An Equilibrium Analysis of Antitrust as a Solution to the Problem of Patent Hold-Up*

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Abstract

Offering manufacturers access to antitrust courts has been proposed as remedy for the problem of post-investment hold-up of manufacturers by innovators of patented technology, sometimes called "patent ambush". In contrast to the default rules provided by contract law, however, parties are unable to contract around mandatory antitrust laws. We show that antitrust can disrupt other, more effcient contractual and organizational solutions (e.g., simple option contracts) to the problem of hold-up. In particular, antitrust laws serve mainly to replace the problem of manufacturer hold-up by the innovator, with the equally serious problem of innovator hold-up by the manufacturer.

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Keywords: Bargaining; Antitrust; Patent ambush; Post-contractual hold-up; Incomplete contracts; Price commitment

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1 Introduction

The economics of patent hold-up are well understood (e.g., Klein, Crawford & Alchian (1978)). Once a manufacturer makes relationship-specific investments to develop products based on a patented technology, the manufacturer can be held up by the patent owner. Of course, post-investment hold-up is not just a problem for the manufacturer. Every business student is taught to anticipate hold-up with the admonition, "look ahead and reason back" (Froeb & McCann 2007). If the manufacturer anticipates that she is at risk of being held up, she will be reluctant to make relationship-specific investments, or demand costly safeguards, including compensation in the form of better terms from the patent holder. This gives both parties an incentive to adopt contracts or organizational forms, such as investments in reputation, bonding or the exchange of "hostages" to reduce the risk of hold-up.

We can add ex-post litigation to this list as another tool that can help mediate transactions between owners and users of intellectual property. Like the gap-filling role played by litigation to resolve contractual disputes arising over unforeseen contingencies, litigation (including antitrust litigation brought by the government or by private parties) can penalize parties that engage in post-investment hold-up. Moreover, the threat of such litigation can deter parties from engaging in such opportunistic behavior. However, in contrast to the default rules provided by contract law, parties are unable to contract around mandatory laws like antitrust. As a consequence, the threat of ex-post antitrust litigation can affect both the terms of trade in the ex-ante bargaining that occurs between parties attempting to make technology choices, as well as supplant other, more efficient solutions to the hold-up problem.

Unlike Farrell, Hayes, Shapiro & Sullivan (2007) who consider only hold-up of the manufacturer by the innovator, we model the entire contracting process between innovator and manufacturer. Accordingly, we evaluate outcomes by using bargaining surplus (i.e., innovator's and manufacturer's welfare) as a welfare metric and thus explicitly account for the innovator's development incentives and the fact that these, too, may be subject to hold-up (Salop 2007, Cotter 2008).[1] Showing that antitrust liability exposes innovators to hold-up by

[1] In the context of antitrust and patent hold-up, a total welfare measure is promoted by Carlton & Heyer (2008), and Kobayashi & Wright (2008). Farrell et al. (2007) or Salop (2007) favor the use of consumer welfare as appropriate welfare measure.

the manufacturers and results in less innovation and lower total welfare than simple contracts, we find that even an idealized antitrust court would displace the very contracting it was trying to encourage. We conclude that courts must be very cautious that antitrust does not disrupt other, more efficient contractual solutions to the hold-up problem because parties cannot contract around mandatory laws like antitrust.

Specifically, we account for the bargaining between creators (called "innovators") and users of intellectual property ("manufacturers") and provide a simple model of sequential bilateral investment[2] where the innovator has sunk the costs of innovation and the manufacturer has made relationship-specific investment to develop and manufacture a product that uses the innovator's patented technology. Without the protection of a contract, the result is a double-sided hold-up problem: downstream manufacturers anticipate hold-up by the innovators and consequently underinvest in relationship-specific development. This shrinks the joint surplus of innovation, and reduces the upstream incentive to innovate.

In the paper by Shapiro (2006), post-investment hold-up stems from the fact that the manufacturer makes her product design decision before she is aware of the validity of the patent. If the manufacturer uses the innovator's technology and the patent turns out to be valid, the innovator's threat of obtaining an injunction is the driving force behind patent hold-up in his analysis. Hence, while in Shapiro (2006) the innovator has a legal claim, in our paper it will be the manufacturer. In this paper, we assume that, ex-ante, the manufacturer makes specific investment to enhance the value of the technology to be realized *if* she decides to use the patented technology. In our model, the design decision is an ex-post decision, whereas in Shapiro (2006) it is ex-ante.

We assume a world of incomplete contracts, meaning the value of the patented technology is uncertain at the time of contracting[3] and parties cannot write contracts conditional on the realized value of the technology. Instead, they use a simple "option" contract based on whether or not the manufacturer decides to adopt the technology.[4] We model ex-ante negotiations and

[2]See Nöldeke & Schmidt (1998). For work on simultaneous bilateral investment see, for instance, Aghion, Dewatripont & Rey (1994), Edlin & Reichelstein (1996), Che & Chung (1999), or Che & Hausch (1999).

[3]Unlike many contributions to the incomplete contracts literature (see, e.g., Hart (1995)), we assume that ex-post trade, i.e., adoption of the patented technology, is not always efficient, calling for *efficient breach* (more precisely: not exercising an option in a buyer-option contract) of a contract as analyzed in the literature on the economic analysis of contracts (see Hermalin, Katz & Craswell (2007) for a comprehensive review).

[4]We do not seek a full solution for the double-sided hold-up problem with sequential investment but argue

ex-post renegotiations between the two parties as random-offer bargaining, meaning that with equal probability parties make price offers the other party can accept or reject.[5] In case of rejection, bargaining ends and both parties realize their outside options (which may or may not be an existing agreement); in case of acceptance, the bargaining offer is implemented.

Our baseline scenario is the case of no legal institution or protection (case '0'). After the value of the patented technology is realized, the parties bargain over the price of the license. This leads to a standard result of double-sided hold-up since the innovator has sunk his development costs while the manufacturer has incurred costs for specific investment and both parties can hold up each other in ex-post bargaining and will not recoup the full returns of their investment. This baseline case is conceptually close to the setup of "early negotiations" in Shapiro (2006, 21ff) where the manufacturer is aware of the patent and a price is negotiated *before* she makes her product design decision. Unlike Shapiro (2006), however, we model the manufacturer's investment decision in addition to the design (i.e., adoption) decision. His setup of early negotiations is one of intermediate negotiations in our model.

If ex-ante price commitment is feasible (case 'C'),[6] simple option contracts, stipulating an up-front contract fee and a license price (equal to zero if the manufacturer adopts an alternative technology), fully solve the manufacturer's and mitigate the innovator's hold-up problem (Proposition 1). Hence, more innovators will decide to invest in the development of new technologies and manufacturers will invest more (and efficiently) in the design of their products. We assume the value of the patented technology and the level of manufacturer's investment to be nonverifiable[7], resulting in incompleteness of the option contract, conditioning on only whether or not the manufacturer adopts.[8]

that even a very simple buyer-option contract is superior to antitrust litigation in mitigating the double-sided hold-up problem.

[5] Ma (1994) suggested this simple bargaining game in a moral hazard framework. With symmetric information and risk-neutral parties it leads to the symmetric Nash-bargaining solution (Schmitz 2006). See Hart & Moore (1999), Bajari & Tadelis (2001), or Schmitz (2008) for related applications.

[6] We assume costless third-party enforcement of contracts through expectation damages as default breach remedy. For economic analyses of remedies for breach of contract, see, e.g., Shavell (1980), Shavell (1984), or Rogerson (1984) for early work and Hermalin et al. (2007) for a comprehensive review.

[7] This is equivalent to saying there is asymmetric information between the innovator and the manufacturer on the one hand, and a third-party enforcer on the other. For a view of contractual incompleteness in this spirit, see Hart & Moore (1988, 1990) or Tirole (1999). In the context of contract law enforcement and antitrust, Kobayashi & Wright (2008, 40) raise the issue of prohibitively high contracting costs as a limitation to the use of contracts.

[8] Huberman & Kahn (1988), Chung (1991), or Schmitz (2002), among others, argue how simple, fixed-terms contracts can solve the contractual hold-up problem. For the use of option contracts, see, e.g., Nöldeke & Schmidt (1995), Lyon & Rasmusen (2004), or Wickelgren (2007).

Having established this positive effect of contractual commitment on parties' investment, we introduce ex-post antitrust litigation through the violation of a RAND commitment. Such a commitment by the innovator, upon acceptance of his patented technology into an industrial standard, stipulates that he must charge *R*easonable *A*nd *N*on*D*iscriminatory prices for the license.[9] In our model with random-offer bargaining, a license price is "not reasonable" if the innovator exploits his market or bargaining power by making a take-it-or-leave-it price offer to the manufacturer.[10] Violation of a RAND commitment implies an antitrust violation, and we assume antitrust litigation to stipulate mandatory damages and be one-sided in the sense that only the manufacturer can sue the innovator for an unreasonable offer, but not vice versa. We will consider different degrees of damages, i.e., zero, single, or trebled.

The first antitrust scenario we look at is the case where parties cannot commit to a price vector ex-ante, but the manufacturer can sue for the innovator's violation of a RAND commitment ex-post (case 'A'). A RAND price in this context is the license price the parties would have agreed to, had they negotiated one ex-ante.[11] This is in accordance with Shapiro (2006, 23ff), Elhauge (2008), or Cotter (2008) who view reasonable royalties "in the sense of awarding the patentee only the share of the expected gains from innovation that the patentee would have bargained for ex-ante under a bilateral monopoly scenario" (Cotter 2008, 16f). By the incomplete contracting assumption, such a price must be independent of the value of the technology and the manufacturer's investment. We assume that, if by random-offer bargaining the innovator is drawn to make an offer, an antitrust court decides in favor of the plaintiff manufacturer with positive probability if the innovator's price offer exceeds the hypothetical contract price. In that case, the court stipulates this hypothetical RAND price and compels damages to be paid by the innovator for violation of RAND terms.

Whether or not antitrust liability (case 'A') is superior to the case of no institutions (case '0') depends on the *effectiveness* of antitrust litigation and the *potential* of the patented technology. We refer to antitrust litigation as being if a law suit's probability of success and the damages

[9] For a comprehensive discussion and review of recent literature, see Lemley (2002) or Chiao, Lerner & Tirole (2006).

[10] This relates to the interpretation of the violation of a RAND commitment in Treacy & Lawrance (2008). Notice, a take-it-or-leave-it offer by the innovator is *a priori* not unreasonable. In equilibrium, however, such an offer will leave the manufacturer with zero profits net of opportunity costs.

[11] Hence, a crucial role of antitrust litigation in this paper is "gap-filling."

(e.g., single or trebled damages) are sufficiently high. If antitrust litigation is ineffective, then the equilibrium outcome will be as for the case of no institutions. If it is effective, then the overall effect will depend on the technology's potential. We refer to *high potential* of technology development if the value of the best alternative technology is low (i.e., the relative value of the patented technology is high) and the probability of success of development is high. In that case, antitrust liability ('A') replaces the manufacturer's hold-up by the innovator's hold-up, and leads to a worse outcome (Proposition 2). Moreover, price commitment (contract litigation) is always better suited to solve the double-sided hold-up problem (arising under '0') than antitrust litigation (Proposition 3).

