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

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March 16, 2009

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 ("patent ambush") in situations of bilateral investment, where innovators decide whether or not to develop a patented technology before manufacturers can invest in relationship-specific assets, enhancing the value of that technology. 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 efficient contractual and organizational solutions (e.g., simple option contracts) to the problem of hold-up.

JEL classification: D21; K21; L14; L4;

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

*Thanks to Stefan Bechtold, Bruce Kobayashi, María Sáez Martí, Nick Netzer, Patrick Schmitz, Armin Schmutzler, Quan Wen, Greg Werden, and seminar participants at Zurich for helpful comments and suggestions.

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1 Introduction

The economics of patent hold-up are well understood (e.g., **?**). 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" (**?**). 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 serve to 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 **?** who consider a consumer welfare measure (i.e., manufacturer surplus), we look at total welfare (i.e., innovator's and manufacturer's joint bargaining surplus) as welfare measure and can thus in equilibrium explicitly account for the innovator's development incentives and the fact that these, too, may be subject to hold-up (**?**, **?**).[1] Showing that antitrust liability exposes innovators to hold-up by 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 and conclude that courts must be very cautious that

[1] In the context of antitrust and patent hold-up, a total welfare measure is promoted by **?**, and **?**. **?** or **?** favor the use of consumer welfare as appropriate welfare measure.

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 **?**, 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 **?** 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 **?** 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 simple contracts based on only whether or not the manufacturer decides to adopt the technology.[4] We model ex-ante negotiations and 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

[2] See **?**. For work on simultaneous bilateral investment see, for instance, **?**, **?**, **?**, or **?**.

[3] Unlike many contributions to the incomplete contracts literature (see, e.g., **?**), 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 **?** for a comprehensive review).

[4] We do not seek a full solution for the double-sided hold-up problem with sequential investment but argue that even a very simple buyer-option contract is superior to antitrust litigation in mitigating the double-sided hold-up problem.

[5] **?** 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 (**?**). See **?**, **?**, or **?** for related applications.

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 **?** where the manufacturer is aware of the patent and a price is negotiated *before* she makes her product design decision.

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]

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 Reasonable And Non$D$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

[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., **?**, **?**, or **?** for early work and **?** 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 **?** (**?**, **?**) or **?**. In the context of contract law enforcement and antitrust, **?** raise the issue of prohibitively high contracting costs as a limitation to the use of contracts.

[8] **?**, **?**, or **?**, among others, argue how simple, fixed-terms contracts can solve the contractual hold-up problem. For the use of option contracts, see, e.g., **?**, **?**, or **?**.

[9] For a comprehensive discussion and review of recent literature, see **?** or **?**.

to the manufacturer.[10] Violation of a RAND commitment implies an antitrust violation, and we assume antitrust litigation to stipulate mandatory trebled damages and be one-sided in the sense that only the manufacturer can sue the innovator for an unreasonable offer, but not vice versa.

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 **?**, **?**, or **?** 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" (**?**, 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 with certainty in favor of the plaintiff manufacturer and stipulates a license fee as specified in the scenario with price commitment.

Whether or not antitrust liability (case "A") is superior to the case of no institutions (case "0") depends on the relative value of the patented technology. For high values of the best alternative technology and a low probability of success of innovator's development—we refer to this as *low potential* of development—antitrust liability ("A") just 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"). We assume the court decides with positive probability in favor of the plaintiff manufacturer and stipulates a predetermined license fee. Note, while in the contract-free scenario with antitrust option ("A")

[10]This relates to the interpretation of the violation of a RAND commitment in **?**. 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."

the manufacturer claims the innovator's offer to be a violation of RAND terms and demands the hypothetical contract price, in this latter case she claims the actual contract price, which she had initially agreed to, to be a violation of such terms and demands a lower license fee. This latter claim is weaker than the former, and a court will side with the manufacturer with less than certainty.[12] 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 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 **?**, among others. In their paper, patents are assumed to be weak in the sense of uncertain validity of the patent,[13] 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.[14] Accounting for downstream 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.[15] 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

[12] A "violation" of RAND terms can be due to opportunistic behavior by the innovator or by a "desirable exercise of his intellectual property rights." If courts find it difficult to distinguish between these two objectives or expressively side with consumers and view the innovator's conduct as "oppressive," "coercive," or of "bad faith," decision errors might arise (**?**, 28, 41).

[13] See also **?** or **?** and **?**.

[14] For recent work, see **?**.

[15] We are hereby referring to the concept of non-deceptive hold-up discussed by **?**.

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 (weakly) convex cost $c(k)$.[16] 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.[17] 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.[18] 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.

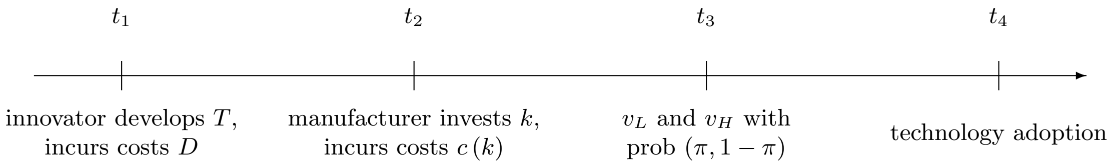
The first-best benchmark is a triple $\langle d, k, (a_L, a_H)\rangle$ with innovation decision $d = 1$ if and only if the innovator develops, investment level k, and the manufacturer's adoption decisions

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

[17] The manufacturer's value-enhancing investment is standard- or patent-specific in the sense discussed in **?**

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

Figure 1: Sequence of events of the sequential investment model



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 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 $a_H^*(k^*) = 1$.[19] The first-best benchmark for this conditional adoption case is thus $\langle 1, k^*, (0,1) \rangle$. Let

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

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.

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

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. 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.

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, an antitrust court sides with the manufacturer and stipulates a license price P_1. 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 agree on an option contract with a price vector $\mathbf{P} = (P_0, P_1)$ between t_1 and t_2. If they do not agree on a contract, they engage in spot-contract 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 renegotiated between t_3 and t_4. The manufacturer's antitrust option at this stage is a threat of ex-post litigation where the court will side with the manufacturer's claim (P_1 is a violation of RAND terms)

[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.

with probability $0 < \beta < 1$ and stipulate a payment of damages trebled, $3(P_1 - P_{RAND})$, where P_{RAND} is common knowledge and known at t_1.[21]

We will later argue that the first-best outcome will not be implementable as equilibrium outcome under all these institutional regimes. 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, $D > I^i$. We 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.

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. Notice, an agreement is in the mutual interest

[21] Notice, by the assumption of a one-sided antitrust option, the manufacturer will sue the innovator only if $P_{RAND} < P_1$. If this does not hold, the manufacturer's antitrust option is without effect and we are back in case "C".

