An Equilibrium Analysis of Antitrust as a Solution to the

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-o er bargaining, meaning that with equal probability parties make price o ers 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 o er 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 speci c 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, 21) 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). He61,is(inno)28(v)5sf uyr7 uyr7decid318(th)5alinvuyr7velo7()365yr7 telterna-

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

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

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

We have not speci ed the valuation and cost functions, but will, for the sake of tractability, assume that adoption is ex-post e cient if and only if the value of the patented technology is high, $a_L(k) = 0$ and $a_H(k) = 1$.[18] The rst-best benchmark for this conditional adoption case is thus $h1; k ; (0; 1)i$. Let

$$W \quad W(k) = (1 \quad) [v_H(k) \quad v_0] \quad c(k)$$(8732 -4ba9ional)-3919ionalk

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 o er and o ers a price higher than the hypothetical contract price, p_I

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 e cientC A

net of investment costs, so that

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

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 $a_L(k^0) = 0$. 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 $v_0 < 2v_H(k^0) - \frac{c(k^0)}{1-\alpha} - \left[v_H(k^*) - \frac{c(k^*)}{1-\alpha} \right] < v_H(k^0)$

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

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

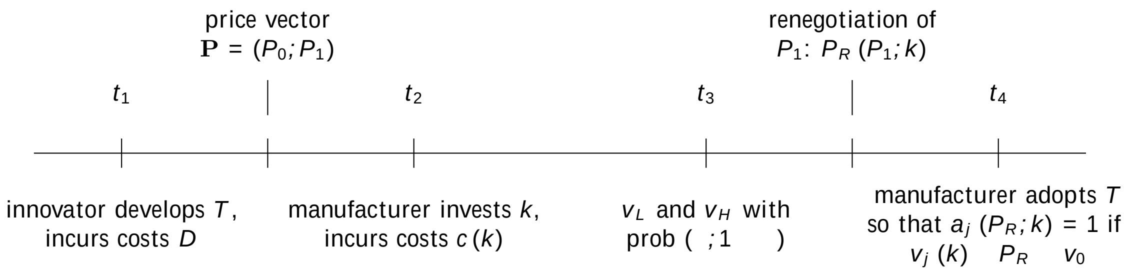
The innovator's expected profits from development are equal to $I^0 - D$. If these are nonnegative, he will develop. The parties' expected joint gains, net of the value of the alternative technology, v_0, sum up to $W(k^0) = M^0 + I^0 - v_0 < W^*$ by $k^0 < k^*$. Since $M^0 - v_0 \geq 0$, it51.369 41 Tf pup

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 su ciently 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 payo s at the renegotiation stage, between t_3 and t_4, are determined by their obligations as compelled by a court enforcing price vector **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 payo s are thus equal to P_1. The manufacturer's payo s depend on whether ex-post adoption of the patented technology yields payo s at least as high as the alternative, v_0. Her decision, given j, will thus depend on the e ective 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 $v_j(k) \quad P_1 \quad v_0$ 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 $P_{R3} = ;$ and $a_j = 0$ for all P_1. Ex-post renegotiation yields an e ective license price of

8
>

$P_R(P_1; k) =$

c44.368 7.525](19 0 Td [(y [(c44 -3.82O 82 10 such that v 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,

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

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

$$
P_1 \leq P^{M1} = v_H(k^*) - v_0. \qquad (7)
$$

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 $P_{R2} = \frac{1}{2}\left(v_H\left(k^0\right) - v_0\right) < P_1$.[26] If the resulting price savings $P_1 - P_{R2}$ more than offset the reduction of ex-post payoffs, amounting to $v_H(k^*) - v_H(k^0)$, investment level k^0 dominates efficient investment and $k^C = k^0$. Let P^{M2} be

P_1, and $k^0 > \tilde{k}$ so that $P^{M2}\left(k^0\right) < P^{M2}\left(\tilde{k}\right)$ where

$$P^{M2}\left(k^0\right) = v_H(k) \quad v_0 \quad \frac{c(k)}{1} \qquad \frac{v_H(k^0) \quad v_0}{2} \quad \frac{c(k^0)}{1} \; :$$

Given D, the rst-best can be implemented if and only if a price vector P *satis es*

$$\frac{D \quad P_0}{1} \quad P_1 \quad P^{M2}\left(k^0\right) :$$

Such a P *exists for all $D \quad W$ 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 rst-best implementation if both the innovator's participation constraint and the manufacturer's e cient-investment constraint $P_1 \quad P^{M2}$ are satis ed. Recall that, by $D \quad W$, development is ex-ante e cient for all 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) o er, they can commit to P_1 as backstop alternative, but cannot commit not to renegotiate it ex-post. The expected payo vector with e ective price $P_R(P_1; k)$ is equal to

$$M^C; I^C = (v_0 + (1 \quad) v_H(k) \quad (1 \quad) P_R(P_1; k) \quad c(k); (1 \quad) P_R(P_1; k)):$$

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 payo vector $M^0; I^0$ is given in equation (4). Notice, the expected outcome from ex-post negotiations is independent of who made the rejected ex-ante o er.