To investigate the disruptive effect of mandatory antitrust law, we finally consider the case where the parties are able to commit to a license price ex-ante, but the manufacturer can sue the innovator in an antitrust court for violating RAND terms (case 'CA') in ex-post renegotiations. We assume the court decides with positive probability in favor of the plaintiff manufacturer and stipulates the hypothetical license fee. Note, the actual price is the ex-ante offer made by either party, the hypothetical price is the cooperatively bargained price, which in our context is just the mean of the two ex-ante price offers. The welfare effect of antitrust liability on top of price commitment is similar to the effect of antitrust as substitute for price commitment and is also worse than simple contracts. This is because it basically replaces manufacturer hold-up with innovator hold-up (Proposition 4).

Bilateral bargaining and the presence of strong and valid patents distinguish our model from the work by Farrell & Shapiro (2008), among others. In their paper, patents are assumed to be weak in the sense of uncertain validity of the patent,[12] but the value of the innovator's technology is fixed. We consider the reverse case, where patents are strong whereas the value of the patented technology is uncertain and, as explicit outside option for the manufacturer, an alternative technology is available. In their paper, the innovator offers license contracts to downstream firms who can either accept, reject the offer and design around the patented technology, or reject the offer and use the technology at the risk of infringing. Moreover, their model comprises more than one downstream manufacturer.[13] Accounting for downstream

[12]See also Lemley & Shapiro (2005) or Shapiro (2003) and Shapiro (2006).
[13]For recent work, see Sen & Tauman (2007).

competition may add a further dimension to the analysis of antitrust litigation. Our paper is deliberately one-sided, though. We consider a pure bilateral monopoly setting, with one upstream innovator and one downstream manufacturer, to isolate the hold-up effect of antitrust litigation from other such effects.

A final word on our patent assumption is warranted. We assume the validity of the patent to be common knowledge. The innovator has disclosed this piece of information, and antitrust liability is therefore not based on the innovator's deceptive conduct via a standard setting organization but rather on ex-post breach of a RAND commitment.[14] While non-deceptive or "anticipated hold-up" may seem like an oxymoron, in the context of incomplete contracts, the threat of hold-up and the negotiation in anticipation of hold-up is part of equilibrium. Any attempt to use antitrust courts to address the problem of unanticipated hold-up will also affect contractual solutions to the problem of anticipated hold-up. Both parties anticipate this behavior and bargain in expectation of it.

The paper is structured as follows: Section 2 introduces a simple model of sequential bilateral investment between a patent owner and a manufacturer. In Section 3, we establish the result of double-sided hold-up and show the remedial effects of a simple option contract. In Section 4, we introduce the manufacturer's antitrust option and show its disruptive effects on total welfare. Finally, Section 5 concludes. The formal proofs of the results are relegated to the Appendix.

2 A simple model of sequential investment

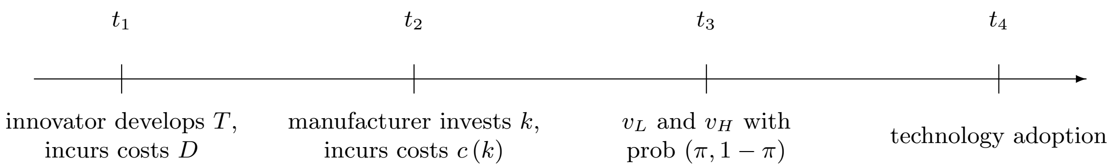
2.1 The setup

The analysis in this paper is based on a simple model of third-party enforcement of incomplete contracts. At the outset of the game, an innovator $\mathcal{I}$ (*he*) develops a patented technology T that is adopted as industrial standard. For the development of T the innovator incurs costs $D > 0$. His participation constraint is such that he will develop if and only if he can expect future payoffs, denoted by I, that cover these costs of innovation, $I \geq D$. In order to benefit from positive effects of the technology, a downstream manufacturer $\mathcal{M}$ (*she*) invests $k \geq 0$ at

[14] We are hereby referring to the concept of non-deceptive hold-up discussed by Kobayashi & Wright (2008, 21ff).

(weakly) convex cost $c(k)$.[15] This investment enhances her revenues from adopting the patented technology and is specific in the sense that it has no value if she decides to adopt an alternative technology with constant net payoffs v_0.[16] Once the manufacturer has invested, revenues $v_j(k)$ are revealed to be either low, $j = L$, or high, $j = H$, so that $v_L(k) < v_H(k)$. Let $v_j(0) = 0$, $v_j' > 0$, and $v_j'' \leq 0$. Both parties observe the realization of the technology's value after the costs of investment have been incurred, where the probability of low value is equal to π.[17] We assume the value as well as investment k to be nonverifiable by third parties. Hence, no contracts can condition on these values. The sequence of events for this setup without institutions is depicted in Figure 1.

Figure 1: Sequence of events of the sequential investment model



The first-best benchmark is a triple $\langle d, k, (a_L, a_H)\rangle$ with innovation decision $d = 1$ if and only if the innovator develops, investment level k, and the manufacturer's adoption decisions a_j, $j = L, H$, that are equal to one if the manufacturer adopts the patented technology, and zero otherwise. Suppose the innovator and the manufacturer could coordinate at the outset of the game, i.e., before the innovator develops, and fully commit to their agreed strategies. In that case, they would agree on a first-best strategy vector (or contract) that maximizes their joint expected surplus net of opportunity costs v_0. The benchmark maximization problem is then given as

$$\max_{k \geq 0,\, a_j \in \{0,1\}} a_L \pi \left[v_L(k) - v_0\right] + a_H (1-\pi) \left[v_H(k) - v_0\right] - c(k) \tag{1}$$

where $a_j^* = 1$ if and only if $v_j(k) \geq v_0$ (adoption is ex-post optimal) and the innovator optimally

[15] We will refer to the manufacturer's specific investment as investment and the innovator's investment (his participation decision) as development or innovation.

[16] The manufacturer's value-enhancing investment is standard- or patent-specific in the sense discussed in U.S. Department of Justice & Federal Trade Commission (2007, note 30)

[17] The probability of success of development, where success implies high value, is $1 - \pi$.

innovates if and only if the expression in (1) is in equilibrium not smaller than his development costs D.

We have not specified the valuation and cost functions, but will, for the sake of tractability, assume that adoption is ex-post efficient if and only if the value of the patented technology is high, $a_L^*(k^*) = 0$ and $a_H^*(k^*) = 1$.[18] The first-best benchmark for this conditional adoption case is thus $\langle 1, k^*, (0,1) \rangle$. Let

$$W^* \equiv W(k^*) = (1-\pi)[v_H(k^*) - v_0] - c(k^*)$$

denote the innovator and manufacturer's expected joint surplus net of the manufacturer's opportunity costs v_0, for efficient investment k^*, given innovation. The highest level of costs D for which innovation is ex-ante efficient is just equal to W^*. Assuming that $D \leq W^*$, so that innovation is always ex-ante efficient if $k = k^*$, throughout the paper will help us set a clear standard with only one direction of deviation.

2.2 Four institutional regimes: Contracts and antitrust

The applied equilibrium concept is subgame perfection; by backward induction we derive the subgame perfect Nash equilibrium (SPNE) outcome arising from four distinct institutional scenarios, $i \in \{0, C, A, CA\}$:

1. *No legal institutions ('0'):* Between periods t_3 and t_4 (in Figure 1) parties engage in spot-contracting. Their expected payoffs from this case are M^0 and I^0 for the manufacturer and innovator, respectively.

2. *Price commitment ('C'):* Parties agree on an option contract with a price vector $\mathbf{P} = (P_0, P_1)$ so that $P_1 = 0$ if the manufacturer ex-post adopts the alternative technology, between periods t_1 and t_2. Either party makes a price offer with probability one half so that $\mathbf{P}$ is equal to the manufacturer's or the innovator's offer. Their outside options at the ex-ante bargaining stage are M^0 and I^0. Between t_3 and t_4 they can renegotiate the price vector and agree on a new license price, i.e., the effective price, P_R.

[18] This is by $v_L(k^*) < v_0$ and $v_H(k^*) > v_0$.

3. *Antitrust ('A'):* Parties engage in spot-contracting between t_3 and t_4. The manufacturer's antitrust option implies that if the innovator is drawn to make the price offer and offers a price higher than the hypothetical contract price, $p_I > P_1$, an antitrust court sides with the manufacturer with probability $\beta < 1$, stipulates a license price P_1 and compels a penalty of $\tau (p_I - P_1)$ with $\tau \geq 0$. If either $p_I \leq P_1$ or the offer has been made by the manufacturer, the success probability is equal to zero.[19] The antitrust option is a threat of ex-post litigation and will be "priced in" at the prior ex-post spot-contracting stage.[20] The parties' expected payoffs are denoted by M^A and I^A.

4. *Price commitment and antitrust ('CA'):* Parties bargain over an option contract with a price vector $\mathbf{P}$ between t_1 and t_2. If they do not agree on a contract, they engage in spot-contracting between t_3 and t_4 (case 'A') so their outside options in ex-ante bargaining are M^A and I^A. If they agree on $\mathbf{P}$, the contract is *re*negotiated between t_3 and t_4. If at this renegotiation stage the innovator makes a price offer $p_I > P_1$, the manufacturer can sue for a violation of RAND terms with a success probability of $0 < \beta < 1$. In that case, the court stipulates a penalty of $\tau (p_I - P_1)$ with $\tau \geq 0$.

We will later argue that the first-best outcome will not be implementable as equilibrium outcome under any of these institutional regimes. This is because by the time the innovator makes his development decision he will anticipate expected payoffs, I^i, and not develop if his costs are higher than what he can expect as his returns, $D > I^i$. Since it is effective only *after* he has made his decision, price commitment will not protect him from hold-up. We are thus concerned with coming "close" to the first-best outcome and relate the four scenarios by determining the manufacturer's investment and the range of D for which the innovator will develop. Table 1 collects these four cases.

[19] We do not need to assume that the court observes which of the party has a made the disputed offer, it is sufficient to assume that it can observe whether or not the offer exceeds the hypothetical price.

[20] Notice, by the one-sidedness of the antitrust option, we do not need to explicitly assume that the court observes who makes an offer. As we will see in the following sections, in equilibrium the manufacturer's offer is always strictly lower than P_1. The manufacturer will therefore have no incentive to ask a court to stipulate this hypothetical contract price if she is drawn to make the offer.

Table 1: Four cases of price commitment and antitrust

	no price commitment	price commitment
no antitrust option	k^0, I^0	k^C, I^C
antitrust option	k^A, I^A	k^{CA}, I^{CA}

3 An efficient contractual solution

In this section, we first give a formal statement of the manufacturer's post-investment hold-up in the light of the bilateral investment model and then show that a simple nonlinear option contract, conditioning on only whether or not the manufacturer adopts the patented technology, can fully restore the manufacturer's investment incentives while increasing the likelihood of development.