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 $p_A = 0$ and the innovator $p_I = v_j(k) - v_0$. The expected price is equal to

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

if $v_j(k) \geq v_0$ and $\{\}$ otherwise.[22] Before the value of the technology is realized, anticipating the equilibrium license price the manufacturer must decide how much to invest, k^0, by maximizing her expected payoffs amounting to $v_L(k) - P$ with probability π and $v_H(k) - P$ with probability $(1-\pi)$, net of investment costs, so that

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

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 $a_L = 0$. In order to keep the analysis focussed, we make the following assumption:

A1 $(1-\pi)\frac{v_H(k^0) - v_0}{2} - c(k^0) \geq 0$ implying $v_H(k^0) > v_0$.

It ensures that adoption of the patented technology is efficient even if the manufacturer has underinvested. This also implies a strictly positive investment level k^0.[23]

The parties' expected payoffs from this scenario without price commitment—and ex-post bargaining over licensing terms—denoted by M^0 and I^0 are

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

The innovator's 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,

[22] 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.

[23] 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 $k^0 = 0$, $a_j = 0$.

v_0, sum up to $W\left(k^0\right) = M^0 + I^0 - v_0$ and are, by $k^0 < k^*$, strictly lower than W^*. 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.[24] 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.*

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

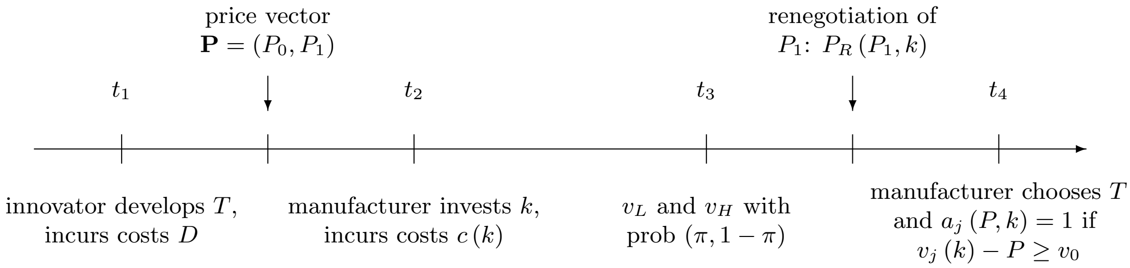
We show that a simple option contract, conditioning on only whether or not the manufacturer adopts the patented technology, serves as such an efficiency-enhancing contractual solution to the hold-up problem. This contract is defined as follows: Once technology T is developed and set as industry standard, 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.[25] 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.

We first derive the renegotiation, i.e. effective license price, P_R, and illustrate how it depends on parties' ex-ante commitment, P_1. We will then discuss the effect of this dependence on the manufacturer's investment as well as the innovator's development decision and show that implementation of the first-best outcome for all D is feasible only if nonlinear pricing is possible.

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

[25] For an analysis of simple contracts with up-front payments, consult, e.g., **?**.

Figure 2: Simple option contracts



Finally, we characterize the equilibrium price commitment and establish a positive effect of ex-ante commitment on the parties' expected joint surplus.

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 the parties' 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 such that $v_j(k) - P \geq v_0$ 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 $P_{R3} \in \{\ \}$ and $a_j = 0$

for all P. Ex-post renegotiation yields an effective license price of

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

as function of P_1 and k.[26] 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 **?** 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,

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

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, i.e., ex-post renegotiated, license price P_R a function of k and gives rise to manufacturer's hold-up. If P_1 is sufficiently low,

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

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

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 relative bargaining position[27] with a renegotiated price of $P_{R2} = \frac{1}{2}\left[v_H(k') - v_0\right] < P_1$. If the resulting price savings $P_1 - P_{R2}$ more than offset the impairment 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 $P_1 \leq P^{\mathcal{M}2} < P^{\mathcal{M}1}$.[28]

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 are 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,[29] but rather shows that, if a price vector $\mathbf{P}$ is stipulated by a third-party and

[27] See, e.g., **?** for variable threat games or the textbook treatment in **?**.

[28] 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 $a_H = 1$.

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

communicated before the innovator sinks his development costs, the equilibrium outcome will be efficient for all D.

Lemma 2. *Let* $k' \in \{k^0, \tilde{k}\}$*, where* $\tilde{k}$ *such that* $v_H(\tilde{k}) - v_0 = P_1 - \varepsilon$*,* $\varepsilon \to 0$*, if* $v_H(k^0) - v_0 \geq P_1$*, and* $k^0 > \tilde{k}$ *so that* $P^{\mathcal{M}2}(k^0) < P^{\mathcal{M}2}(\tilde{k})$ *where*

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

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

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

This holds for all $D \leq W^*$ *if and only if the price vector* $\mathbf{P}$ *is nonlinear and* P_0 *unrestricted.*

If only linear pricing is available, 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,

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

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, constrain linear pricing and a first-best is implementable if and only if

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

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 $\mathbf{P}$.[30] Since the license price is bargained over *after* the innovator has made his development decision, he will not able to 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, $P_0 = 0$.[31] If the innovator (manufacturer) accepts the manufacturer's (innovator's) offer, they can commit to this 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

$$\left(\pi v_0 + (1-\pi)\, v_H(k) - (1-\pi)\, P_R(P_1, k) - c(k),\, (1-\pi)\, P_R(P_1, k)\right).$$

If the innovator 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).

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

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

for the manufacturer.[32] Since $(1-\pi)\left(v_H(k^*) - v_0\right) - c(k^*) > (1-\pi)\left(v_H\left(k^0\right) - v_0\right) - c\left(k^0\right)$

[30] By random take-it-or-leave-it-offer bargaining, we obtain one *expected* contract price vector—equivalent to the cooperatively determined price vector—but two *realized* contract price vectors—equal to the chosen party's offer.

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

[32] 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_A, will be such that the innovator is just willing to accept the license price, $(1-\pi)\, P_R(p_A, k) = I^0$, so that $P_R(p_A, k) = \frac{1}{2}\left(v_H\left(k^0\right) - v_0\right)$. By Assumption A1, $v_H\left(k^0\right) > v_0$, hence $P_R(p_A, k) = p_A$ and p_A as given.

it holds that $P^{\mathcal{M}2} \geq p_I > p_A$. Hence, no matter who makes the offer, the manufacturer will efficiently invest at t_2 once the contract is entered, $k^C = k^*$.[33]

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

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

and will decide to develop the technology if he can expect to recover the costs of development, i.e. $d = 1$ if and only if $I^C = (1-\pi)\, P_1 \geq D$. Note, since $P_1 = \frac{I^C}{1-\pi} > \frac{I^0}{1-\pi} = p_A$, 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. These conclusions also apply to the more general case of nonlinear pricing.

