fee that expropriates the entire ex-post surplus, the innovator’s ability to do the same is restricted by litigation. We find that this kind of ex-post litigation acts like a “tax” on innovation. Future research may find other ways to define and enforce RAND commitments to offset the effects of this tax.
References


A Proofs

Proof of PROPOSITION 1

Proof. We have already shown that the innovator will not develop if $\beta < \beta^*$. For $\beta > \beta^*$, note that the manufacturer’s expected payoffs in (8) are strictly increasing in $\beta$. The first derivative of (8) with respect to $\beta$ is

$$
\frac{(1 - \pi) (v(k^0) - v_0)}{\partial \beta} + \left(1 - \pi\right) \beta \frac{\partial v(k^0)}{\partial k} - 1 \frac{dk^0}{d\beta} > 0.
$$

The first term is strictly positive by the observation that the manufacturer’s ex-post participation constraint is not binding. The second term is equal to zero by the envelope theorem. Moreover, note that the innovator’s expected royalty returns are equal to zero if $\beta < \beta^*$ or $\beta = 1$ but strictly positive otherwise so that he will develop for $D > 0$ only if $\beta \in [\beta^*, 1]$. Let $\beta^I \equiv \arg \max I^{PA} (\beta)$, satisfying the first order condition

$$
\left(1 - \pi\right) \frac{\partial v(k^0)}{\partial k} - (1 - \beta) (v(k^0) - v_0) = 0.
$$

For $\beta > \beta^*$ the second term is strictly positive (as the manufacturer’s ex-post adoption constraint is not binding). The first term is strictly positive only if $\beta < 1$. The highest value of $D$ for which the innovator is possibly willing to develop is $D = I^{PA} (\beta^I)$. Because $\beta^I < 1$, this upper level is strictly smaller than $w(k^*)$ and innovation in the PA-case will always be insufficient. For general $0 < D < I^{PA} (\beta^I)$, suppose $\beta^I = \beta$, then $I^{PA} (\beta)$ is decreasing in $\beta$ and the innovator will develop for all intermediate values $\beta \in [\beta^*, \beta]$ where $\beta \equiv \beta (\pi, v_0, D)$ such that $I^{PA} (\beta) = D$. If $\beta^I > \beta$ and $I^{PA} (\beta) < D$, the innovator will develop for all intermediate values $\beta \in [\beta_1, \beta_2]$ where $I^{PA} (\beta_1) \equiv I^{PA} (\beta_2) = D$ and $\beta_1 < \beta^I < \beta_2$. If $\beta^I > \beta$ and $I^{PA} (\beta) > D$, the innovator will develop for $\beta \in [\beta, \beta^*]$. Notice, for $\beta < \beta^*$, the innovator is in fact better off with lower bargaining power, i.e., with a higher value of $\beta^*$. Ex-ante, parties have aligned interests with respect to $\beta$. If renegotiation design were feasible, an optimal sharing rule $\beta^*$ would have to balance the positive short-run effects of a high value of $\beta$ on the manufacturer’s investment incentives and the negative long-run effects of a high $\beta$ on the innovator’s development incentives, so that $\beta^* \in [\beta^I, 1)$.

Q.E.D.

Proof of LEMMA 1

Proof. We first characterize the effective price $p_e$ and then derive necessary and sufficient conditions for efficient investment by the manufacturer. Finally, we show that the equilibrium prices $\bar{p}_M$ and $\bar{p}_I$ satisfy these conditions and are renegotiation-proof, i.e., $p_e = \bar{p}_i$ for $i, e = M, I$.

