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Hold-Up and Patent Licensing of Cumulative Innovations with Private Information

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Abstract: When innovation is cumulative, early patentees hold claims against later innovators. Then potential hold-up may cause prospective second stage innovators to forego investing in R&D. It is sometimes argued that *ex ante* licensing (before R&D) avoids hold-up. This paper explores *ex ante* licensing when information about development cost is private. In this case, contracts may not be written *ex ante*. Moreover, the socially optimal division of profit occurs with weak patents and *ex post* licensing. Empirical evidence on licensing conforms to a model with private information. In some innovative industries, little *ex ante* licensing occurs, suggesting hold-up remains a problem.

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I. Introduction

The strengthening and extension of intellectual property rights over the last two decades have raised concerns about "hold-up" for cumulative innovation.[1] When innovation is cumulative—that is, when new products benefit from previous innovations, possibly infringing previous patents—an early patent holder has a potential claim against subsequent innovators. Anticipating the expected cost of such claims, a second innovator may choose to perform a sub-optimal level of R&D or, perhaps, not to invest in the innovation at all. The concern is that stronger patent rights may increase the occurrence of hold-up, reducing R&D incentives, thus slowing the pace of innovation.

However, firms may find private means to avoid this hold-up. Specifically, firms may license *ex ante*. Green and Scotchmer [1995] present a model with symmetric information where the initial patent holder can offer a license before the second firm sinks funds into R&D. When R&D investment is socially desirable, but when the second firm cannot recoup its R&D investment under an *ex post* license, the first firm offers an *ex ante* license that permits the second firm to make a net profit. This license avoids hold-up and the associated efficiency losses.

Based on the efficacy of such *ex ante* licenses, a strand of the patent literature argues in favor of broad (but short) patents that provide the strongest incentives to the initial innovator, confident that subsequent innovators will not be held up. This literature includes Kitch's "prospect theory."[2] Scotchmer [1996] considers that it may even be desirable to prohibit patents for second innovators. Moreover, in response to arguments that transaction costs may prevent licensing, Merges [1999] and Shapiro [2001] point out that institutions such as cross-licenses, patent pools and joint ventures reduce some transaction costs.

But the efficacy of *ex ante* licenses for cumulative innovation depends on an assumption that the values and costs of prospective innovative opportunities are common knowledge. This is a very strong assumption and with apparently little supporting evidence. Indeed, the mechanism design literature on patents makes *asymmetric* information the standard assumption.[3] As Brian Wright points out [1983], if the values and costs of technological opportunities were common

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[1] See Merges and Nelson [1990], Heller and Eisenberg [1998], Mazzoleni and Nelson [1998], Rai [1999, 2001], Bessen and Maskin [2000], Hall and Ziedonis [2001], and Shapiro [2001].

[2] Gallini and Scotchmer [2001] review this literature, and, although they recognize the assumption of effective licensing, they conclude "with some caution, we can extract from the literature a case for broad (and short) patents."

[3] See Gallini and Scotchmer [2001] for a review of this literature.

knowledge, then patents would be entirely unnecessary—prizes or research contracts would be preferred means of encouraging innovation.

Private information about development costs seems likely because of the apparently great heterogeneity in ability, expertise and effort among innovating organizations. Because of this heterogeneity, firms with small R&D budgets not infrequently challenge much larger R&D organizations. Yet this ability, expertise and effort are hard to observe and monitor.

Moreover, the concept of sequential innovation seems implicitly to assume the existence of private information. Indeed, hold-up only arises when the second innovator is a *different firm* from the first innovator. But why doesn't the first innovator develop the second innovation? With its patent, the first firm has greater incentive to develop a second non-competing innovation because it has no need to pay royalties; it may also have information about the first innovation long before other firms. So if the first innovator, holding a patent, had all the information necessary to produce a non-competing second innovation, it would do so, no other potential developer would enter, and sequential innovation would not occur. Usually it is argued that sequential innovation occurs because the second firm possesses specialized information, such as expertise in a particular technology (see, for instance, Scotchmer [1991, p. 31]).[4] But how, then, can the first firm know the *cost* of developing and applying that expertise? This seems unlikely. Moreover, the second innovator has strong reason *not* to reveal this and related information. As in Gallini and Wright [1990], such information may allow the first firm to develop the technology *itself*, so the prospective licensee has strong incentives to keep that information private. Thus sequential innovation seems implicitly to involve private information about costs and is thus inconsistent with a symmetric information model.[5]