3.1 Post-investment hold-up without price commitment

For a formal characterization of post-investment hold-up when no contractual or organizational solutions are in place, suppose that, once the value of the patented technology and the manufacturer's investment have been realized and $v_j(k) \geq v_0$ so that ex-post adoption is efficient, the parties bargain over the price for the license. An agreement is in the mutual interest of both parties. In equilibrium, the price offers made by the parties, each with probability one half, match the other party's outside option payoffs and are accepted, so that for $v_j(k) \geq v_0$, the manufacturer will adopt, $a_j = 1$. The manufacturer will offer $p_M = 0$ and the innovator $p_I = v_j(k) - v_0$. The expected (and effective) price is equal to

$$P = \frac{v_j(k) - v_0}{2} \tag{2}$$

if $v_j(k) \geq v_0$ and $P = \emptyset$ otherwise.[21] Before the value of the technology is realized, the manufacturer must decide how much to invest, k^0, by maximizing her expected payoffs amounting to $v_L(k) - P = \frac{v_L(k)+v_0}{2}$ with probability π and $v_H(k) - P = \frac{v_H(k)+v_0}{2}$ with probability $(1-\pi)$,

[21] If $v_j(k) < v_0$, the manufacturer will accept (offer) only negative prices, which the innovator is not willing to offer (accept). In that case, there will be no ex-post adoption.

net of investment costs, so that

$$k^0(\pi, v_0) \equiv \arg\max_{k\geq 0} \pi a_L(k) \frac{v_L(k) + v_0}{2} + (1-\pi) a_H(k) \frac{v_H(k) + v_0}{2} - c(k). \quad (3)$$

The manufacturer pays the full costs of investment but receives only half of the returns. A post-investment hold-up problem emerges as the manufacturer will try to protect herself against the innovator's ex-post opportunism by investing below the efficient level, $k^0 < k^*$, so that $a_L(k^0) = 0$. In order to keep the analysis focussed, we only consider cases under the following restriction on v_0. The second inequality ensures that adoption of the patented technology is efficient even if the manufacturer has underinvested so that $a_H(k^0) = 1$ and $k^0 > 0$.[22] The first inequality will induce a positive bias on the welfare results for the antitrust scenarios. For second-best technologies v_0 not satisfying this inequality the efficiency implications of antitrust litigation will be even more detrimental.

A1 $v_0 < 2v_H(k^0) - \frac{c(k^0)}{1-\pi} - \left[v_H(k^*) - \frac{c(k^*)}{1-\pi}\right] < v_H(k^0)$

The parties' expected payoffs from this scenario of ex-post bargaining over licensing terms, denoted by M^0 and I^0, are

$$(M^0, I^0) = \left(\pi v_0 + (1-\pi) \frac{v_H(k^0) + v_0}{2} - c(k^0), (1-\pi) \frac{v_H(k^0) - v_0}{2}\right). \quad (4)$$

The innovator's expected profits from development are equal to $I^0 - D$. If these are nonnegative, he will develop. The parties' expected joint gains, net of the value of the alternative technology, v_0, sum up to $W(k^0) = M^0 + I^0 - v_0 < W^*$ by $k^0 < k^*$. Since $M^0 - v_0 \geq 0$, it follows that $I^0 < W^*$, implying that the innovator will not develop for all D for which innovation is ex-ante efficient.[23] We can now summarize these baseline results of double-sided hold-up.

Lemma 1 (Double-sided hold-up). *If parties cannot commit to prices ex-ante but negotiate the terms of the license ex-post, the manufacturer will underinvest, $k^0 < k^*$, and the innovator will not develop for all possible realizations of development costs D for which innovation is ex-ante efficient.*

[22] If $v_H(k^0) < v_0$, the manufacturer will anticipate not to adopt the patented technology and not invest at all to begin with, so that $k^0 = 0$, $a_j = 0$.

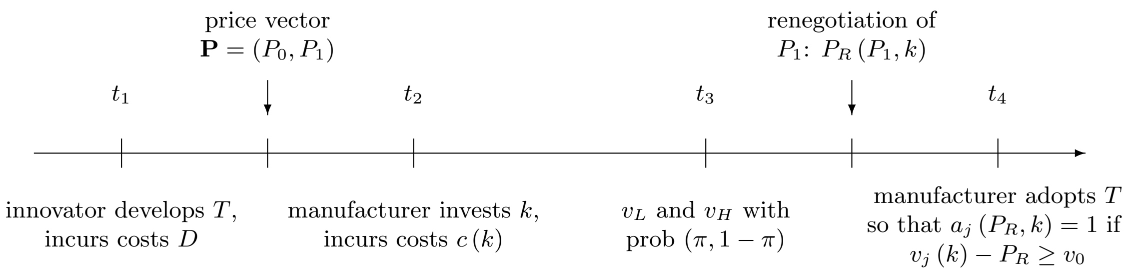
[23] If $M^0 - v_0 < 0$, the manufacturer will not participate and adopt the alternative technology for all j.

Without the ability to commit to a price, the downstream manufacturer anticipates hold-up in the event that the value of the patented technology turns out to be high. The resulting underinvestment reduces the joint gains from innovation which makes it less likely that the innovator will sink the costs of development. As a result, both parties will have an incentive to adopt contractual or organizational forms of commitment to reduce this risk of double-sided hold-up and increase their expected joint surplus.

3.2 Ex-ante price commitment

We show that a simple option contract, conditioning on only whether or not the manufacturer adopts the patented technology, serves as such an efficiency-enhancing contractual solution to the hold-up problem. It solves the manufacturer's hold-up problem and mitigates the innovator's problem. This contract is defined as follows: Once technology T is developed and set as industry standard, the parties commit to an enforceable price vector $\mathbf{P} = (P_0, P_1)$. The first price, P_0, is a nonrecoverable fixed payment by the manufacturer to the innovator to be paid upfront.[24] The second price, P_1, is the conditional license fee to be paid by the manufacturer if and only if she decides to adopt the technology, $a = 1$. If the manufacturer chooses the alternative technology, $a = 0$, then no money is transferred.

Figure 2: Simple option contracts



We first derive the renegotiation price, i.e. effective license price, P_R, and illustrate how it depends on parties' ex-ante commitment through P_1. We then show that this incomplete contracts solves the manufacturer's hold-up problem but does not solve the innovator's problem. In particular, implementation of the first-best outcome is feasible for *all* D only if nonlinear pricing is available. This is because too high a license price P_1 may give the manufacturer an

[24]For an analysis of simple contracts with up-front payments, consult, e.g., Edlin (1996).

incentive to underinvest in order to obtain a better renegotiated price. An upfront payment P_0 allows for sufficiently high returns for the innovator to trigger investment without inducing the manufacturer to shirk and underinvest.

3.2.1 Ex-post renegotiations

Figure 2 depicts the respective sequence of events. After the value of T has been observed, the parties can renegotiate price P_1. Let P_R denote this renegotiated price. The parties' outside option payoffs at the renegotiation stage, between t_3 and t_4, are determined by their obligations as compelled by a court enforcing price vector $\mathbf{P}$. For simplicity, we assume an aggrieved party to be fully compensated for any nonconformity by the other party. Under the contract, it is the innovator's obligation to sell technology T if the manufacturer decides to adopt. Opportunistic hold-up by threatening not to sell the license to the manufacturer can thus not be a credible threat, since not selling the license is strictly dominated once $P_1 > 0$ if parties cannot agree to P_R. The innovator's outside option payoffs are thus equal to P_1. The manufacturer's payoffs depend on whether ex-post adoption of the patented technology yields payoffs at least as high as the alternative, v_0. Her decision, given j, will thus depend on the effective license price and investment k. Note, we can distinguish three scenarios: First, the patented technology dominates the alternative so that nonadoption is not a credible bargaining threat for the manufacturer and the parties will settle on a price $P_{R1} = P_1$. Second, given P_1, the patented technology is dominated by the alternative but a nonnegative price P_1 such that $v_j(k) - P_1 \geq v_0$ exists. By the nature of the option contract the manufacturer can credibly employ the nonadoption threat in the ex-post bargaining game, resulting in an expected renegotiated price P_{R2} as given in equation (2). Third, no nonnegative price such that ex-post adoption is individually rational (and indeed optimal) exists, i.e., $v_j(k) < v_0$, so that $P_{R3} = \emptyset$ and $a_j = 0$ for all P_1. Ex-post renegotiation yields an effective license price of

$$P_R(P_1, k) = \begin{cases} P_{R1} = P_1 & \text{if } v_j(k) - P_1 \geq v_0 \\ P_{R2} = \frac{v_j(k) - v_0}{2} & \text{if } v_j(k) - P_1 < v_0 \text{ and } v_k(k) \geq v_0 \\ \emptyset \quad (\text{and } a = 0) & \text{if } v_j(k) < v_0 \end{cases} \tag{5}$$

as function of P_1 and k.[25] Notice, if this price is a function of investment, the manufacturer's investment incentives will be distorted. Equation (5) suggests that, since the initial contract price P_1 drives the effective price P_R, it also affects the manufacturer's investment k. This distinguishes our results from the setup in Shapiro (2006) where the equilibrium royalties do not interfere with the manufacturer's investment decision.

3.2.2 Manufacturer's investment and innovator's development

Anticipating these license prices and her ex-post decision $a_j(P_R, k) \in \{0, 1\}$ at stage t_2, the manufacturer decides on how much to invest by maximizing her expected payoffs over investment k,

$$\begin{aligned} k^C(P_1, \pi) \equiv \arg\max_k \quad & \pi a_L(P_R(P_1, k), k)[v_L(k) - P_R(P_1, k)] + \\ & (1-\pi) a_H(P_R(P_1, k), k)[v_H(k) - P_R(P_1, k)] - c(k). \end{aligned} \tag{6}$$

As the renegotiated price P_R depends on P_1, the manufacturer's investment decision will do so, too. To see this, first suppose that P_1 is such that $P_R(P_1, k) = P_{R2}$. For $a_L = 0$ and $a_H = 1$, the maximization problem is equivalent to equation (3) and thus $k^C = k^0 < k^*$. If, alternatively, P_1 is sufficiently low so that $v_H(k^*) - P_1 \geq v_0$ and the renegotiated price $P_{R1} = P_1$ independent of k, the manufacturer can appropriate the full returns of her investment, resulting in efficient investment incentives and $k^C = k^*$. Too high a license price P_1 thus renders the effective license price P_R a function of k and gives rise to manufacturer's hold-up. To determine the critical value for P_1, first suppose that P_1 is sufficiently low so that

$$P_1 \leq P^{\mathcal{M}1} = v_H(k^*) - v_0. \tag{7}$$

In that case the innovator cannot appropriate any of the manufacturer's quasi-rents and $k^C = k^*$. As the following argument illustrates, however, condition (7) is not sufficient for efficient investment. Suppose the condition holds and the effective price is P_1. Now, if instead the manufacturer chooses an investment level k' such that $v_H(k') - P < v_0$, she improves her

[25] For notational simplicity, we drop the dependence of P_R on the value of the patented and alternative technology.

relative bargaining position with a renegotiated price of $P_{R2} = \frac{1}{2}\left[v_H(k') - v_0\right] < P_1$.[26] If the resulting price savings $P_1 - P_{R2}$ more than offset the reduction of ex-post payoffs, amounting to $v_H(k^*) - v_H(k')$, investment level k' dominates efficient investment and $k^C = k'$. Let $P^{\mathcal{M}2}$ be such that the manufacturer (weakly) prefers k^* over $k' < k^*$ if and only if $P_1 \leq P^{\mathcal{M}2} < P^{\mathcal{M}1}$.[27]

After the innovator makes his development decision, the parties commit to a price vector $\mathbf{P}$. At stage t_1, the innovator sinks his development costs D if $\mathbf{P}$ is such that the overall payments he expects to receive from the manufacturer,

$$I^C = P_0 + (1 - \pi) P_R\left(P_1, k^C\right) \geq D, \tag{8}$$

where $P_R\left(P_1, k^C\right) = P_1$ if $P_1 \leq P^{\mathcal{M}2}$ and $P_R\left(P_1, k^C\right) = P_{R2}$ if otherwise, fully compensate for these costs.