First, given some $\bar{p}_i$, the innovator’s outside option in ex-post bargaining is $\bar{p}_i$ because not selling the license is not a credible threat for all $\bar{p}_i \geq 0$. He cannot offer a higher price $p_e = p_1 > \bar{p}_i$ ex-post. Whether or not the manufacturer can offer a lower price, $p_e = p_M < \bar{p}_i$ depends on her outside option which depends on whether adoption of the technology is profitable. Recall that for a low value of the technology, the manufacturer will always choose the next-best alternative. For a high value of the technology, we must distinguish three cases: First, the patented technology is more profitable than the alternative, $v(k) - \bar{p}_i \geq v_0$ so that nonadoption is not a credible bargaining threat for the manufacturer and the parties will settle on a price $p_e = \bar{p}_i$. Second, $v(k) - \bar{p}_i < v_0$ but a nonnegative price $p'$ such that $v(k) - p' \geq v_0$ exists. The manufacturer can credibly exercise the nonadoption threat, resulting in an expected renegotiated price equal to $(1 - \beta) (v(k) - v_0)$. Third, no nonnegative price such that ex-post adoption is optimal exists, i.e., $v(k) < v_0$, so that $p_e (\bar{p}_i, k) = \emptyset$ and the parties will not be able to agree on a price $p_e$ such that the manufacturer adopts the patented technology.

\[
p_e = \begin{cases} 
\bar{p}_i & \text{if } v(k) - \bar{p}_i \geq v_0 \\
(1 - \beta) (v(k) - v_0) & \text{if } v(k) - \bar{p}_i < v_0 \text{ and } v(k) \geq v_0 \\
\emptyset & \text{if } v(k) < v_0
\end{cases}
\]  

(A1)
Second, for all \( \beta < 1 \), a necessary condition for efficient investment at stage \( t_3 \) is
\[
\bar{p}_i \leq v(k^*) - v_0
\]
(A2)
because the manufacturer will otherwise only recoup a share \( \beta \) of the returns of her investment as the innovator will with probability \( 1 - \beta \) make an ex-post price offer \( p_I = v(k) - v_0 \). Equation (A2), however, is not sufficient for efficient investment. Suppose it holds, then \( (k^*, \bar{p}_i) \) is a Nash equilibrium: The innovator’s best response against investment \( k^* \) is a price \( p_I = \bar{p}_i \), and because the effective price is not a function of \( k \) (the manufacturer’s offer \( p_M = \bar{p}_i \), too), the manufacturer’s best response is efficient investment \( k^* \). The manufacturer’s expected payoffs (at investment-stage \( t_3 \)) are \( v_0 + w(k^*) - (1 - \pi) \bar{p}_i \).

Moreover, suppose \( \bar{p}_i \) and \( k^{PA} \) are such that \( v(k^{PA}) - \bar{p}_i < v_0 \), then \( (k^{PA}, v(k) - v_0) \) is another Nash-equilibrium: The innovator’s best response against such an investment level is a price offer \( p_I = v(k) - v_0 \) (the manufacturer’s offer is \( p_M = 0 \)); the manufacturer anticipates a price \( (1 - \beta) (v(k) - v_0) \) and her best response is \( k^{PA} \). The manufacturer’s expected payoffs are \( v_0 + M^{PA}(\beta) \). The second Nash equilibrium is not subgame-perfect if the manufacturer’s payoffs are lower than from the first equilibrium, or if
\[
\bar{p}_i \leq \frac{w(k^*) - M^{PA}(\beta)}{1 - \pi}.
\]
(A3)

An ex-ante price satisfying equation (A3) is sufficient for efficient investment. Note that (A2) is never binding.

Third, ex-ante offers \( \bar{p}_i \) have to make the offeree indifferent between accepting and rejecting an offer. Suppose the manufacturer’s offer \( p_M \) satisfies equation (A3), then \( p_e = p_I = p_M = \bar{p}_M \). The lowest such ex-ante offer the innovator is willing to accept is
\[
\bar{p}_M = \frac{I^{PA}(\beta)}{1 - \pi}.
\]

Because \( I^{PA}(\beta) + M^{PA}(\beta) = w(k^{PA}) \leq w(k^*) \) for all \( \beta \), such an offer indeed satisfies (A3) and the manufacturer’s investment is \( k^* \). For the innovator’s ex-ante offer, suppose that \( \bar{p}_I \) satisfies equation (A3). The manufacturer will \( k^* \) and accept the offer for all prices that satisfy \( (1 - \pi)(v(k^*) - v_0 - \bar{p}_I) - k^* \geq M^{PA}(\beta) \) so that the innovator offers
\[
\bar{p}_I = \frac{w(k^*) - M^{PA}(\beta)}{1 - \pi}.
\]
satisfying the sufficient condition in (A3). Q.E.D.