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 Pareto-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 **?**, 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 $P_1 = p_I$.[34] 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 benchmark case against which we will compare the results with antitrust liability in the next section.

[33] By Lemma 2, $p_I \leq P^{\mathcal{M}2}$ holds for both k' so that $k^C = k^*$.

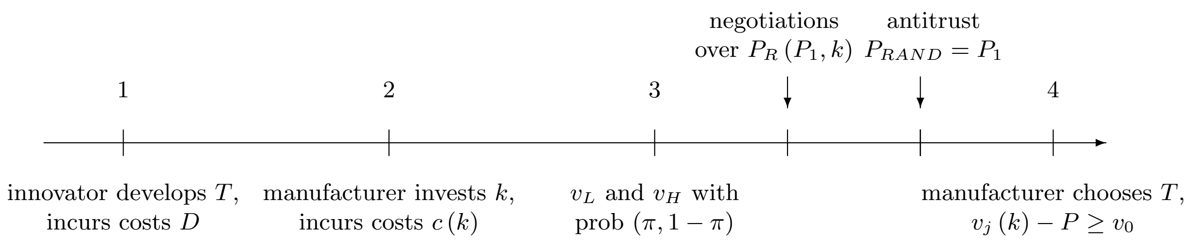
[34] Let, as is the standard assumption in the hold-up literature, ex-post renegotiation be under a bilateral monopoly situation, and let, for simplicity, bargaining be of the random-offer form.

4 Bargaining in the shadow of antitrust

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_A, she will not be inclined to call upon the court since the innovator will accept any price offer $p_A \geq 0$ made by the manufacturer who will therefore offer $p_A = 0 < P_1$. If, on the other hand, the innovator is to make a price offer, p_I, the manufacturer can accept, reject (and both parties realize their outside option payoffs $(v_0, 0)$), or approach the court so that $P_{RAND} = P_1$. If the manufacturer's payoffs from adoption are higher than her opportunity costs, $v_j(k) - p_I \geq v_0$, she will approach a court for any $p_I > P_1$ but accept the offer if $p_I \leq P_1$. The innovator will want to offer $p_I = P_1$. If, however, $v_j(k) - P_1 < v_0$, the manufacturer will reject, yielding payoffs of zero for the innovator. The innovator's offer will induce the manufacturer to accept, $p_I = \min\{P_1, v_j(k) - v_0\}$ for $v_j(k) \geq v_0$. The effective price is thus equal to

$$P_R(P_1, k) = \frac{\min\{P_1, v_j(k) - v_0\}}{2} \tag{13}$$

if $v_j(k) \geq v_0$ and $P_R(P_1, k) = \{\}$, so that there is no ex-post trade of a license if otherwise. Since $v_H(k^*) - v_0 > v_H(k^0) - v_0 > P_1$,[35] $\min\{P_1, v_j(k) - v_0\} = P_1$ and, by equation (12), the

[35] The latter inequality is established in the proof of Proposition 2 in the Appendix; see equation (B5). Moreover, the price savings from underinvestment, k', are $\frac{1}{2}[P_1 - (v_H(k') - v_0)]$. The price savings for defective behavior in Lemma 2 are higher, $P_1 - \frac{1}{2}(v_H(k') - v_0)$, and the sufficient condition for efficient investment under contract liability, $P_1 \leq P^{\mathcal{M}2}$, stricter than under antitrust liability in this section.

effective price is independent of k so that the manufacturer invests efficiently, $k^A = k^*$. Given this effective price, the expected returns for the innovator are equal to

$$I^A = \frac{1-\pi}{2} P_1. \tag{14}$$

By Assumption A1 and $v_H\left(k^0\right) > v_0$, $I^A < I^0$. We thus have two countervailing effects of antitrust liability relative to the institution-free setup. On the one hand, given innovation, the manufacturer's investment incentives are fully restored; on the other hand, the innovator's development incentives are distorted, and the first effect on the manufacturer will be less effective as the innovator is less likely to develop.[36] 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.

The overall effect of antitrust liability in our setup of bilateral investment is not straightforward but 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 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 antitrust liability. In Proposition 2 we determine the impact of the *institution of antitrust* 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 by assuming that D is uniformly distributed. In Proposition 3 we take the institution-free equilibrium outcome as reference case and compare the two institutional regimes, price commitment ("C") and antitrust ("A") to see which one better solves the double-sided hold-up problem laid out in Lemma 1.

[36]**?** acknowledges this latter effect and stresses the emergence of hold-up of the innovator.

Proposition 2. *Suppose price commitment is not feasible. 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 relegated to the Appendix. We set up the problem and construct two examples in support of the claims. Q.E.D.

Remark. *Recall,* $k^A = k^* > k^0$ *but* $I^A < I^0$. *The question of interest is* H*ow much of a disruption of the innovator's development incentives are offset by restored manufacturer's investment incentives. Suppose, for tractability,* D *is uniformly distributed over* $[0, W^*]$. *The effect of the institutional rules can be determined referring to the expected social surplus which is defined as*

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

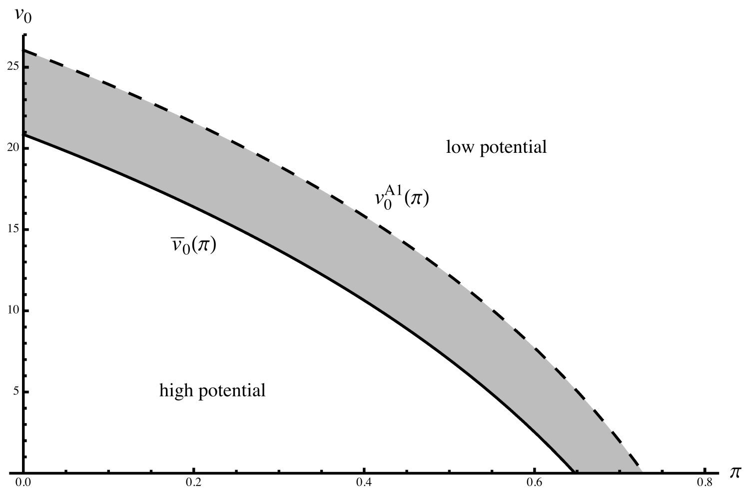
where $i \in \{0, A\}$.