Given development costs D, for a first-best $\langle 1, k^*, (0, 1)\rangle$ to be implemented, P_0 and P_1 need to be chosen (post-innovation) such that (1) $I^C \geq D$, (2) the manufacturer is willing to participate, i.e, her expected payoffs net of opportunity costs v_0,

$$(1 - \pi)\left[v_H\left(k^C\right) - P_R\left(P_1, k^C\right) - v_0\right] - c\left(k^C\right) - P_0 \geq 0, \tag{9}$$

are nonnegative, and (3) $P_1 \leq P^{\mathcal{M}2}$ so that $k^C = k^*$. In Lemma 2 we show that such a price vector exists and first-best implementation is possible for *all* $D \leq W^*$ if and only if nonlinear pricing is available. Notice, this does not imply that the parties will agree on such a price vector,[28] but rather shows that, if a price vector $\mathbf{P}$ is stipulated by a third-party and communicated before the innovator sinks his development costs, the equilibrium outcome will be efficient for all D.

Lemma 2. *Let $k' \in \left\{k^0, \tilde{k}\right\}$, where $\tilde{k}$ such that, for $\varepsilon \to 0$, $v_H(\tilde{k}) - v_0 = P_1 - \varepsilon$ if $v_H\left(k^0\right) - v_0 \geq$*

[26] See, e.g., Nash (1953) for variable threat games or the textbook treatment in Muthoo (1999).

[27] See Lemma 2 for a proof of the second inequality. To give a characterization of this defection investment level k', suppose $P^{\mathcal{M}2} < P_1$ and $v_H\left(k^0\right) - v_0 < P_1 < P^{\mathcal{M}1} = v_H(k^*) - v_0$. Then, $P_R = P_{R2}$ and $k' = k^0$. If, on the other hand, k^0 such that $v_H\left(k^0\right) - v_0 \geq P_1$, the manufacturer's nonadoption threat at the renegotiation stage is noncredible. In that case, $k' = \tilde{k} < k^0$ such that $v_H(\tilde{k}) - v_0 = P_1 - \varepsilon$ and $\varepsilon > 0$ arbitrarily small. Notice, for strictly positive P_1, $v_H(\tilde{k}) - v_0 > 0$ and $a_H = 1$.

[28] In fact, as we in Proposition 1, the sunk development costs prevent first-best implementation for all D in equilibrium.

P_1, and $k^0 > \tilde{k}$ so that $P^{\mathcal{M}2}\left(k^0\right) < P^{\mathcal{M}2}\left(\tilde{k}\right)$ where

$$P^{\mathcal{M}2}\left(k'\right) = v_H\left(k^*\right) - v_0 - \frac{c\left(k^*\right)}{1-\pi} - \left[\frac{v_H\left(k'\right) - v_0}{2} - \frac{c\left(k'\right)}{1-\pi}\right].$$

Given D, the first-best can be implemented if and only if a price vector $\mathbf{P}$ satisfies

$$\frac{D - P_0}{1-\pi} \leq P_1 \leq P^{\mathcal{M}2}\left(k'\right).$$

Such a $\mathbf{P}$ exists for all $D \leq W^*$ if and only if it is nonlinear and P_0 unrestricted.

If only linear pricing is available so that $P_0 = 0$, a license price P_1 allows for first-best implementation if both the innovator's participation constraint and the manufacturer's efficient-investment constraint $P_1 \leq P^{\mathcal{M}2}$ are satisfied. Recall that, by $D \leq W^*$, development is ex-ante efficient for all D,

$$\frac{D}{1-\pi} < v_H\left(k^*\right) - v_0 - \frac{c\left(k^*\right)}{1-\pi}.$$

The manufacturer's moral hazard problem at the investment stage t_2, i.e. the incentive to underinvestment in order to obtain additional bargaining leverage and a lower price, however, constrains linear pricing and a first-best is implementable if and only if

$$\frac{D}{1-\pi} \leq v_H\left(k^*\right) - v_0 - \frac{c\left(k^*\right)}{1-\pi} - \underbrace{\left[\frac{v_H\left(k'\right) - v_0}{2} - \frac{c\left(k'\right)}{1-\pi}\right]}_{>0 \text{ by Assumption A1}},$$

which is more restrictive than $D \leq W^*$. Albeit efficient, for too high a D the innovator will not develop the technology because he will anticipate—it is of mutual interest to both parties—efficient pricing ex-post, $P_1 \leq P^{\mathcal{M}2}$, not allowing him to recover the full costs of investment.

3.2.3 Ex-ante price bargaining

The results in Lemma 2 apply to the general existence of a first-best price vector. Now, suppose, the parties meet after t_1 and negotiate the contract price vector $\mathbf{P}$.[29] Since the license price is bargained over *after* the innovator has made his development decision, he will not able to

[29]By random take-it-or-leave-it-offer bargaining, we obtain one *expected* contract price vector, $\frac{p_M + p_I}{2}$, equivalent to the cooperatively determined price vector, but two *realized* contract price vectors, (p_M, p_I), equal to the chosen party's offer.

recoup his development costs. This results in a post-development hold-up of the innovator by the manfacturer: the second side of double-sided hold-up.

For the time being, let only linear pricing be available.[30] If the innovator (manufacturer) accepts the manufacturer's (innovator's) offer, they can commit to P_1 as backstop alternative, but cannot commit not to renegotiate it ex-post. The expected payoff vector with effective price $P_R(P_1, k)$ is equal to

$$\left(M^C, I^C\right) = \left(\pi v_0 + (1-\pi) v_H(k) - (1-\pi) P_R(P_1, k) - c(k), (1-\pi) P_R(P_1, k)\right).$$

If the innovator (manufacturer) rejects, parties will negotiate a price after the manufacturer's investment and the value of the patented technology have been realized. The respective expected payoff vector $\left(M^0, I^0\right)$ is given in equation (4). Notice, the expected outcome from ex-post negotiations is independent of who made the rejected ex-ante offer.

The equilibrium offers are

$$p_I = v_H(k^*) - v_0 - \frac{c(k^*)}{1-\pi} - \left[\frac{v_H\left(k^0\right) - v_0}{2} - \frac{c\left(k^0\right)}{1-\pi}\right] \tag{10}$$

for the innovator and

$$p_M = \frac{v_H\left(k^0\right) - v_0}{2} \tag{11}$$

for the manufacturer.[31] Since $(1-\pi)(v_H(k^*) - v_0) - c(k^*) > (1-\pi)\left(v_H\left(k^0\right) - v_0\right) - c\left(k^0\right)$ it holds that $P^{\mathcal{M}2} \geq p_I > p_M$. Hence, no matter who makes the offer, the manufacturer will efficiently invest at t_2 once the contract is entered so that $k^C = k^*$.[32]

At the innovation stage t_1, the innovator anticipates the expected bargaining outcome,

$$P_1 = \frac{p_M + p_I}{2} = \frac{1}{2}\left[v_H(k^*) - v_0 + \frac{c\left(k^0\right) - c(k^*)}{1-\pi}\right] < P^{\mathcal{M}2} \tag{12}$$

[30] This restriction is without loss of generality as we argue in the proof of Proposition 1.

[31] The innovator's offer, p_I, will be such that the manufacturer is just willing to accept the price, anticipating the renegotiated price in equation (5). Hence, the manufacturer's acceptance decision depends on the effective price $P_R(p_I, k)$ rather than the precommitted p_I. Since $P_{R1} > P_{R2}$, the innovator will be inclined to offer p_I such that $P_R(p_I, k) = p_I$. The lowest such price is the one given. This generates higher expected payoffs for the innovator than under no price commitment, $(1-\pi) p_I > I^0$. The manufacturer's offer, p_M, will be such that the innovator is just willing to accept the license price, $(1-\pi) P_R(p_M, k) = I^0$, so that $P_R(p_M, k) = \frac{1}{2}\left(v_H\left(k^0\right) - v_0\right)$. By Assumption A1, $v_H\left(k^0\right) > v_0$, hence $P_R(p_M, k) = p_M$ and p_M as given.

[32] By Lemma 2, $p_I \leq P^{\mathcal{M}2}$ holds for both $k' \in \left\{\tilde{k}, k^0\right\}$.

and will decide to develop the technology if he can expect to recover the costs of development, i.e.,

$$I^C = (1-\pi)\, P_1 \geq D.$$

Note, since $P_1 = \frac{I^C}{1-\pi} > \frac{I^0}{1-\pi} = p_M$, the innovator's revenues under a simple contract are strictly larger than in the scenario where parties cannot commit to a price vector, $I^C > I^0$. But, since $P_1 < p_I < W^*$ and therefore $I^C < I^*$, the innovator's decision will be subject to post-development hold-up. Notice, conditional on the innovator's development, the manufacturer's expected payoffs under the case of price commitment are

$$M^C = \pi v_0 + (1-\pi)\left[v_H(k^*) - P_1\right] - c(k^*)\,.$$

Since the manufacturer can always decide not agree to a price vector, her payoffs will be at least as high as under case '0', $M^C \geq M^0$.

Proposition 1. *If parties can ex-ante commit to a price vector* $\mathbf{P}$ *the manufacturer will efficiently invest* $k^C = k^* > k^0$. *Moreover, innovation is more likely than in the scenario without price commitment but will not be undertaken for some* D, $I^0 < I^C < W^*$. *Price commitment in 'C' leads to a welfare improvement over no institution in '0'.*

The implications of the proposition do not hinge on the bargaining technology for the price vector. Suppose, as in Farrell & Shapiro (2008), the innovator sets prices ex-ante, i.e., is in the position to make take-it-or-leave-it price offers to the manufacturer with certainty, so that $P_1 = p_I$.[33] The innovator will generate higher expected returns but will nonetheless have to make concessions to the manufacturer—who will reject too high an offer and wait for ex-post negotiations—and not receive the full expected surplus, a necessary condition for first-best implementation, since by equation (10) $(1-\pi)\, p_I < W^*$.