This paper extends the model of Green and Scotchmer to include private information about the cost of R&D. It also considers cross-licensing and variation in patent strength. I develop this model first with symmetric information and then with private information about R&D costs. Finally, I present evidence about licensing in the semiconductor industry, which is considered to have a high degree of cumulative innovation.

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4 Even complementary physical assets seem unlikely to explain sequential innovation. If another firm had complementary physical assets helpful to the development effort, it would make sense for the first firm to rent those assets and still perform the development itself. It is certainly easier to contract over the rental of physical assets than the value of the first firm's patent and the quality of the second firm's development abilities. This argument is similar to the model of Aghion and Tirole [1994] where non-integrated development requires development costs (effort) that cannot be monitored.

5 Similar asymmetries affect a variety of licensing negotiations. In the author's experience negotiating software product licenses, some negotiations were difficult because one party lacked sufficient information to see the value of licensing. In others, one party attempted to use negotiations to obtain information to enable them to develop a competing product.

Information asymmetry poses a problem for *ex ante* contracting. The first firm needs to lower its royalty to permit the second firm to enter profitably. But not knowing how much the second firm's R&D will actually cost, the first firm will be reluctant to lower royalties too much. The model under asymmetric information generates the following results:

1. With "strong" patents (defined below), all licenses are written *ex ante*; but with "weak" patents, all licenses are *ex post*.
2. In both patent regimes, efficiency losses occur as firms choose not to develop socially desirable products. Moreover, this is true even with cross-licensing.
3. Socially optimal (second best) patent strength is "weak," with all licenses written *ex post*.

Thus under asymmetric information, *ex ante* licensing does not eliminate efficiency losses, and, in fact, the use of *ex ante* patent licenses implies above-optimal patent strength and unnecessary efficiency losses.

Moreover, several pieces of empirical evidence suggest that in industries known for cumulative innovation, licensing behavior conforms to the model of asymmetric information:

1. *Ex ante* licensing occurs quite infrequently (about 5% of licenses) in the computer and electronics industries. Only in chemicals and pharmaceuticals does it occur more often, and these are industries considered to have stronger patents, consistent with theory.
2. The strengthening of patents in the mid-1980's increased semiconductor royalties, but did not increase industry R&D intensity as implied by the symmetric model.
3. The strengthening of patents prompted a shift in emphasis of licensing away from pure cross-licensing and toward royalty extraction in the semiconductor industry.

There is a large literature on patent licensing, however, most of this literature assumes symmetric information. Gallini and Wright [1990] study licensing where the licensor has private information about the value of an already-developed the innovation. The model here concerns private information held by the licensee and the effect of this information on the prospects for *ex ante* licensing. Licensing cumulative innovation under symmetric information is modeled in Green and Scotchmer [1995], Scotchmer [1996], Maurer and Scotchmer [2002] and Schankerman and Scotchmer [2001].

The next section presents the basic model with symmetric information. Section III introduces asymmetric information, Section IV reviews some empirical evidence and Section V concludes.

II. A Model with Symmetric Information

A. *Ex post* licensing and patent strength

Following Green and Scotchmer, the setting here explores the division of profit between two firms, A and B. The effect of competitors is ignored. Under symmetric information, the analysis here differs from Green and Scotchmer principally in two ways: patent strength is a variable policy instrument and firm A may receive reciprocal benefits from B's development. This allows consideration of cross-licensing.