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. 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*"), 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 **?** 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 (**?**, **?**) ignores these considerations. If the technology is of low potential[37], 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 4 provides an 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) combinations to the right of the dashed line do not satisfy Assumption A1. The solid line depicts the set of all (v_0, π) such that the positive effect on manufacturer's investment is just offset by the negative effect

[37] The extent of *low potential* is restricted by Assumption A1, i.e., both v_0 and π are bounded above. See the proof of Proposition 2 for more on this.

Figure 4: Antitrust with positive effect relative to no price commitment



on innovator's development incentives. The shaded area depicts all parameterizations for which the former more than offsets the latter, for high potential development to the left of $\bar{v}_0(\pi)$ the latter effect dominates.

For a given set of parameters, the antitrust option may mitigate 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 the manufacturer 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 antitrust liability since $k^C = k^A = k^*$ and $I^C > I^A$ so that it always results in higher welfare. Price commitment is Pareto-superior to antitrust.*

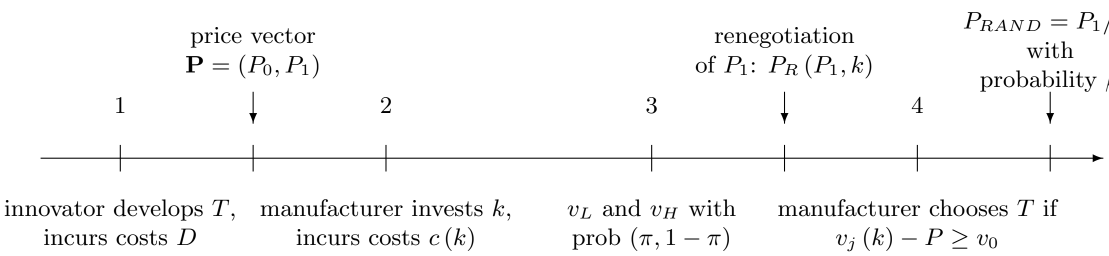
Remark. *Notice, unlike in Proposition 2 this result holds for all v_0 and π satisfying Assumption A1 and a strictly increasing* cdf *of D over $\left[I^A, I^C\right]$.*

Organizational arrangements, as the simple fixed-terms contracts in our analysis, are superior to ex-post access to antitrust courts. As we have shown, both regimes induce the manufacturer to efficiently invest, yet her ex-post bargaining leverage results in lower anticipated revenues for the innovator who will be less likely to develop.

4.2 Antitrust liability with price commitment

In this last section we are concerned with the effect of the manufacturer's antitrust claim on efficiency if price commitment is feasible. Similar to the setup in the previous section, we assume the manufacturer, after having adopted the patented technology and *paid* a predetermined license price P_1, to be able to bring the contract before an antitrust court for innovator's violation of a RAND commitment. The manufacturer's probability of success in court, β, is common knowledge. If successful, an antitrust court stipulates a RAND price $P_{RAND} < P_1$ and the manufacturer receives the price difference $P_1 - P_{RAND}$ while the innovator, after having received P_1, pays antitrust penalties amounting to the price difference trebled, $3(P_1 - P_{RAND})$.[38] The manufacturer's claim in the previous section (for institution scenario "A") was valid only if the innovator had made an unreasonable price offer. In this section, we assume the court cannot observe (after stage 4) who made the realized price offer P_1 (before stage 2) but will side with the manufacturer with less than certainty. See Figure 5 for an illustration of this sequence of events.

Figure 5: Antitrust liability with price commitment



We derive the parties' equilibrium behavior by backward induction. Given β, at stage 4 the manufacturer expects to pay a court imposed price of

$$P_C(P_1) = P_1 - \beta(P_1 - P_{RAND}).$$

The innovator receives payments P_1 with certainty but will with probability β pay antitrust damages. His expected revenues at stage 4, given adoption, are equal to $P_1 - 3\beta(P_1 - P_{RAND})$. The renegotiated, effective license price $P_R(P_1, k)$ will depend on P_C and whether or not a

[38]Notice, if $P_{RAND} > P_1$ the manufacturer will never sue the innovator. Moreover, since the antitrust option is one-sided, such a price will take us back to the price commitment scenario without antitrust (ineffective antitrust).

nonadoption threat by the manufacturer is credible. Antitrust courts may overrule an ex-ante contract price P_1, but do not interfere with an ex-post renegotiated price P_R, hence $\beta = 0$ once parties have agreed ex-post.[39] To simplify the analysis and for illustration purposes, we fix the RAND license price. Moreover, the manufacturer's probability of litigation success is assumed to be sufficiently low.

A2 $P_{RAND} = \frac{P_1}{f}$, where $f > 1$, and $\beta < \frac{f}{2(f-1)} \equiv \bar{\beta}$.

The expected price P_C under this assumption thus equals

$$P_C\left(P_1\right) = \left(1 - \frac{f-1}{f}\beta\right) P_1 = \gamma P_1. \tag{15}$$

For renegotiation of P_1, we again discuss two cases that will eventually allow for equilibrium adoption under $P_R\left(P_1, k\right)$.

First, suppose $v_j\left(k\right) - P_C\left(P_1\right) \geq v_0$. The manufacturer will adopt the technology and take the case to court if parties do not agree on a renegotiated price. The maximum price she is willing to accept is P_C, i.e. the expected price she is going to pay off the equilibrium path (if the price is *not* renegotiated but she will ex-post adopt). The lowest price the innovator is willing to accept is equal to $P_1 - 3\beta\left(P_1 - P_{RAND}\right)$, his expected payoffs from manufacturer's adoption under P_1 and court error β. With each party making an offer with probability 1/2, the renegotiated price is equal to $P_{R1} = P_1 - 2\beta\left(P_1 - P_{RAND}\right)$, and by Assumption A2

$$P_{R1} = \left(1 - \frac{(f-1)}{f}2\beta\right) P_1 = \delta P_1. \tag{16}$$

Notice, $\delta > 0$ and, for $\beta > 0$, $0 < \delta < \gamma < 1$.

Second, let $v_j\left(k\right) - P_C\left(P_1\right) < v_0$ but $v_j\left(k\right) \geq v_0$. If parties do not agree on a new price, the manufacturer will decide not to adopt the patented technology as the expected price P_C yields net payoffs lower than the payoffs from the best alternative technology. The maximum price she is willing to pay is equal to $v_j\left(k\right) - v_0$. The lowest price the innovator is willing to accept

[39] Note, the manufacturer adopts the technology *before* going to court. This implies that if she loses her case she can not decide not to adopt. This is why the *expected* court imposed price is used here. If she could go to court *before* her adoption decision, she could wait for the litigation result and then decide not to adopt if price P_1 were sufficiently high such that $v_j\left(k\right) - P_1 < v_0$. This latter case is ruled out by assuming that the court's decision is binding such that the manufacturer cannot walk away if not satisfied.

is zero, as he would otherwise not generate any revenues. This yields a renegotiated price P_{R2} as given in equation (2).