The results in Proposition 1 illustrate how simple organizational structures—here we look at noncontingent fixed-terms option contracts—can solve the post-investment hold-up problem and restore the manufacturer's investment incentives. The results in the proposition serve as

[33] Let ex-post renegotiation be under a bilateral monopoly situation, as is the standard assumption in the hold-up literature, and let, for simplicity, bargaining be of the random-offer form.

benchmark case against which we will compare the results with antitrust liability in the next section.

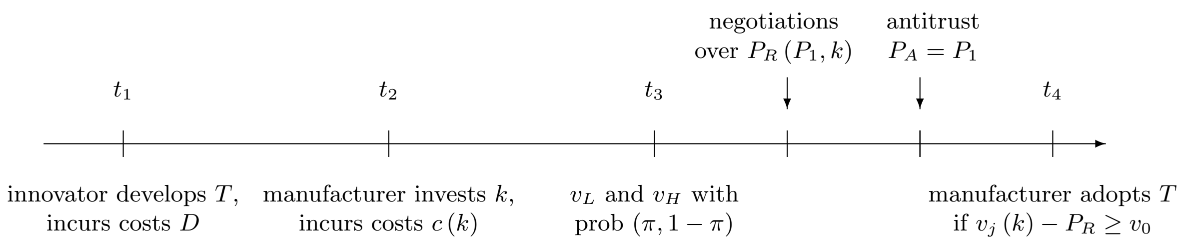
4 Bargaining in the shadow of antitrust

After having laid out the baseline results for the case of no institutions ('0') and price commitment ('C') we now proceed to show how the availability of ex-post antitrust litigation affects the equilibrium outcomes. In a first step we view antitrust litigation ('A') as a substitute for price commitment (i.e., contract litigation) and argue that it has limited capabilities in the sense that it has (if *effective*) positive welfare effects if and only if development of the patented technology is of low *potential* (Proposition 2). Moreover, if available, price commitment should always be prioritized (Proposition 3). In a next step we are concerned with the effect of the manufacturer's antitrust claim on welfare *if* price commitment is feasible, i.e., we allow for ex-ante bargaining over a price vector $\mathbf{P}$ and ex-post antitrust litigation if the innovator's offer at the renegotiation stage is a violation of RAND terms. ...

4.1 Antitrust liability without price commitment

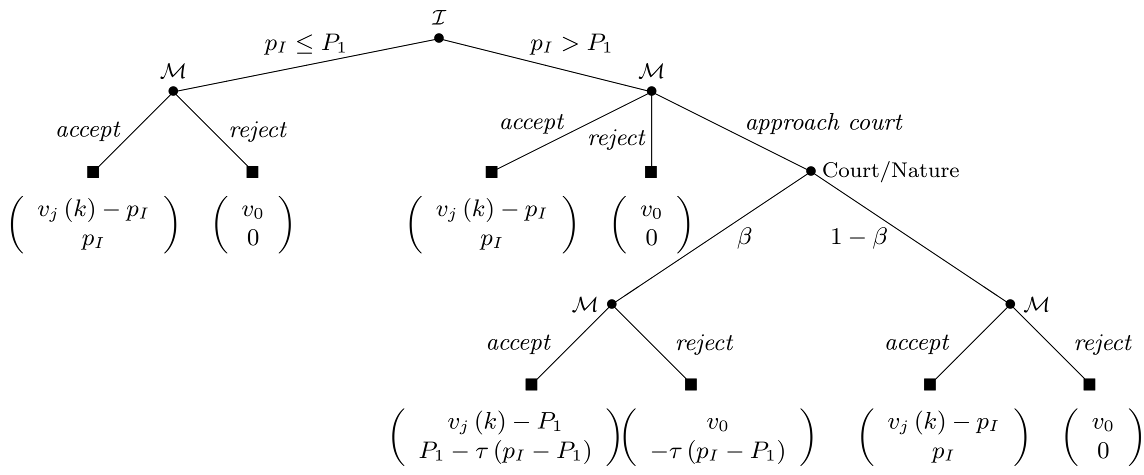
We extend the basic model without institutions by granting the manufacturer access to an antitrust court in case of the innovator's violation of RAND terms. The sequence of events is depicted in Figure 3.

Figure 3: Antitrust liability without price commitment



The random-offer-bargaining approach gives us a simple means to model the manufacturer's option. If she is drawn to make a price offer p_M in the bargaining game after t_3, she will not be inclined to call upon the court since the innovator will accept any price offer $p_M \geq 0$ made by the manufacturer who will therefore offer $p_M = 0$ so that $p_M < P_1$. If, on the other hand, the innovator is to make a price offer, p_I, the manufacturer can accept, reject so that both parties realize their outside option payoffs $(v_0, 0)$, or approach the court and sue the innovator for violation of RAND terms. This antitrust law suit is never successful if $p_I \leq P_1$. If the innovator's offer is $p_I > P_1$, the manufacturer's suit is successful with probability $\beta > 0$ and unsuccessful with probability $1 - \beta$. In the former case, the court stipulates a license price of P_1 and compels antitrust damages $\tau (p_I - P_1)$ with $\tau \geq 0$. After the court's verdict the manufacturer will decide whether or not to adopt and pay the court imposed price. If the law suit is unsuccessful, the innovator's offer p_I remains valid and the manufacturer will decide whether to accept or reject. The extensive form of the subgame of the innovator's offer is depicted in Figure 4.

Figure 4: Extensive form of the innovator's offer-subgame



The innovator's price offer[34] depends on the litigation parameters and is equal to

$$p_I = \begin{cases} P_1 & \text{if } (1+\tau)\beta > 1 \\ v_H(k) - v_0 & \text{if } (1+\tau)\beta \leq 1. \end{cases} \tag{13}$$

Notice, by Assumption A1 the innovator's offer is always strictly positive so that $p_M < p_I$. Equation (13) immediately implies that if $(1+\tau)\beta \leq 1$, the threat of antitrust litigation does

[34]See the proof of Proposition 2 for details.

not have an effect on either party's offer. In this case of *ineffective* litigation the result is as if antitrust litigation were not available at all and the equilibrium results from Lemma 1 apply.

We refer to *effective* antitrust litigation if $(1+\tau)\beta > 1$ which is induced by either high penalties, τ, or a high probability of the plaintiff's success in court, β. A value of $\tau = 0$ implies no penalty for a violation of RAND terms. In case of success the court simply regulates a price without any further consequences. For $\tau = 1$, the innovator pays single damages, while for $\tau = 3$ damages are trebled. Also, the higher τ, the lower the lower bound of β for antitrust litigation to be effective.

For such effective antitrust litigation, the effective price is independent of k so that the manufacturer invests efficiently, $k^A = k^*$, and her expected payoffs, conditional on innovator's development, are

$$M^A = \pi v_0 + (1-\pi)\left[v_H(k^*) - \frac{P_1}{2}\right] - c(k^*) \tag{14}$$

We thus observe a welfare improving aspect of antitrust liability since it solves the manufacturer's hold-up problem. Notice, however, that given this effective price, the expected returns for the innovator are equal to

$$I^A = \frac{1-\pi}{2}P_1 \tag{15}$$

and by Assumption A1 ($v_H(k^0) - v_0 > P_1$) lower than in the institution-free scenario, $I^A < I^0$. This second aspect of antitrust litigation has negative welfare implications as it implies a distortion of the innovator's development incentives, rendering the positive effect on the manufacturer less effective as the innovator is less likely to develop.[35] The very remedy that is in effect to mitigate hold-up of the manufacturer by the innovator is now allowing for hold-up of the innovator by the manufacturer.

As we argue below, the overall effect of (effective) antitrust liability in our setup of bilateral investment is ambiguous and depends on the value of the best alternative technology, v_0, and the probability of low value of the patented technology, π. These two parameters characterize the *potential*, or relative value, of development. A low value of the best alternative technology, v_0, implies a high relative impact of the patented technology. Moreover, a small π results in a high probability of a high-value realization of the patented technology—a low π implies a high

[35] Cotter (2008, 17) acknowledges this latter effect and stresses the emergence of hold-up of the innovator.

probability of success of development. We say the patented technology is of high potential if both v_0 and π are low.

The following two propositions present overall welfare effects of effective antitrust liability. In Proposition 2 we determine the impact of antitrust as legal remedy if ex-ante price commitment is not available—we compare cases '0' and 'A'. Here, the overall effect is ambiguous and depends on the underlying parameterization. To quantify the effects, we derive the expected social surplus of the patented technology, denoted by $\mathbb{E}W^i(v_0, \pi)$, assuming that D is uniformly distributed between 0 and W^*,

$$\mathbb{E}W^i(v_0, \pi) = \int_0^{I^i} \left(W\left(k^i\right) - D\right) \frac{1}{W^*} dD = \frac{2W\left(k^i\right) - I^i}{2W^*} I^i \tag{16}$$

where $i \in \{0, A\}$.

Proposition 2. *Suppose price commitment is not feasible and let $(1 + \tau)\beta > 1$. If the patented technology is of high potential, antitrust liability has a negative expected welfare effect. This effect is positive if the technology is of low potential.*

Proof. The proof is by construction and relegated to the Appendix. Q.E.D.

These results suggest that for a high-potential technology, where the weight of the innovator's development decision is relatively high, antitrust liability leads to lower overall efficiency. Only for low-potential technologies can antitrust litigation such that $(1 + \tau)\beta > 1$ improve on efficiency. For the case of no institutions ('0') we have seen that hold-up of the manufacturer results in insufficient specific investment. On the other hand, antitrust liability, ('A'), if effective, elsewhere applied to mitigate this hold-up problem, just replaces the manufacturer's hold-up by the innovator's hold-up, and leads to a worse outcome. The concerns articulated by Cotter (2008) and quantified in the proposition may thus result in a situation where *no* institutional rules are better than poorly chosen (antitrust) rules. Applying a consumer welfare (manufacturer surplus) standard (Farrell et al. 2007, Salop 2007) ignores these considerations. If the technology is of low potential, the positive effect of antitrust liability on the manufacturer's investment incentives more than offsets the decrease in innovation as result from lower returns for the innovator.