Consider firms A and B where firm A has a patent and firm B has developed a technology that infringes this patent.[6] Although firm B has a different product, it uses a technique that is the same or is similar to the technique described in A's patent. This describes the common situation where innovation is cumulative and patents have breadth or scope. Note that cumulative innovation does *not* necessarily imply that firm A's innovation is a technical *prerequisite* to B's innovation. This situation requires a stronger condition of technical dependency, which is discussed below.

For simplicity, assume that the two firms do not compete with each other; this assumption does not fundamentally change the results.

Let v_B designate the profits that can be made on B's product. Firm B's development cost is c_B, $c_B > 0$. In this section, I assume that this cost is common knowledge; in the next section, this cost is private information and only its distribution is common knowledge.

Let firm A receive reciprocal benefits from firm B's development. For example, in the process of developing its product, B may make an improvement to the process covered in A's patent that is valuable to A. Assume that B patents this improvement. Under patent law, even though B infringes A's patent, A cannot use the improvement without a (cross) license from B. Let the value of these reciprocal benefits to A be w. Assume that the firms extract the full social value of innovations so that the social value of B's innovation is $v_B + w$.

Given c_B, it is then socially desirable to develop all innovations for which

(1) $$v_B + w > c_B .$$

Now consider first the case of *ex post* licensing A's patent. Firm B develops its product and then firm A asserts its patent against B. The firms begin licensing discussions. If negotiations

[6] Green and Scotchmer also consider the case where firm B does not infringe, but the firms license essentially for anti-competitive reasons.

break down, firm A might take B to court, possibly obtaining a preliminary injunction. Alternatively, firm B might undertake additional development efforts to "invent around" the patent. These non-cooperative possibilities constitute the "threat points" to a bargaining problem. I assume that there are advantages to settling, and that the result of the bargaining is determined by patent strength, *s*. That is, *s* is defined as the share of the patent's value received by the patent holder. Green and Scotchmer assume *s* = ½, but here it varies, $0 < s \leq 1$.

Patent strength is determined partly by policy and partly by technical factors that vary from industry to industry. Chemicals and pharmaceuticals are often considered to have high invent-around costs; semiconductors, machinery and electronics are considered to have low invent-around costs. Policy factors that affect strength include the degree to which the courts presume patents are valid, the use of preliminary injunctions and the interpretation of the "doctrine of equivalents," which influences the cost of inventing around. It is straightforward to present a model where *s* is the Nash solution to a bargaining problem involving invent-around costs and probability of litigation success. I omit these details to simplify the exposition.

For A's patent, a license that settles A's (potential) lawsuit against B will grant A profits $s\, v_B$ and B profits of $(1-s)v_B$. B can also file a lawsuit against A, that will settle with B getting *sw* and A getting $(1-s)w$.

From this definition, given patent strength *s*, an *ex post* license will grant firms A and B profits on the second stage innovation (ignoring A's first stage profits and costs) of

(2) $$\left\{s\, v_B \;+\; (1-s)\, w,\;\; (1-s)v_B \;+\; s\;\, w - c_B\right\}$$

respectively. If B were to accept a license from A with royalty *r*, the firms would get respectively

(3) $$\left\{r + w,\;\; v_B - c_B - r\right\}$$

Comparing (3) and (2), the *ex post* royalty must be

(4) $$r_1 \;=\; s\left(v_B - w\right).$$

Since this license is negotiated after cost c_B is sunk, it may offer firm B negative profits. In general, firm B will anticipate the possibility of negative profits, and choose not to sink investment c_B initially if this is the case. This implies an "individual rationality" constraint:

(5) $$r \leq \; v_B - c_B \quad .$$

Specifically, if an *ex post* license fee is $r_1 > v_B - c_B$, then, in the absence of an *ex ante* license, B will choose not to develop its product. This constitutes "hold up" or "licensing failure."

B. Licensing failure avoided with *ex ante* contracts

However, in this case, firm A can offer an *ex ante* license with a lower royalty. I assume that an *ex ante* contract is legally binding and cannot be renegotiated.

A negotiation over a prospective *ex ante* contract differs from the *ex post* negotiation above in several ways. The "threat point" is no longer litigation or "inventing around." Assuming that A only offers an *ex ante* contract when B's individual rationality constraint is not met, if negotiations fail, B simply does not develop its product. Considerations involving patent strength do not affect the negotiation.