We have demonstrated earlier that, if the manufacturer can threaten not to adopt the patented technology for sufficiently high P_1, she can inflict on the innovator a lower effective price, $P_{R2} < P_1$, which results in incentives to underinvestment. A necessary condition for efficient investment satisfies $v_H(k^*) - P_C(P_1) = v_H(k^*) - \gamma P_1 \geq v_0$, so that

$$P_1 \leq \widetilde{P}^{\mathcal{M}1} \equiv \frac{P^{\mathcal{M}1}}{\gamma}. \tag{17}$$

A price satisfying this necessary condition, however, may still result in underinvestment if the price savings more than offset the losses from lower ex-post valuation. By the line of argument in the previous section (see Lemma 2 for the formal steps), the sufficient condition for efficient investment is

$$P_1 \leq \widetilde{P}^{\mathcal{M}2} \equiv \frac{P^{\mathcal{M}2}}{\delta}. \tag{18}$$

By Assumption A2, both $\widetilde{P}^{\mathcal{M}1} > 0$ and $\widetilde{P}^{\mathcal{M}2} > 0$. Notice, since $\delta < \gamma$ for $\beta > 0$, $\widetilde{P}^{\mathcal{M}2} < \widetilde{P}^{\mathcal{M}1}$ is not guaranteed.[40]

A price satisfying equation (18) will induce efficient investment incentives for the manufacturer. Moreover, if a price vector $\mathbf{P}$ such that $P_0 + (1-\pi) P_R(P_1, k) \geq D$ exists or is expected as result of negotiations, then a first-best outcome is implemented for a given D. If

$$\widetilde{P}^{\mathcal{I}} \equiv \frac{P^{\mathcal{I}}}{\delta} = \frac{D - P_0}{\delta(1-\pi)} \leq P_1 \leq \min\left\{\frac{P^{\mathcal{M}1}}{\gamma}, \frac{P^{\mathcal{M}2}}{\delta}\right\} \tag{19}$$

for *all* $D \leq W^*$, then the first-best is implementable for all D. Notice, if $\beta = 0$ so that the manufacturer's antitrust option is not effective, then $\delta = \gamma = 1$ and the results are as reported in Lemma 2. For positive β, satisfying Assumption A2, Lemma 3 summarizes the effect of the manufacturer's antitrust option on the feasibility of efficient investment so that $k^{CA} = k^*$.

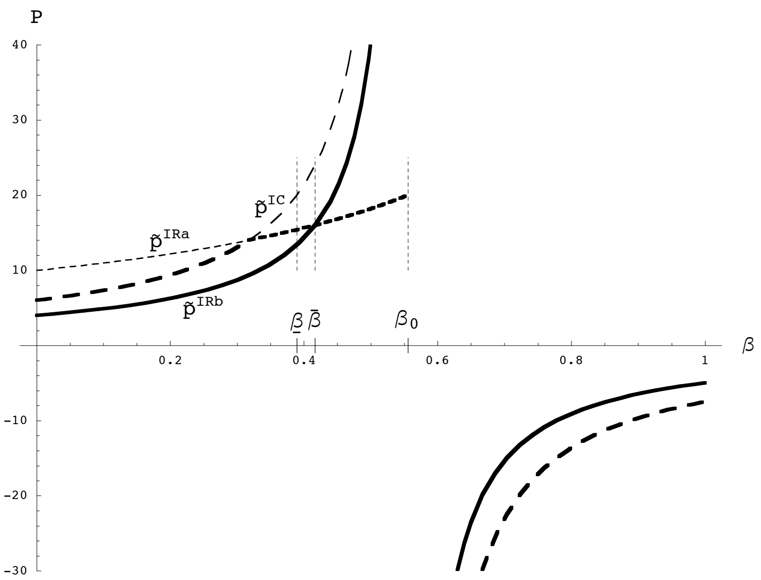
Lemma 3. *Let the pricing technology be restricted so that $P_0 < D$, and let $\beta < \bar{\beta}$. If $P^{\mathcal{I}} \leq P^{\mathcal{M}2}$ and a license price P_1 such that $k^{CA} = k^*$ exists for $\beta = 0$, the set of such P_1 expands for*

[40] For the case "C", $P^{\mathcal{M}1}$ was never binding.

low values, shrinks for intermediate values, and is empty for sufficiently high values of β. If $P^{\mathcal{I}} > P^{\mathcal{M}2}$ and no such license price exists for $\beta = 0$, none exists for all $\beta < \bar{\beta}$.

Figure 6 plots the conditions for development and efficient investment for a showcase calibration.[41] As shown in the proof of Lemma 3, for sufficiently small values of the error court, $\beta < \beta_0$, antitrust liability increases the range of licenses prices P_1, given D and P_0, that allow for first-best implementation. This set of efficient license prices is represented by the shaded area in Figure 6. For immediate values, $\beta_0 < \beta < \beta_1$, the non-empty set of efficient license prices becomes smaller as β increases, and it is empty for all $\beta > \beta_1$. This means, if in the simple price commitment case an efficient outcome will result (for $\beta = 0$), the antitrust option disrupts the availability of efficient licenses when the probability that the court sides with the manufacturer is sufficiently large. Moreover, if there is no first-best implementation for $\beta = 0$, there is none for all $\beta > 0$.

Figure 6: The range of efficient P_1 is increasing if and only if $\beta < \beta_0$



Notice, if the pricing technology is unrestricted and nonlinear price vectors $\mathbf{P}$ are feasible, there exists a $\mathbf{P}$ that implements the first-best for all $D \leq W^*$ and all β. Lemma 4 thus extends the results from Lemma 2.

[41] $v_H(k) = \phi \ln k$, $c(k) = k$, $\phi = 20$, $\pi = \frac{1}{2}$, $v_0 = 1$, $f = 8$, and $D = 8$ so that $\beta_0 \approx 0.44$, $\beta_1 \approx 0.45$, and $\bar{\beta} = 4/7$.

Lemma 4. *Given $\beta < \bar{\beta}$, a first-best can be implemented for all $D \leq W^*$ if and only if the price vector is nonlinear.*

Lemmata 3 and 4 are concerned with the existence of a *general* price vector $\mathbf{P}$ that allows for first-best implementation. The differences between Lemma 2 on the one hand and Lemmata 3 and 4 on the other are driven by two factor: court error β and trebled damages. Suppose the court never sides with the manufacturer and $\beta = 0$, then $\delta = \gamma = 1$ and the results from Lemma 2 apply.[42] Moreover, if the innovator does not have to pay trebled damages but just the price difference, $P_1 - P_{RAND}$, then $0 < \delta = \gamma < 1$ for all $\beta > 0$. The antitrust option simply shifts up and extends the range of efficient license price by a factor $\frac{1}{\gamma}$. It remains non-empty for all β. Ex-post implementation is therefore not noticeably affected relative to $\beta = 0$ if antitrust damages are *not* trebled.