Figure 5: Positive effects of effective antitrust for low potential development

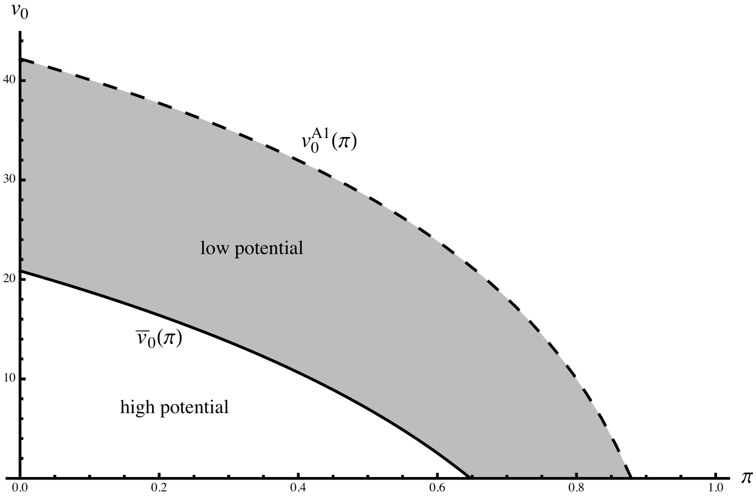


Figure 5 provides a showcase illustration of the claims in Proposition 2 for logarithmic valuation, $v_H(k) = 20 \ln k$, and linear investment costs, $c(k) = k$. All (v_0, π) coordinates to the northeast of the dashed line $(v_0^{A1}(\pi))$ do not satisfy Assumption A1. The solid line $(\bar{v}_0(\pi))$ graphs the set of all (v_0, π) such that the positive effect on manufacturer's investment is just offset by the negative effect on innovator's development incentives. The shaded area depicts all parameterizations for which the former more than offsets the latter and antitrust litigation such that $(1+\tau)\beta > 1$ is welfare enhancing. Finally, for high potential development to the southwest of $\bar{v}_0(\pi)$ the latter effect dominates and $(1+\tau)\beta \leq 1$ is optimal.[36]

Table 2: Antitrust litigation relative to no price commitment

	ineffective litigation $(1+\tau)\beta \leq 1$	effective litigation $(1+\tau)\beta > 1$
low potential high (v_0, π)	k, I, and W unaffected	$k \uparrow$, $I \downarrow$, $W \uparrow$
high potential low (v_0, π)	k, I, and W unaffected	$k \uparrow$, $I \downarrow$, $W \downarrow$

Table 2 provides an overview of the results. If $(1+\tau)\beta \leq 1$ and antitrust litigation is ineffective, the double-sided hold-up results from Lemma 1 apply. Now, suppose that development of the patented technology is of low potential. In that case, stipulating trebled damages has

[36]See the proof of Proposition 2 for an example with linear valuation and quadratic investment costs. In that case, effective antitrust litigation is always superior.

positive welfare implications if $\beta > \frac{1}{4}$, meaning if courts on average side with manufacturer plaintiffs at least one out of four times. When ex-post bargaining over the license agreement, parties anticipate this effectiveness of antitrust litigation and will agree on an expected price of $\frac{P_1}{2}$. Although this lowers the innovator's expected revenues and we will observe innovation less often, the positive effect on the manufacturer's investment incentives more than offsets the negative effects on the innovator's development. If, instead, development is of high potential, effective antitrust litigation fares worse relative to no price commitment. In that case, single damages or no damages for violation of RAND terms so that $(1 + \tau)\beta \leq 1$ will prevent the detrimental effects of antitrust litigation.

In Proposition 3 we take the institution-free equilibrium outcome as reference case and compare the two institutional regimes, price commitment ('C') and effective antitrust ('A') to see which one better solves the double-sided hold-up problem laid out in Lemma 1. For a low-potential technology, effective antitrust litigation mitigates the double-sided hold-up problem that arises in the institution-free case. When directly comparing the governance structures of price commitment ('C') with antitrust ('A') we can conclude that the former is superior. Although under both institutional regimes the manufacturer will efficiently invest, the bargaining leverage that she obtains by this antitrust option results in aggravated hold-up of the innovator and reduces his incentive to development.

Proposition 3. *Price commitment is superior to effective antitrust liability since* $k^C = k^A = k^*$ *and* $I^C > I^A$ *so that it always results in higher welfare.*

Remark. *Notice, unlike in Proposition 2 this result holds for all* v_0 *and* π *satisfying Assumption A1 and a strictly increasing* cdf *of* D *over* $\left[I^A, I^C\right]$.

Organizational arrangements, as the simple fixed-terms contracts in our analysis, are superior to ex-post access to antitrust courts in the sense that they enhance overall efficiency by increasing the parties' expected joint surplus. They are, however, not necessarily *Pareto*-superior. Suppose the parties could vote over the kind of legislation to be adopted, price commitment 'C' or antitrust litigation 'A', before the innovator makes his development decision at stage t_1.

The innovator' expected profits are equal to

$$\mathbb{E}I^i = \int_0^{I^i} \frac{I^i - D}{W^*} dD = \frac{\left(I^i\right)^2}{2W^*}. \tag{17}$$

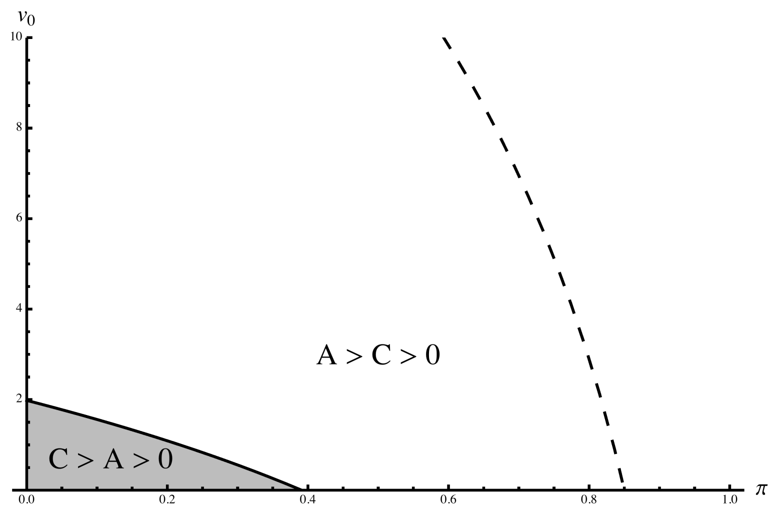
Since $I^A \leq I^0 < I^C$, we obtain

$$\mathbb{E}I^A \leq \mathbb{E}I^0 < \mathbb{E}I^C.$$

The innovator thus always prefers price commitment over antitrust litigation because it does not give the manufacturer a chance to hold him up by threatening to go to court. The results for the manufacturer, on the other hand, are ambiguous. Her conditional expected payoffs (conditional on the innovator's development) are $M^0 \leq M^C < M^A$, yet the unconditional expected payoffs also depend on the innovator's decision. They are denoted by

$$\mathbb{E}M^i = \int_0^{I^i} \frac{M^i}{W^*} dD + \int_{I^i}^{W^*} \frac{v_0}{W^*} dD = \frac{\left(M^i - v_0\right) I^i}{W^*} + v_0. \tag{18}$$

Figure 6: The manufacturer prefers antitrust over price commitment



For the calibration in use in Figure 5, the shaded area in Figure 6 depicts all (v_0, π)-tuples for which the manufacturer prefers price commitment over antitrust litigation as legal remedy. Recall that for the case of antitrust litigation the manufacturer receives a larger share of a smaller expected pie. For high potential technologies it turns out that the manufacturer will prefer a smaller share of a larger pie over a larger share of a smaller pie. For all (v_0, π)-tuples to the northeast of the shaded area and the southwest of the solid lines the reverse holds true.

4.2 Antitrust liability with price commitment

In this last part of the analysis we are concerned with the effect of the manufacturer's antitrust claim on efficiency *if* price commitment is feasible, meaning that we account for both antitrust liability and price commitment. We assume that the manufacturer can (successfully) sue the innovator for violation of RAND terms if the latter has made an excessive price offer in ex-post renegotiations of $\mathbf{P}$.

First, let antitrust litigation be ineffective, i.e., $(1+\tau)\beta \leq 1$. The parties' outside options in ex-ante price bargaining are equal to $\left(M^0, I^0\right)$. In that case, the results from Proposition 1 immediately apply. Now, suppose antitrust litigation is effective, i.e., $(1+\tau)\beta > 1$. The parties' outside options are $\left(M^A, I^A\right)$ and the expected payoffs equal to the expected payoffs from the case of antitrust liability without price commitment. The results from Proposition 2 and 3 apply. The formal arguments of $\left(M^{CA}, I^{CA}\right) = \left(M^A, I^A\right)$ are briefly given below.

Suppose the manufacturer is drawn to make the ex-ante price offer, p_M.[37] In order to induce the innovator (with outside option payoffs equal to $I^A = \frac{1-\pi}{2}P_1$) to accept she must offer a price that does not make the latter worse off. The lowest such offer is

$$p_M = \frac{P_1}{2}.$$

By the arguments presented for equation (5), this price p_M will be renegotiated so that the effective price is $P_R = \frac{P_1}{2}$ and the manufacturer's investment choice $k^{CA} = k^*$. The manufacturer's expected payoffs from her offer are then

$$M^{CA}(p_M) = \pi v_0 + (1-\pi)\left[v_H(k^*) - \frac{P_1}{2}\right] - c(k^*) = M^A.$$

Moreover, $I^{CA}(p_M) = I^A$. If, on the other hand, the innovator is drawn to make the ex-ante price offer, the highest price p_I that will induce the manufacturer (with outside option payoffs

[37] We consider only the case of linear pricing. Since linear prices satisfy the manufacturer's incentive compatibility constraint, $P^{\mathcal{M}2}$, ruling out nonlinear pricing does not impose any restrictions on our welfare results.

of M^A) to invest is defined by

$$\pi v_0 + (1-\pi)\left[v_H(k) - p_I\right] - c(k) \geq M^A = \pi v_0 + (1-\pi)\left[v_H(k^*) - \frac{P_1}{2}\right] - c(k^*).$$

Note, for $p_I \leq \frac{P_1}{2}$, the parties will ex-post renegotiate so that $P_R = p_I$ and $k^{CA} = k^*$. The manufacturer will thus accept any such p_I. For any $\frac{P_1}{2} < p_I \leq P_1$, we obtain $P_R = p_I$ and $k = k^*$, the manufacturer, however, will not accept such a price offer but instead rely on effective antitrust litigation. Hence, the highest offer p_I which the manufacturer is willing to accept is

$$p_I = \tfrac{P_1}{2},$$

equal to the expected price from ex-post negotiations under the antitrust option. For this price, the innovator's expected payoffs are

$$I^{CA}(p_I) = \frac{1-\pi}{2}P_1 = I^A.$$

Moreover, $M^{CA}(p_I) = M^A$.

We have therefore established $M^{CA}(p_M) = M^{CA}(p_I) = M^A$ and $I^{CA}(p_I) = I^{CA}(p_M) = I^A$. Hence, if price commitment (i.e., contract litigation) is feasible, introducing (effective) ex-post antitrust litigation replaces this price commitment. By Proposition 2 this implies that if the patented technology is of high potential, innovator's antitrust liability has a negative effect on overall expected welfare because it gives rise to an innovator's hold-up problem. Antitrust litigation displaces the positive effects of price commitment relative to no institutions established in Proposition 1. The results are summarized in the following proposition.