The equilibrium o ers are

$$p_I = v_H(k \ ) \quad v_0 \quad \frac{c(k \ )}{1} \quad " \frac{v_H \ k^0 \quad v_0}{2} \quad \frac{c \ k^0}{1} \# \qquad (10)$$

for the innovator and

$$p_M = \frac{v_H \ k^0 \quad v_0}{2} \qquad (11)$$

for the manufacturer.[31] Since $(1 \quad)(v_H(k \ ) \quad v_0) \quad c(k \ ) > (1 \quad) \ v_H \ k^0 \quad v_0 \quad c \ k^0$ it holds that $P^{M2} \quad p_I > p_M$. Hence, no matter who makes the o er, the manufacturer will e ciently 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,

$$P_1 = \frac{p_M + p_I}{2} = \frac{1}{2} \ " v_H(k \ ) \quad v_0 + \frac{c \ k^0 \quad c(k \ )}{1} \# < P^{M2} \qquad (12)$$

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

[31] The innovator's o er, 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 e ective price $P_R(p_I; k)$ rather than the precommitted p_I. Since $P_{R1} > P_{R2}$, the innovator will be inclined to o er p_I such that $P_R(p_I; k) = p_I$. The lowest such price > P

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

$$I^C = (1 \quad) P_1 \quad D:$$

Note, since $P_1 = \frac{I^C}{1} > \frac{I^0}{1} = p_M$, 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 payo s under the case of price commitment are

$$M^C = \quad v_0 + (1 \quad) [v_H (k \ ) \quad P_1] \quad c (k \ ):$$

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

Proposition 1. *If parties can ex-ante commit to a price vector* P *the manufacturer will e - ciently 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 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 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

by the manufacturer who will therefore o er $p_M = 0$ so that $p_M < P_1$. If, on the other hand, the innovator is to make a price o er, p_I, the manufacturer can accept, reject so that both parties realize their outside option payo s $(v_0; 0)$, or approach the court and sue the innovator for violation of RAND terms. This antitrust law suit is never successful if $p_I \quad P_1$. If the innovator's o er is $p_I > P_1$, the manufacturer's suit is successful with probability $\quad > 0$ and unsuccessful with probability $1 \quad$. In the former case, the court stipulates a license price of P_1 and compels antitrust damages $\quad (p_I \quad P_1)$ with $\quad 0$. 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 o er p_I remains valid and the manufacturer will decide whether to accept or reject. The extensive form of the subgame of the innovator's o er is depicted in Figure 4.

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

I

p_I

not have an e ect on either party's o er. In this case of *ine ective* litigation the result is as if antitrust litigation were not available at all and the equilibrium results from Lemma 1 apply.

We refer to *e ective* antitrust litigation if (1 +) > 1 which is induced by either high penalties, , or a high probability of the plainti 's success in court, . A value of = 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 = 1, the innovator pays single damages, while for = 3 damages are trebled. Also, the higher , the lower the lower bound of for antitrust litigation to be e ective.

For such e ective antitrust litigation, the e ective price is independent of k so that the manufacturer invests e ciently, $k^A = k$, and her expected payo s, conditional on innovator's development, are

$$M^A = v_0 + (1 \quad)$$

probability of success of development. We say the patented technology is of high potential if both v_0 and   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 $\mathbb{E}W^i(v_0;\ )$, assuming that D is uniformly distributed between 0 and W,

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

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

Proposition 2. *Suppose price commitment is not feasible and let* $(1 + \ )\ > 1$. *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 $(1 + \ )\ > 1$ 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 e ects of e ective 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 $(v_0; \ )$ coordinates to the northeast of the dashed line ($v_0^{A1}(\ )$) do not satisfy Assumption A1. The solid line ($v_0(\ )$) graphs the set of all $(v_0; \ )$ such that the positive e ect on manufacturer's investment is just o set by the negative e ect on innovator's development incentives. The shaded area depicts all parameterizations for which the former more than o sets the latter and antitrust litigation such that $(1 + \ ) \ > 1$ is welfare enhancing. Finally, for high potential development to the southwest of $v_0(\ )$ the latter e ect dominates and $(1 + \ ) \ 1$ is optimal.[36]

Table 2: Antitrust litigation relative to no price commitment

	ine ective litigation $(1 + \ ) \ 1$	e ective litigation $(1 + \ ) \ > 1$
low potential high $(v_0; \ )$	k, I, and W una ected	k ", I #, W "
high potential low $(v_0; \ )$	k, I, and W una ected	k ", I #, W #