In the final part of this section we derive the equilibrium outcome given ex-ante price bargaining.[43] Before the manufacturer incurs investment costs $c(k)$ the parties meet to bargain over the equilibrium price vector $\mathbf{P}$. If they cannot agree on such a price vector, the manufacturer will invest k in t_2, and both parties observe the value of the patented technology in t_3 before they bargain over a license price ex-post. The anticipated revenues from these ex-post negotiations with antitrust option, and outside option payoffs, are equal to M^A for the manufacturer and I^A for the innovator. The effective license price from ex-post bargaining is given in equation (13). It is independent of k. This implies, if parties cannot agree on a license price P_1, the manufacturer will efficiently invest. We formally show in the proof of Proposition 4 that the same holds true if they agree on a price. The total surplus they bargain over is equal to W^* and thus as high as in the expected joint surplus they receive under the outside option, $\left(M^A - v_0\right) + I^A = W^*$. An agreement in the "$CA$" case will make them just as well off as the "A" case; and the price they will agree on will induce an effective price that is just equal to the effective price under the outside option which is independent of k. Hence, in equilibrium the manufacturer will invest $k^{CA} = k^*$ and the innovator will generate expected returns of $I^{CA} = I^A$. Whether or not they will agree on a price, depends on the court error β.

[42] The same holds true for $f < 1$ so that $P_{RAND} > P_1$.

[43] We focus on linear pricing in this exposition, however, as we argue in the proof of Proposition 1, the implications for nonlinear pricing are analogous.

Proposition 4. *Suppose price commitment is feasible. Antitrust liability distorts the innovator's development incentives, $I^C > I^{CA}$. Price commitment is therefore (Pareto-)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.

We have briefly commented on the role β and innovator's trebled antitrust damages in the context of Lemma 4. Notice that the implications from Proposition 4 hold even for $\beta = 0$ and simple damages. This is due to the close relationship of "A" and "CA" and the fact that the results of the antitrust case "A" are independent of β and trebled damages.

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: Antitrust prompts innovator's hold-up

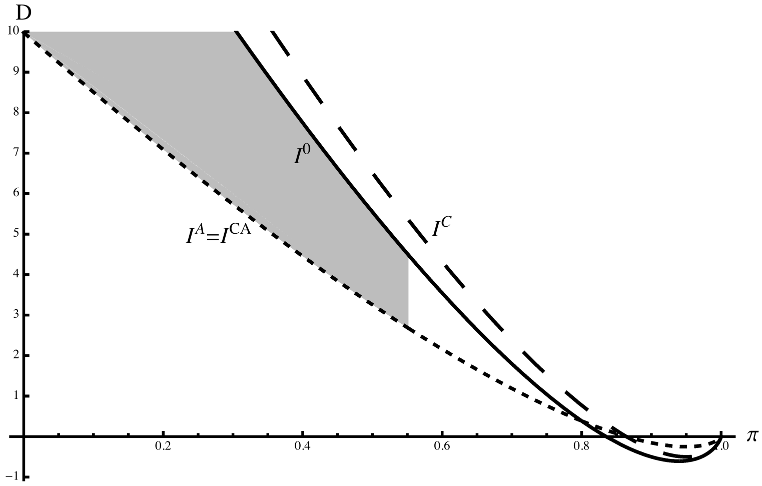


Figure 7 summarizes the innovator's development decisions for the four cases considered.[44] The solid line depicts innovators' expected revenues, I^0, in the case of no institutions. All values of D below this line induce innovation of the patented technology. The dashed line is the graph of the expected 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 bargain-

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

ing; 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.

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 (spot-contracting once development costs D have been sunk and k and j realized) are equal to

$$W\left(k^0\right) = M^0 + I^0 - v_0 = (1-\pi)\left[v_H\left(k^0\right) - v_0\right] - c\left(k^0\right) < W^* \tag{B1}$$

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 $v_H(k) > v_0$, $I^0 > 0$. 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 $a_L(P_1, k^*) = 0$ and $a_H(P_1, k^*) = 1$, yielding manufacturer's expected payoffs of

$$\pi v_0 + (1-\pi)\left[v_H(k^*) - P_{R1}\right] - c(k^*). \tag{B2}$$

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

$$\pi v_0 + \frac{1-\pi}{2}\left[v_H(k') + v_0\right] - c(k'). \tag{B3}$$

She will not deviate from $k^C = k^*$ if (B2) $\geq$ (B3),

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

and

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

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

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

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 $k^* > k'$,

$$P^{\mathcal{M}2} - P^{\mathcal{M}1} = -\left[\frac{v_H(k') - v_0}{2} + \frac{c(k^*) - c(k')}{1-\pi}\right] < 0 \tag{B4}$$

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

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 $\frac{D-P_0}{1-\pi} > P^{\mathcal{M}2}(k')$, 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

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

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 $\mathbf{p}_A = (p_{A0}, p_{A1})$ and $\mathbf{p}_I = (p_{I0}, p_{I1})$ so that $P_0 = \frac{p_{A0}+p_{I0}}{2}$ and $P_1 = \frac{p_{A1}+p_{I1}}{2}$. The manufacturer's offer will make the innovator just indifferent between the expected returns from $\mathbf{p}_A$ and contract-free licensing, so that

$$p_{A0} + (1-\pi) p_{A1} = I^0.$$

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 $p_{A0} \geq 0$ 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 Pareto-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. Let

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

The object of interest is the set of $(v_0, \pi) \in \Omega$ such that

$$\mathbb{E}W^A(v_0, \pi) := \frac{2W(k^A) - I^A}{2W^*} I^A = \frac{2W(k^0) - I^0}{2W^*} I^0 =: \mathbb{E}W^0(v_0, \pi),$$

where $W(k^A) > W(k^0)$; 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

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

Notice, $I^A < I^0$ since

$$\begin{aligned} P_1 &< v_H\left(k^0\right) - v_0 \\ \frac{1}{2}\left[v_H\left(k^*\right) - v_0 + \frac{c\left(k^0\right) - c\left(k^*\right)}{1-\pi}\right] &< v_H\left(k^0\right) - v_0 \\ v_H\left(k^*\right) - v_0 - \frac{c\left(k^*\right)}{1-\pi} - \left(v_H\left(k^0\right) - v_0 - \frac{c\left(k^0\right)}{1-\pi}\right) &< v_H\left(k^0\right) - v_0 \\ v_H\left(k^*\right) - v_H\left(k^0\right) - \left(v_H\left(k^0\right) - v_0\right) &< \frac{c\left(k^*\right)}{1-\pi} - \frac{c\left(k^0\right)}{1-\pi} \end{aligned} \tag{B5}$$

holds for all $(v_0, \pi) \in \Omega$ (in particular: Assumption A1) by $v_H\left(k^0\right) > v_0$ and $c\left(k^*\right) - c\left(k^0\right)$.