Proposition 4. *Suppose price commitment is feasible. Ex-post antitrust liability induces the manufacturer to invest efficiently, $k^{CA} = k^*$, yet it distorts the innovator's development incentives since $I^{CA} < I^C$. Price commitment is therefore superior to antitrust liability since $k^C = k^{CA} = k^A = k^*$ and $I^C > I^{CA} = I^A$ so that it always results in higher welfare.*

Proposition 4 extends the implications from Proposition 3 but presents a much stronger case: Price commitment is not only superior to antitrust litigation when directly compared, but social welfare is impaired when the parties' incentives are distorted by allowing for antitrust litigation (with positive β) once an enforceable contract $\mathbf{P}$ exists. Therefore we can conclude, if antitrust 'A' is the reference case, then adding price commitment does not have an impact on overall welfare since 'A' and 'CA' yield identical results. Yet, if price commitment 'C' is the reference case, adding mandatory antitrust rules has a negative effect on overall welfare since 'C' results in more development of the patented technology than 'CA' while litigation (contract and/or antitrust) solves the manufacturer's hold-up problem in either case.

Drawing on the results from Proposition 3, in the context of antitrust case 'A' we discussed the implications of the effect of antitrust with respect to the parties' ex-ante voting behavior. Because $I^A = I^{CA}$ and $M^A = M^{CA}$, the conclusions from that discussion also apply to case 'CA'. Organizational structures such as simple fixed-terms option contracts in this analysis are not *Pareto*-superior. If they could choose, manufacturers would not pick institutions under 'C' but under 'A' ('CA') since the threat of antitrust litigation gives them a bargaining leverage over the innovators. See Figure 6 and the discussion thereof.

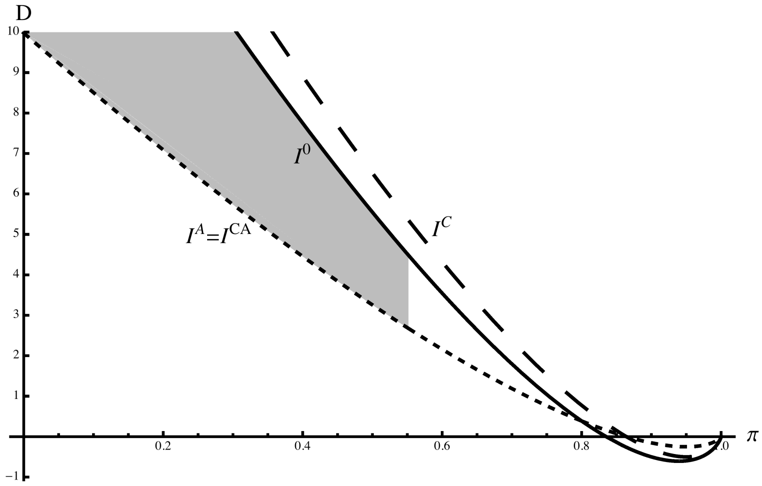
5 Conclusion

Equilibrium, or anticipated, hold-up is a problem for both the victim, as well as the perpetrator of hold-up. Both parties have an incentive to adopt contractual and organizational forms to minimize the costs of hold-up. In our simple model of sequential investment, we have shown that antitrust liability is less efficient than simple contracts in minimizing these costs of hold-up. We have also shown that the mandatory nature of antitrust—parties cannot contract around it—means that parties cannot simply choose between antitrust or contracts. The threat of antitrust liability on top of simple contracts shifts bargaining rents from creators (innovators) to users (manufacturers) of intellectual property in an inefficient way. This antitrust liability has two countervailing effects: while restoring manufacturers' investment incentives, it exposes innovators to hold-up by the manufacturers and results in less innovation.

Figure 7 summarizes the innovator's development decisions for the four cases considered.[38] The solid line depicts innovators' expected revenues, I^0, in the case of no institutions. All values of D below this line induce innovation of the patented technology. The dashed line is

[38] Calibration: Logarithmic valuation with $v_0 = 10$. Notice, probability π is restricted by Assumption A1.

Figure 7: Antitrust prompts innovator's hold-up



the graph of the expected revenues, I^C, in the case of simple contracts. Finally, the dotted line depicts the expected revenues with antitrust, $I^A = I^{CA}$. The shaded area characterizes the additional restriction of antitrust liability on innovation. All these levels of D induce equilibrium innovation under '0' while 'A' prevents it.

Of course, the real world is a lot more complex than our simple theoretical model. In particular, courts may be more sophisticated than we give them credit for, but there are also a wider range of governance structures than we have considered. Anonymous spot-market transactions, long-term contracts, joint ventures, dual sourcing, and vertical integration have been used in various combinations to mediate transactions between the users, developers, and creators of intellectual property. Each of these organizational and contractual forms has advantages in the sense that they can increase joint surplus by reducing transactions costs, depending on the particular attributes of the trading relationship. At various times in the life cycle of an innovation, some of these organizational forms will be better than others, and we expect organizational forms and contracts to evolve to address the coordination and contracting problems in the most efficient way. It is not clear to us that antitrust liability could improve on bilateral bargaining; and it may well displace more efficient solutions to the problem of hold-up. Moreover, it may also retard the efficient evolution of contractual and organizational forms in response to changing industry conditions.

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A Technical appendix: Proofs

Proof of Lemma 1

Proof. By equation (3), manufacturer's investment is $k^0 < k^*$. The joint expected gains from contract-free licensing are equal to

$$W\left(k^0\right) = M^0 + I^0 - v_0 = (1-\pi)\left[v_H\left(k^0\right) - v_0\right] - c\left(k^0\right) < W^* \tag{A.1}$$

and strictly positive since, by Assumption A1,

$$M^0 - v_0 = (1-\pi)\frac{v_H\left(k^0\right) - v_0}{2} - c\left(k^0\right) \geq 0$$

and, for $v_H\left(k^0\right) > v_0$, $I^0 > 0$. Moreover, since $W\left(k^0\right) < W^*$ and $M^0 - v_0 \geq 0$, $I^0 < W^*$ so that the innovator will *not* develop for all $D \leq W^*$. Q.E.D.

Proof of Lemma 2

Proof. We first derive $P^{\mathcal{M}2}$ to show that $0 < P^{\mathcal{M}2} < P^{\mathcal{M}1}$ and then proof the two claims in the Lemma.

Let $P_1 \leq P^{\mathcal{M}1}$, then $a_L\left(P_1, k^*\right) = 0$ and $a_H\left(P_1, k^*\right) = 1$, yielding manufacturer's expected payoffs of

$$\pi v_0 + (1-\pi)\left[v_H\left(k^*\right) - P_{R1}\right] - c\left(k^*\right). \tag{A.2}$$

Her expected payoffs under insufficient investment k', such that $P_R = P_{R2}$, are

$$\pi v_0 + \frac{1-\pi}{2}\left[v_H\left(k'\right) + v_0\right] - c\left(k'\right). \tag{A.3}$$

She will not deviate from $k^C = k^*$ if (A.2) $\geq$ (A.3),

$$\pi v_0 + (1-\pi)\left[v_H\left(k^*\right) - P_{R1}\right] - c\left(k^*\right) \geq \pi v_0 + \frac{1-\pi}{2}\left[v_H\left(k'\right) + v_0\right] - c\left(k'\right),$$

and

$$P_1 = P_{R1} \leq P^{\mathcal{M}2} = v_H\left(k^*\right) - v_0 - \frac{c\left(k^*\right)}{1-\pi} - \left[\frac{v_H\left(k'\right) - v_0}{2} - \frac{c\left(k'\right)}{1-\pi}\right].$$

By $D \leq W^*$, $v_H\left(k^*\right) - v_0 - \frac{c(k^*)}{1-\pi} \geq 0$. Moreover,

$$v_H\left(k^*\right) - v_0 - \frac{c\left(k^*\right)}{1-\pi} > \frac{v_H\left(k^0\right) - v_0}{2} - \frac{c\left(k^0\right)}{1-\pi} > \frac{v_H(\tilde{k}) - v_0}{2} - \frac{c(\tilde{k})}{1-\pi},$$

hence $P^{\mathcal{M}2} > 0$ and $P^{\mathcal{M}2}\left(k^0\right) < P^{\mathcal{M}2}(\tilde{k})$. By Assumption A1 ($v_H\left(k^0\right) > v_0$) and $k^* > k'$,

$$P^{\mathcal{M}2} - P^{\mathcal{M}1} = -\left[\frac{v_H\left(k'\right) - v_0}{2} + \frac{c\left(k^*\right) - c\left(k'\right)}{1-\pi}\right] < 0 \tag{A.4}$$

for all $k' \in \left\{k^0, \tilde{k}\right\}$, and constraint (7) is never binding.

Claim 1. *The first-best can be implemented if and only if a price vector* $\mathbf{P}$ *satisfies* $\frac{D-P_0}{1-\pi} \leq P_1 \leq P^{\mathcal{M}2}\left(k'\right)$.

Given an "entry fee" P_0, the term $\frac{D-P_0}{1-\pi}$, derived from equation (8), denotes the minimal effective license price P_R such that the innovator is willing to develop the patented technology. If P_1 is less than $P^{\mathcal{M}2}$, the effective price is $P_R = P_1$ and the manufacturer will invest efficiently. If a P_1 such that both inequalities in the claim hold, the first-best is implemented for a given D. If such a P_1 does not exist so that $\frac{D-P_0}{1-\pi} > P^{\mathcal{M}2}\left(k'\right)$, the innovator is not willing to develop (if $P_1 < \frac{D-P_0}{1-\pi}$) or the manufacturer will underinvest (if $P_1 > \frac{D-P_0}{1-\pi}$).

Claim 2. *First-best implementation is possible if and only if* $\mathbf{P}$ *is nonlinear and* P_0 *unrestricted.*

First, since $P^{\mathcal{M}2} > 0$, $P_1 = 0$ will always induce efficient investment by the manufacturer. The manufacturer is willing to participate if the inequality in equation (9) holds for $k^C = k^*$ and $P_R(0, k^*) = 0$ so that

$$(1-\pi)\left[v_H(k^*) - v_0\right] - c(k^*) \geq P_0.$$

By $D \leq W^*$, there is always a P_0 such that the condition holds and $\frac{D-P_0}{1-\pi} \leq P_1 = 0$. If $\mathbf{P}$ is linear (or P_0 bounded above), then the first-best is not implementable for all $D \leq W^*$. In particular, if $P_0 < D - (1-\pi) P^{\mathcal{M}2}$, then P_1 is such that either the innovator will not develop (if $P_1 \leq P^{\mathcal{M}2}$ so that $\frac{D-P_0}{1-\pi} > P_1$) or the manufacturer will underinvest (if $P_1 > P^{\mathcal{M}2}$ so that $\frac{D-P_0}{1-\pi} \leq P_1$). Q.E.D.