Table 2 provides an overview of the results. If $(1 + \ ) \ 1$ and antitrust litigation is ineffective, the double-sided ho m 0 27.098 l S Q BT /F8 10.900 d 3 BT /]TJt 10.9091 Tf fective, positive welfare implications if $> \frac{1}{4}$

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

of M^A) to invest is defined by

$$v_0 + (1 \quad)[v_H(k) \quad p_I] \quad c(k) \quad M^A = \quad v_0 + (1 \quad) \; v_H(k \;) \quad \frac{P_1}{2} \quad c(k \;):$$

Note, for $p_I \quad \frac{P_1}{2}$, 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 $\frac{P_1}{2} < p_I \quad P_1$, 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

$$p_I = \frac{P_1}{2};$$

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

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

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 litigation (with positive) once an enforceable contract 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.

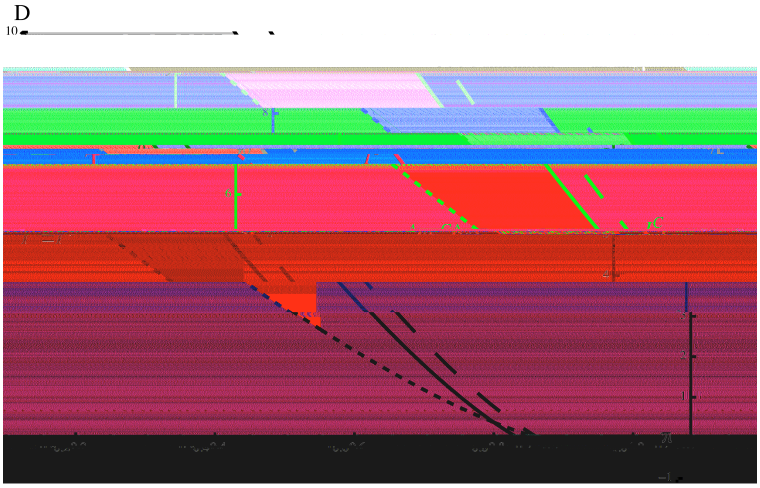
5 Conclusion

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 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 e cient way. It is not clear to us that antitrust liability could improve on bilateral bargaining; and it may well displace more e cient solutions to the problem of hold-up. Moreover, it may also retard the e cient 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

$$W\ \ k^0\ \ = M^0 + I^0\ \ \ v_0 = (1\ \ \ )\ v_H\ \ k^0\ \ \ \ v_0\ \ \ \ c\ \ k^0\ \ < W^* \tag{A.1}$$

and strictly positive since, by Assumption A1,

$$M^0\ \ \ v_0 = (1\ \ \ )\frac{v_H\ \ k^0\ \ \ \ v_0}{2}\ \ \ c\ \ k^0\ \ \ \ 0$$

and, for $v_H\ \ k^0\ \ > v_0$, $I^0 > 0$. Moreover, since $W\ \ k^0\ \ < W^*$ and $M^0\ \ \ v_0\ \ \ 0$, $I^0 < W^*$ so that the innovator will *not* develop for all $D\ \ \ W^*$. 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 $P_1\ \ \ P^{\mathcal{M}1}$, then $a_L\ (P_1; k^*) = 0$ and $a_H\ (P_1; k^*) = 1$, yielding manufacturer's expected payoffs of

$$v_0 + (1\ \ \ )\,[v_H\ (k^*)\ \ \ P_{R1}]\ \ \ c\,(k^*): \tag{A.2}$$

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

$$v_0 + \frac{1}{2}\,[v_H\ (k') + v_0]\ \ \ c\,(k'): \tag{A.3}$$

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

$$v_0 + (1\ \ \ )\,[v_H\ (k^*)\ \ \ P_{R1}]\ \ \ c\,(k^*)\ \ \ \ v_0 + \frac{1}{2}\,[v_H\ (k') + v_0]\ \ \ c\,(k');$$

and

$$P_1 = P_{R1}\ \ \ P^{\mathcal{M}2} = v_H\ (k^*)\ \ \ v_0\ \ \ \frac{c\,(k^*)}{1}\ \ \ \ \frac{v_H\ (k')\ \ \ v_0}{2}$$

Claim 2. *First-best implementation is possible if and only if* P *is nonlinear and* P_0 *unrestricted.*