$W\left(k^i\right)$ 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
$$\bar{v}_0(\pi) \approx \phi\left[\ln\left((1-\pi)\phi\right) - 1.953\right]. \tag{B6}$$
and $\bar{v}_0(\pi) > 0$ if $\pi < 1 - \frac{7.050}{\phi}$. Assumption A1 is satisfied for strictly positive v_0 if $\pi < 1 - \frac{2\exp(1)}{\phi}$ 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 $\pi < 1 - \frac{7.050}{\phi} < 1 - \frac{2\exp(1)}{\phi}$. 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 4. 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 lower left 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
$$\bar{v}_0(\pi) = \frac{\left(9 - 2\sqrt{29}\right)(1-\pi)\phi^2}{80} \leq 0. \tag{B7}$$
$\mathbb{E}W^A(v_0, \pi) = \mathbb{E}W^0(v_0, \pi)$ 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. The argument for Pareto-superiority is analogous to Proposition 1. Q.E.D.

Proof of Lemma 3 The thresholds for "low", "intermediate", and "high" values of β are defined as follows: Let

1. $$\beta_1 = \frac{P^{\mathcal{M}1} - P^{\mathcal{I}}}{2P^{\mathcal{M}1} - P^{\mathcal{I}}} \frac{f}{f-1},$$

such that $\widetilde{P}^{\mathcal{I}} < \widetilde{P}^{\mathcal{M}1}$ for all $\beta < \beta_1$ and $\widetilde{P}^{\mathcal{I}} > \widetilde{P}^{\mathcal{M}1}$ for $\beta_1 < \beta < \bar{\beta}$; and

2. given $P^{\mathcal{I}} \leq P^{\mathcal{M}2}$, β_0 such that $P^{\mathcal{M}2} - P^{\mathcal{I}} = \widetilde{P}^{\mathcal{M}1} - \widetilde{P}^{\mathcal{I}}$ and $P^{\mathcal{M}2} - P^{\mathcal{I}} = \widetilde{P}^{\mathcal{M}1} - \widetilde{P}^{\mathcal{I}}$ for $\beta < \beta_0$, vice versa,

so that

1. $\beta_0 < \beta_1 < \bar{\beta}$ if $P_0 < D$, and
2. $\beta_0 < \beta_1 = \bar{\beta}$ if $P_0 = D$.

"Low" values are such that $\beta < \beta_0$, "intermediate" values are $\beta_0 < \beta < \beta_1$, and "high" values are $\beta_1 < \beta < \bar{\beta}$. The formal arguments are as follows: *(1)* $\beta_0 < \beta_1$: If $P^{\mathcal{I}} > P^{\mathcal{M}2}$, then β_0 is not defined. If $P^{\mathcal{I}} < P^{\mathcal{M}2}$, and by $P^{\mathcal{M}2} < P^{\mathcal{M}1}$, $\frac{P^{\mathcal{M}1}}{\gamma} > \frac{P^{\mathcal{I}}}{\delta}$ for low values of β and $\frac{P^{\mathcal{M}1}}{\gamma} < \frac{P^{\mathcal{I}}}{\delta}$ for sufficiently high values of β, since γ is strictly positive for $\beta \nearrow \bar{\beta}$ and $\widetilde{P}^{\mathcal{M}1}$ finite. Both δ and γ are continuous and strictly decreasing in β, $\widetilde{P}^{\mathcal{I}}$ and $\widetilde{P}^{\mathcal{M}1}$ are constant, hence by the intermediate value theorem, $\frac{P^{\mathcal{M}1}}{\gamma}$ and $\frac{P^{\mathcal{I}}}{\delta}$ intersect; moreover, there exists a β_0 such that $0 < \beta_0 < \beta_1$. See Figure 6 for an illustration. To show that $\beta_1 < \bar{\beta}$ if $P_0 < D$, simply rearrange to get

$$2\left[P^{\mathcal{M}1} - P^{\mathcal{I}}\right] < 2P^{\mathcal{M}1} - P^{\mathcal{I}}.$$

(2), $\beta_1 = \bar{\beta}$ if $P_0 = D$ is derived by simple rearranging and the fact that $P^{\mathcal{I}} = 0$.

The formal wording of the first claim is as follows:

Claim 1. *Let $P^{\mathcal{I}} \leq P^{\mathcal{M}2}$ and $\left|P^{\mathcal{I}}, P^{\mathcal{M}2}\right|$ the range of efficient license prices for $\beta = 0$:*

1. *equation (19) is satisfied and a license price such that $k^{CA} = k^*$ exists for all $\beta < \beta_1$;*
2. $\left|\frac{P^{\mathcal{I}}}{\delta}, \min\left\{\frac{P^{\mathcal{M}1}}{\gamma}, \frac{P^{\mathcal{M}2}}{\delta}\right\}\right| > \left|P^{\mathcal{I}}, P^{\mathcal{M}2}\right|$ *for $\beta < \beta_0$;*
3. $\left|\frac{P^{\mathcal{I}}}{\delta}, \min\left\{\frac{P^{\mathcal{M}1}}{\gamma}, \frac{P^{\mathcal{M}2}}{\delta}\right\}\right| < \left|P^{\mathcal{I}}, P^{\mathcal{M}2}\right|$ *for $\beta_0 < \beta < \beta_1$;*
4. $\left|\frac{P^{\mathcal{I}}}{\delta}, \min\left\{\frac{P^{\mathcal{M}1}}{\gamma}, \frac{P^{\mathcal{M}2}}{\delta}\right\}\right| \subseteq \emptyset$ *for $\beta_1 < \beta < \bar{\beta}$.*

Proof.