**Proof of PROPOSITION 2**

*Proof.* The efficiency of manufacturer’s investment is by Lemma 1. To see that price commitment increases the likelihood of innovation, suppose \( \beta \geq \beta \). By \( w(k^{PA}) = I^{PA}(\beta) + M^{PA}(\beta) > 0 \), the innovator is more likely to develop for all \( \beta < 1 \), i.e., for higher values of \( D \) compared to the PA-case. The same holds true for \( \beta < \beta \) so that \( I^C(\beta) = (1 - \beta) w(k^*) > 0 = I^{PA}(\beta) \) for all \( \beta < 1 \). For \( \beta = 1 \), \( I^{PA}(1) = 0 \) so that \( I^C(1) = 0 \). Q.E.D.

**Proof of LEMMA 2**

*Proof.* If the manufacturer makes the offer, the innovator will accept any nonnegative price so that \( p_M = 0 \). For the innovator’s offer, first let \( p_I > R \). Because litigation is assumed to be costless, any such excessive price offer will induce the manufacturer to sue the innovator for a violation of his RAND commitment. Suppose the manufacturer adopts the patented technology for both \( R \) and \( p_I \). If the manufacturer wins, the innovator’s payoffs are \( p_I - \tau (p_I - R) \); if she loses, the innovator receives \( p_I \). When making an excessive offer at stage \( t_5 \), the innovator’s expected payoffs (taking expectations over
the court’s decision) are
\[\gamma (p_I - \tau (p_I - R)) + (1 - \gamma) p_I = (1 - \gamma \tau ) p_I + \gamma \tau R.\]

If \(\gamma \tau < 1\), the innovator’s payoffs are strictly increasing in \(p_I \leq v(k) v_0\). As a result, the innovator will offer \(p_I = v(k) - v_0\) if \(v(k) > v_0\) and \(p_I = 0\) otherwise. If \(\gamma \tau > 1\), the innovator’s payoffs are decreasing in \(p_I\) and he will offer \(p_I \rightarrow R\). Note, if \(\gamma \tau = 1\), the innovator is indifferent; we assume that he offers \(p_I \rightarrow R\) then. For the parties’ equilibrium price offer we can see that it does not matter whether or not the manufacturer receives the full amount of what the innovator pays.

Now, let \(p_I \leq R\). The manufacturer will win a law suit for violation of a RAND commitment with zero probability (the reduced form game tree in Figure B1 accounts for this) and will accept any offer the manufacturer receives the full amount of what the innovator pays.

**Proof of LEMMA 3**

*Proof. “ONLY IF:”* Suppose \(\gamma \tau < 1\), then RAND enforcement is not effective and the manufacturer invests \(k^{PA} (\beta) < k^*\) for all \(\beta < 1\).

“IF:” First, note that if \(k = k^*\), the reasonable price \(R\) is binding as by \(\bar{p}_M < R < \bar{p}_I < v(k^*) - v_0\) it holds that \(R < v(k^*) - v_0\). By equation (10), the manufacturer’s investment \(k^R\) will depend on whether or not the reasonable price \(R\) is binding at this investment level. More specifically, the manufacturer invests \(k = k^*\) if \(R\) is binding for investment \(k^{PA}\). Suppose that \(R < v(k^{PA}) - v_0 < v(k^*) - v_0\). Then the reasonable price is binding for \(k^{PA}\) and the manufacturer solves
\[
\max_k ((1 - \pi) (v(k) - v_0 - (1 - \beta) R) - k)
\]
so that \(k = k^{PA}\) and \(\pi\) is indeed binding. The respective returns for the manufacturer are
\[
M^R (\cdot | k^{PA}) = M^{PA} (\beta).
\]