Proof of Proposition 1

Proof. The proof for linear contracts is along the discussion in the text. For the case of nonlinear contract offers, let $\mathbf{p}_A = (p_{M0}, p_{M1})$ and $\mathbf{p}_I = (p_{I0}, p_{I1})$ so that $P_0 = \frac{p_{M0}+p_{I0}}{2}$ and $P_1 = \frac{p_{M1}+p_{I1}}{2}$. The manufacturer's offer will make the innovator just indifferent between the expected returns from $\mathbf{p}_A$ and contract-free licensing, so that

$$p_{M0} + (1-\pi) p_{M1} = I^0.$$

Likewise, the innovator will offer $\mathbf{p}_I$ to make the manufacturer indifferent between her contract payoffs and M^0 under contract-free licensing,

$$\pi v_0 + (1-\pi) v_H(k) - c(k) - p_{I0} - (1-\pi) p_{I1} = M^0.$$

Linear pricing is just a special case of nonlinear pricing with $P_0 \geq 0$. If $p_{M0} \geq 0$ and $p_{I0} \geq 0$, then the license price offers (as well as the expected license price) under nonlinear pricing will not be higher than under linear pricing, satisfying $P_1 \leq P^{\mathcal{M}2}$, and independent of k. By the bargaining technology (i.e., random offers) it holds that $M^0 > P_0 + (1-\pi) P_1 = I^C > I^0$, establishing the proof of the first claim.

As to the second claim (Price commitment leads to welfare-improvement), notice that $I^C > I^0$ and $M^C > M^0$. Given development, both parties are made strictly better off (a result driven by outside options I^0 and M^0 and the fact that neither party will accept an offer that makes her worse off than spot-contracting in '0'). Since the innovator will develop more often, this will be realized more often. Q.E.D.

Proof of Proposition 2

Proof. Before setting up two showcase examples to illustrate the claims in the Proposition, we first derive the price innovator's price offers in equation (13). Note that for $j = L$ the manufacturer will not want to adopt the patented technology but choose the best alternative instead. Hence, we will only concentrate on $j = H$. The manufacturer's ex-ante investment is denoted by k^A. The threat of antitrust litigation does not make the manufacturer worse off but will have a positive effect on her investment incentives so that $k^A \geq k^0$. By Assumption A1 this implies that $v_H\left(k^A\right) - v_0 \geq P_1$.

1. The manufacturer's price offer $p_M = 0$ is straightforward as the innovator will accept any nonnegative offer.

2. For the innovator's offer, first suppose that $p_I \leq P_1$. In order to induce the manufacturer to accept, $p_I \leq v_H\left(k^A\right) - v_0$. Hence, $p_I = \min\left\{P_1, v_H\left(k^A\right) - v_0\right\} = P_1$. Now, suppose $P_1 < v_H\left(k^A\right) - v_0 < p_I$. If the law suit is unsuccessful, then the manufacturer will not accept but instead adopt the best alternative; if the law suit is indeed successful, the manufacturer will accept and adopt T. Given p_I, the innovator's expected returns are$\beta\left[P_1 - \tau(p_I - P_1)\right]$. These are maximized for $p_I = P_1$, violating the assumption of $P_1 < v_H\left(k^A\right) - v_0 < p_I$. Hence, $p_I \not> v_H\left(k^A\right) - v_0$. Now, let $v_H\left(k^A\right) - v_0 \geq p_I$. In that case, the manufacturer will not outright reject but either accept the offer or go to court. Once the court has been approached, she will adopt T for either verdict. She will thus approach the court as long as

$$\beta\left(v_H\left(k^A\right) - P_1\right) + (1-\beta)\left(v_H\left(k^A\right) - p_I\right) = v_H\left(k^A\right) + \beta(p_I - P_1) - p_I \geq v_H\left(k^A\right) - p_I,$$

or $\beta(p_I - P_1) \geq 0$. Hence, if the innovator makes an offer greater than the hypothetical contract price, his expected payoffs from that offer are

$$\beta[P_1 - \tau(p_I - P_1)] + (1-\beta)p_I = p_I - (\tau+1)\beta(p_I - P_1).$$

The innovator's offer at or below the hypothetical contract price is exactly the hypothetical contract price and his expected payoffs from that offer equal to P_1. Hence, he will make an offer greater than the hypothetical contract price if

$$p_I - (\tau+1)\beta(p_I - P_1) \geq P_1$$

or

$$1 \geq (1+\tau)\beta.$$

For $1 < (1+\tau)\beta$, we can conclude that $p_I = P_1$; for $1 \geq (1+\tau)\beta$ what is left is to determine the upper bound for this price offer. Above, we have found that $p_I \not> v_H(k^A) - v_0$. The manufacturer's choice of rejection of the offer (rendering the innovator's payoffs equal to zero) is dominated as long as $v_H(k^A) - \beta P_1 - (1-\beta)p_I \geq v_0$ or

$$\frac{v_H(k^A) - v_0 - \beta P_1}{1-\beta} \geq p_I.$$

It is straightforward to see that this highest p_I is greater than P_1 and $v_H(k^A) - v_0$. Hence, if $(1+\tau)\beta \leq 1$ the innovator can offer $v_H(k) - v_0$ which the manufacturer will accept after having approached a court.

We now proceed to the proof of the Proposition. Let

$$\Omega \equiv \{(v_0, \pi) : v_0 \geq 0, \pi \in [0,1], \text{ Assumption A1 is satisfied}\}.$$

The object of interest is the set of $(v_0, \pi) \in \Omega$ such that $\mathbb{E}W^A(v_0, \pi) = \mathbb{E}W^0(v_0, \pi)$ where

$$\mathbb{E}W^i(v_0, \pi) \equiv \int_0^{I^i} \frac{W(k^i) - D + v_0}{W^*} dD + \int_{I^i}^{W^*} \frac{v_0}{W^*} dD = \frac{2W(k^i) - I^i}{2W^*} I^i.$$

Note that $W(k^A) > W(k^0)$; for $k^A = k^*(\pi)$

$$W(k^A) = (1-\pi)[v_H(k^*(\pi)) - v_0] - c(k^*(\pi))$$

and for $k^0 = k^0(\pi)$

$$W(k^0) = (1-\pi)\left[v_H(k^0(\pi)) - v_0\right] - c(k^0(\pi)).$$

Moreover,

$$I^0 = \frac{1-\pi}{2}\left(v_H(k^0(\pi)) - v_0\right)$$

and

$$I^A = \frac{1-\pi}{2} P_1 < I^0.$$

$W(k^i)$ and I^i, $i \in \{A, 0\}$ are continuous in $(v_0, \pi) \in \Omega$, so that there exists a function $\bar{v}_0 : [0,1] \to \mathbb{R}$ such that $\mathbb{E}W^A(v_0, \pi) = \mathbb{E}W^0(v_0, \pi)$. If $(\bar{v}_0(\pi), \pi) \in \Omega$, $\bar{v}_0(\pi)$ separates Ω, and $\mathbb{E}W^A(v_0, \pi) < \mathbb{E}W^0(v_0, \pi)$ if $v_0 < \bar{v}_0(\pi)$, vice versa. If it does not, $\mathbb{E}W^A(v_0, \pi) < \mathbb{E}W^0(v_0, \pi)$ or $\mathbb{E}W^A(v_0, \pi) > \mathbb{E}W^0(v_0, \pi)$ for all $(v_0, \pi) \in \Omega$.

Given π, let $v_0 = v_0^{\mathbf{A1}}(\pi)$ such that Assumption A1 is satisfied. The following two showcase calibrations illustrate the claims in the Proposition.

1. Suppose logarithmic valuation and linear investment costs, $v_H(k) = \phi \ln k$, $\phi > 0$, and $c(k) = k$.

Then

$$\bar{v}_0(\pi) \approx \phi\left[\ln\left((1-\pi)\phi\right) - 1.953\right]. \tag{A.5}$$

and $\bar{v}_0(\pi) > 0$ if $\pi < 1 - \frac{7.050}{\phi}$. Assumption A1 is satisfied for strictly positive v_0 if $\pi < 1 - \frac{4}{\sqrt{\exp(1)\phi}}$ so that $0 < v_0^{\mathbf{A1}}$. A positive $v_0 < \bar{v}_0(\pi)$ exists so that $\mathbb{E}W^A(v_0, \pi) < \mathbb{E}W^0(v_0, \pi)$ for all $\pi < 1 - \frac{7.050}{\phi} < 1 - \frac{2.436}{\phi}$. If, on the other hand, for a given π, opportunity costs v_0 are sufficiently large and satisfying Assumption A1, then granting the manufacturer an antitrust option has positive efficiency effects, $\mathbb{E}W^A(v_0, \pi) > \mathbb{E}W^0(v_0, \pi)$. This case of logarithmic valuation, for $\phi = 20$, and linear costs is depicted in Figure 5. The dashed line is the graph for $v_0^{\mathbf{A1}}(\pi)$, the solid line for $\bar{v}_0(\pi)$. The shaded area in between depicts all $(v_0, \pi) \in \Omega$ for which the expected social surplus in the antitrust case 'A' is higher than in the institution-free case '0', $\mathbb{E}W^A(v_0, \pi) > \mathbb{E}W^0(v_0, \pi)$. For all (v_0, π) to the southwest of $\bar{v}_0(\pi)$ the antitrust option has a negative effect on the parties' social surplus so that $\mathbb{E}W^A(v_0, \pi) < \mathbb{E}W^0(v_0, \pi)$.

2. Suppose linear valuation and quadratic investment costs, $v_H(k) = \phi k$, $\phi > 0$, and $c(k) = k^2$. Then

$$\bar{v}_0(\pi) = \frac{\left(9 - 2\sqrt{29}\right)(1-\pi)\phi^2}{80} \leq 0. \tag{A.6}$$

$\mathbb{E}W^A(v_0, \pi) = \mathbb{E}W^0(v_0, \pi)$ for $(v_0, \pi) = (0, 1)$ and $\mathbb{E}W^A(v_0, \pi) > \mathbb{E}W^0(v_0, \pi)$ for all $(\bar{v}_0(\pi), \pi < 1)$.

Q.E.D.

Proof of Proposition 3

Proof. In both regimes the manufacturer invests efficiently, $k^C = k^A = k^*$. The expected returns for the innovator are $I^C = (1-\pi)P_1 > \frac{1-\pi}{2}P_1 = I^A$ where P_1 is given in equation (12). If the cumulative distribution function of D is strictly increasing over $\left[I^A, I^C\right]$, $D < I^C$ is less restrictive for innovator's development than $D < I^A$, establishing the proof for the first claim. Q.E.D.

Proof of Proposition 4

Proof. The proof follows straight from the observation that the effective prices are independent of k so that $k^{CA} = k^*$ and the fact that $M^{CA}(p_M) = M^{CA}(p_I) = M^A$ and $I^{CA}(p_I) = I^{CA}(p_M) = I^A$. By Proposition 3, $I^C > I^A = I^{CA}$, establishing the effects of antitrust liability on development incentives. Q.E.D.