1. If $P^{\mathcal{I}} \leq P^{\mathcal{M}2}$ for $\beta = 0$, then $\widetilde{P}^{\mathcal{I}} \leq \widetilde{P}^{\mathcal{M}2}$ for all $\beta < \bar{\beta}$. By definition of β_1, $\widetilde{P}^{\mathcal{I}} \leq \widetilde{P}^{\mathcal{M}1}$ for all $\beta \leq \beta_1$.
2. By the definition of β_0: For all $\beta < \beta_0$, $\widetilde{P}^{\mathcal{I}} \leq \widetilde{P}^{\mathcal{M}2}$ and $P^{\mathcal{M}2} - P^{\mathcal{I}} > \widetilde{P}^{\mathcal{M}1} - \widetilde{P}^{\mathcal{I}}$.
3. By the definitions of β_0 and β_1.
4. By the definition of β_1 and the intermediate value theorem (see the argument above).

Q.E.D.

The second claim shows that antitrust cannot restore first-best implementation:

Claim 2. *If $P^{\mathcal{I}} > P^{\mathcal{M}2}$ for $\beta = 0$, no license price P_1 such that $k^{CA} = k^*$ exists for $\beta < \bar{\beta}$.*

Proof. If $P^{\mathcal{I}} > P^{\mathcal{M}2}$, then $\widetilde{P}^{\mathcal{I}} > \widetilde{P}^{\mathcal{M}2}$ since $\frac{P^{\mathcal{I}}}{\delta} > \frac{P^{\mathcal{M}2}}{\delta}$. Q.E.D.

Proof of Lemma 4

Proof. IF: If $P_0 = D$, and the price vector nonlinear, then $\widetilde{P}^{\mathcal{I}} = 0$ for all β. For $\beta < \beta_0$ it holds that $\min = \left\{\widetilde{P}^{\mathcal{M}1}, \widetilde{P}^{\mathcal{M}2}\right\} > 0$ and a license price P_1, satisfying the manufacturer's conditions of efficient investment, exists.

ONLY IF: If the innovator cannot recoup the full development costs through the contract entry fee P_0, say $P_0 = 0$, there are sufficiently high levels of D such that $\frac{D-P_0}{\delta(1-\pi)} = \widetilde{P}^{\mathcal{I}} > \min\left\{\widetilde{P}^{\mathcal{M}1}, \widetilde{P}^{\mathcal{M}2}\right\}$. The formal steps are analagous to the proof of the second claim in Lemma 2. Q.E.D.

Proof of Proposition 4

Proof. For the proof of this Lemma, we first show that in equilibrium $k^{CA} = k^*$, i.e. the effective price P_R is independent of k, and then argue that $M^{CA} = M^A$ and $I^{CA} = I^A$. The superiority of "C" over "CA" is straightforward from Proposition 3.

1. If parties do not agree on a price vector, they part and the manufacturer will invest anticipating the effective price P_R^A, i.e. it is as if they had not been able to commit to a price vector as analyzed in the antitrust case "A". This effective price is independent of k and the manufacturer's investment undiluted, $k^{CA} = k^*$ (See Propositions 2 and 3). It remains to show that $k^{CA} = k^*$ if an agreement is reached.

   (a) Let the innovator make an offer, p_I. In order for the manufacturer to accept, it has to satisfy

   $$\pi v_0 + (1-\pi)\, v_H(k) - (1-\pi)\, P_R^{CA}(p_I, k) - c(k) \geq M^A$$

   so that

   $$P_R^{CA}(p_I, k) \leq \underbrace{v_H(k) - \frac{c(k)}{1-\pi} - \left(v_H(k^*) - \frac{c(k^*)}{1-\pi}\right)}_{\leq 0} + \frac{P_1}{2}. \tag{B8}$$

   If p_I such that $v_H(k^*) - P_C(p_I) = v_H(k^*) - \gamma p_I < v_0$, then $P_R^{CA}(p_I, k) = \frac{v_H(k) - v_0}{2}$ and $k = k^0$. But in that case condition (B8) is satisfied only if $\frac{v_H(k^0) - v_0}{2} < \frac{P_1}{2}$, which does not hold by equation (B5). It implies that for too high an offer p_I the manufacturer will not accept. If p_I is sufficiently low, $P_R^{CA}(p_I, k) = P_{R1} = \delta p_I$, $k^{CA} = k^*$ and (B8) reads $p_I \leq \frac{P_1}{2\delta}$. The highest such p_I the innovator can offer is equal to $p_I = \frac{P_1}{2\delta}$. Moreover, if

   $$v_H(k^*) - \gamma \frac{P_1}{2\delta} \geq v_0, \tag{B9}$$

   holding for sufficiently low β, the innovator will offer such a p_I and the manufacturer will accept. For β such that (B9) does not hold, the manufacturer will reject unless the innovator offers a lower price, $p_I < \frac{P_1}{2\delta}$, so that $P_R^{CA}(p_I, k^*) = \frac{P_1}{2}$ with probability $(1-\pi)$. Since the latter can anticipate payoffs $I^A = (1-\pi)\frac{P_1}{2}$ if no agreement is reached, $p_I = \frac{P_1}{2\delta}$ is the lowest price offer the innovator is willing to make. An agreement is reached only for $\beta < \beta_I$ where β_I such that

   $$v_H(k^*) - \frac{\gamma(\beta_I)}{\delta(\beta_I)} \frac{P_1}{2} = v_0.$$

   Notice, since p_I such that $k = k^*$, the manufacturer will invest $k^{CA} = k^*$ for all β.

   (b) The lowest offer the innovator is willing to accept is such that $\delta p_A = \frac{P_1}{2}$, hence $p_A = \frac{P_1}{2\delta}$. Lower offers will induce him to reject and generate I^A. The highest offer the manufacturer is willing to make is $p_A = \frac{P_1}{2\delta}$, all higher offers will not satisfy (B8). Moreover, β is to be such that (B9) holds, otherwise $P_R^{CA}(p_A, k) = \frac{v_H(k) - v_0}{2} > \delta p_A$ which the manufacturer is not willing to make. Hence, for $\beta < \beta_I$, her price offer is $p_A = \frac{P_1}{2\delta}$. For $\beta > \beta_I$, no agreement is reached. In either case, the effective price is independent of k and the manufacturer will invest $k^{CA} = k^*$.

2. If $\beta < \beta_I$, the license price is $\frac{P_1}{2\delta}$ resulting in an effective price of $\frac{P_1}{2}$ and $I^{CA} = (1-\pi)\frac{P_1}{2} = I^A$. Since $k^{CA} = k^A = k^*$, $W(k^{CA}) = W(k^A)$ and $M^{CA} = M^A$. If $\beta > \beta_I$, no agreement is reached, and, since $k^{CA} = k^A = k^*$, the anticipated revenues are $I^{CA} = I^A$ and $M^{CA} = M^A$.

3. By Proposition 3, $I^C > I^{CA}$. Manufacturer's specific investment is efficient, but the innovator will be less likely to develop the technology if the antitrust option is available once ex-ante price commitment is possible.

Q.E.D.