Alternatively, for the second Nash equilibrium suppose the manufacturer has invested such that the reasonable price becomes binding and \(p_I = R\) is the innovator’s best response. In that case, the manufacturer’s best response against the innovator’s price offer is the solution of
\[
\max_k ((1 - \pi) (v(k) - v_0 - (1 - \beta) R) - k)
\]
so that \(k = k^*\) and \(R\) is indeed binding. The respective returns for the manufacturer are
\[
M^R (\cdot | k^*) = w(k^*) - (1 - \pi) (1 - \beta) R.
\]

Notice that only the second Nash equilibrium is subgame-perfect because
\[
M^R (\cdot | k^{PA}) < M^R (\cdot | k^*)
\]
\[
M^{PA} (\beta) < w(k^*) - (1 - \pi) (1 - \beta) R
\]
\[
(1 - (1 - \beta)^2) w(k^{PA}) - \beta M^{PA} (\beta) < (1 - (1 - \beta)^2) w(k^*)
\]
holds with strict inequality for all $\beta \in (0, 1)$ so that the manufacturer will invest $k^R = k^*$ and realize strictly larger payoffs than under $k^{PA}$. For $\beta = 0$ and $\beta = 1$ the above expressions hold with equality.

The final step is to show that the manufacturer’s ex-ante participation constraint is satisfied, $w(k^*) - (1 - \pi) (1 - \beta) R \geq 0$ or

$$R \leq \frac{w(k^*)}{(1 - \pi) (1 - \beta)}.$$

This holds for all $\beta$ by

$$R \leq \bar{p}_I = \frac{w(k^*) - M^{PA}(\beta)}{1 - \pi} \leq \frac{w(k^*)}{(1 - \pi) (1 - \beta)}.$$

Q.E.D.

**Proof of LEMMA 4**

*Proof.* RAND enforcement facilitates long-run innovation if and only if equation (12) is violated. This will hold true as long as

$$\text{Proof of PROPOSITION 5}$$

*Proof.* By Proposition 2 and Lemma 3, $k^C = k^R = k^*$. By the definition of $R$, $I^C(\beta) = (1 - \pi) R > (1 - \pi) (1 - \beta) R = I^R(\beta)$ for all $\beta \in (0, 1)$.

Q.E.D.

**Proof of PROPOSITION 5**

*Proof.* Note: The superscript ‘CR’ denotes the case of ex-post enforcement of RAND terms with price commitment through an option-to-license contract. The structure of the bargaining game is as follows. The manufacturer [innovator] makes a take-it-or-leave-it license-price offer $\bar{p}_M^{CR}$, $\bar{p}_I^{CR}$ with probability $\beta$ [1 - $\beta$]. If the innovator [manufacturer] rejects, the manufacturer invests $k$ before the value of the technology is realized and parties enter ex-post negotiations with the manufacturer’s option of RAND enforcement. The innovator [manufacturer] will accept any ex-ante price that makes him [her] at least as well off as ex-post negotiations. The parties’ outside options are $I^R (\beta) = (1 - \pi) (1 - \beta) R$ and $M^R (\beta) = w(k^*) - I^R (\beta)$. As a result, the manufacturer’s and innovator’s ex-ante price offers are

$$\bar{p}_M^{CR} = \frac{I^R(\beta)}{1 - \pi} \leq R \quad \text{and} \quad \bar{p}_I^{CR} = \frac{w(k^*) - M^R(\beta)}{1 - \pi} = \frac{I^R(\beta)}{1 - \pi} \leq R.$$  

Because $\bar{p}_M \leq R \leq \bar{p}_I$ and $I^R(\beta) = (1 - \beta) R$ so that $\frac{I^R(\beta)}{1 - \pi} \leq \bar{p}_I$ for all $\beta$, both $\bar{p}_M^{CR}$ and $\bar{p}_I^{CR}$ satisfy the sufficient condition for efficient investment in equation (A3). Moreover, by equation (A1), the effective price is $p_e = \bar{p}_i^{CR}$ for both $i, c = M, I$. As a result, $I^{CR}(\beta) = I^R(\beta)$.

Q.E.D.
B Innovator’s *ex-post* offer under ‘R’

Figure B1: Reduced extensive form of the innovator’s *ex-post* price offer