First, since $P^{\mathcal{M}2} > 0$, $P_1 = 0$ will always induce e cient 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

$$(1 \quad)[v_H(k^*) \quad v_0] \quad c(k^*) \quad P_0.$$

By $D \quad W^*$, there is always a P_0 such that the condition holds and $\frac{D-P_0}{1-} \quad P_1 = 0$. If P is linear (or P_0 bounded above), then the rst-best is not implementable for all $D \quad W^*$. In particular, if $P_0 < D \quad (1 \quad)P^{\mathcal{M}2}$, then P_1 is such that either the innovator will not develop (if $P_1 \quad P^{\mathcal{M}2}$ so that $\frac{D-P_0}{1-} > P_1$) or the manufacturer will underinvest (if $P_1 > P^{\mathcal{M}2}$ so that $\frac{D-P_0}{1-} \quad P_1$). 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 o ers, 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 o er will make the innovator just indi erent between the expected returns from $\mathbf{p}_A$ and contract-free licensing, so that

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

Likewise, the innovator will o er $\mathbf{p}_I$ to make the manufacturer indi erent between her contract payo s and M^0 under contract-free licensing,

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

Linear pricing is just a special case of nonlinear pricing with $P_0 \quad 0$. If $p_{M0} \quad 0$ and $p_{I0} \quad 0$, then the license price o ers (as well as the expected license price) under nonlinear pricing will not be higher than under linear pricing, satisfying $P_1 \quad P^{\mathcal{M}2}$, and independent of k. By the bargaining technology (i.e., random o ers) it holds that $M^0 > P_0 + (1 \quad)P_1 = I^C > I^0$, establishing the proof of the rst 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 o (a result driven by outside options I^0 and M^0 and the fact that neither party will accept an o er that makes her worse o 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

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or $(p_I \quad P_1) \quad 0$. Hence, if the innovator makes an o er greater than the hypothetical contract price, his expected payo s from that o er are

$$[P_1 \quad (p_I \quad P_1)] + (1 \quad) p_I = p_I \quad (\quad + 1) \quad (p_I \quad P_1):$$

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

$$p_I \quad (\quad + 1) \quad (p_I \quad P_1) \quad P_1$$

or

$$1 \quad (1 + \quad) \; :$$

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

$$\frac{v_H \; k^A \quad v_0 \quad P_1}{1} \quad p_I:$$

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

We now proceed to the proof of the Proposition. Let

$$f(v_0; \;) : v_0 \quad 0; \quad 2\, [0;1] ; \text{ Assumption A1 is satis ed} g:$$

The object of interest is the set of $(v_0; \;)\; 2$ such that $\mathbb{E}W^A(v_0; \;) = \mathbb{E}W^0(v_0; \;)$ where

$$\mathbb{E}W^i(v_0; \;) \quad \int_0^{I^i} \frac{W \; k^i \quad D + v_0}{W^*} dD + \int_{I^i}^{W} \frac{v_0}{W^*} dD = \frac{2W \; k^i \quad I^i}{2W^*} I^i:$$

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

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

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

$$W \; k^0 = (1 \quad) \; v_H \; k^0(\;) \quad v_0 \quad c \; k^0(\;) \; :$$

Moreover,

$$I^0 = \frac{1}{2} \; v_H \; k^0(\;) \quad v_0$$

and

$$I^A = \frac{1}{2} P_1 < I^0:$$

$W \; k^i$ and I^i, $i \; 2 \; fA; 0g$ are continuous in $(v_0; \;)\; 2$, so that there exists a function $v_0 : [0;1] \; ! \; \mathbb{R}$ such that $\mathbb{E}W^A(v_0; \;) = \mathbb{E}W \; !$

Then

$$v_0(\ ) \quad [\ln((1 \quad) \ ) \quad 1{:}953]: \qquad \text{(A.5)}$$

and $v_0(\ ) > 0$ if $< 1 \quad \frac{7:050}{}$. Assumption A1 is satis ed for strictly positive v_0 if $< 1 \quad p\frac{4}{\exp(1)}$ so that $0 < v_0^{\mathbf{A1}}$. A positive $v_0 < v_0(\ )$ exists so that $\mathbb{E}W^A(v_0;\ ) < \mathbb{E}W^0(v_0;\ )$ for all $< 1 \quad \frac{7:050}{} < 1 \quad \frac{2:436}{}$. If, on the other hand, for a given , opportunity costs v_0 are su ciently large and satisfying Assumption A1, then granting the manufacturer an antitrust option has positive e ciency e ects, $\mathbb{E}W^A(v_0;\ ) > \mathbb{E}W^0(v_0;\ )$. This case of logarithmic valuation, for $= 20$, and linear costs is depicted in Figure 5. The dashed line is the graph for $v_0^{\mathbf{A1}}(\ )$, the solid line for $v_0(\ )$. The shaded area in between depicts all $(v_0;\ ) \; 2$ for which the expected social surplus in the antitrust case `$A$' is higher than in the institution-free case `0', $\mathbb{E}W$ *forall* <

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