Also, firms may face considerable time pressure to conclude the negotiations quickly. For example, B's innovation may be subject to first-mover advantages that might be snatched by another firm using a different technology. Such time pressure does not affect *ex post* negotiations because in that case the negotiations take place after any first-mover advantages have already been captured. If time pressures are great enough, the Rubinstein-Ståhl [1982] model suggests that the first firm makes a single offer and captures all of the surplus.

I assume that *ex ante* negotiations do, in fact, take the form of firm A making a take-it-or-leave-it offer and firm B either accepting or rejecting that offer. In this situation, firm A captures all of the bargaining surplus. This assumption simplifies the exposition and it also biases the results in favor of *ex ante* licensing. If firm A fails to offer an *ex ante* license under this assumption, firm A will certainly not offer an *ex ante* license when it is less profitable to do so. Below I briefly consider the effect of relaxing this assumption. I also examine other aspects of *ex ante* negotiations including transaction costs and moral hazard.

With a single offer, firm A extracts all of the bargaining surplus. Specifically, firm A offers an *ex ante* license with royalty

(6) $$r_0 = v_B - c_B - \varepsilon$$

where ε is an arbitrarily small positive number. Then under the *ex ante* license firm A will earn $v_B + w - c_B - \varepsilon$ and firm B will earn just ε which is positive. If condition (1) holds, so that the innovation is socially desirable, then this contract is profitable to both parties, so the contract will be made. This implies

> Proposition 1. Efficiency under symmetric information. Under symmetric information, the firms A and B will find a licensing contract that permits firm B to invest in all socially beneficial innovations.

There are two solution regions as shown in Figure 1. The horizontal axis represents c_B and the vertical axis represents *r*. The downward sloping line is $c_B + r = v_B$. Given (5), the optimal license must fall on or below this diagonal line (individual rationality). The horizontal line, $r = r_1$, is also shown. Since firm B can always get this royalty by refusing an *ex ante* license, the optimal license must also fall on or below this line (incentive compatibility). If firm B has high costs, in the range $v_B - r_1 < c_B < v_B + w$, the individual rationality constraint binds, *ex ante* contracts will be written and $r_0 < r_1$. If firm B has low costs, in the range $0 < c_B \leq v_B - r_1$, the incentive compatibility constraint binds and the *ex post* license (or an equivalent *ex ante* license) provides maximum royalties to A. In this range, an *ex ante* contract could also be written, paying the same royalty, r_1, but since firms face some positive transaction costs and since development is uncertain, I assume that all contracts in this lower cost range are actually formed *ex post*. Combined, the optimal license grants a royalty

(7) $$r^* = \min(r_0,\ r_1) = \min\left(v_B - c_B - \varepsilon,\ s(v_B - w)\right).$$

Note also that if $w > 0$, some royalties may actually be negative. For *ex post* contracts, royalties (from B to A) are negative when $w > v_B$. Clearly, in this case the contracts take on the character of a cross-license with "balancing royalties." The firm with the less valuable patent pays a net royalty to the other firm. With *ex ante* contracts, royalties are negative when $w > v_B - c_B$. In this case, the contract takes on the character of a "work-for-hire" development contract where firm A pays firm B to develop an innovation that is mainly valuable to A but has some compensating value to B. In both such cases, the second innovation is primarily valuable to A, not B. Such cases cannot really be described as "hold-up" and realistically involve some additional considerations as in Aghion and Tirole [1994]. The exposition below assumes that $v_B > w$ to focus on licensing that is not work-for-hire.

C. Optimal patent strength under symmetric information

As Green and Scotchmer point out, since *ex ante* contracting permits *all* socially desirable second stage projects to be developed, social policy should be directed to ensuring that socially desirable first stage innovations are developed. In this model, the social planner's policy instrument is patent strength, *s*, so this section explores what patent strength maximizes the occurrence of socially desirable first stage innovations.

Now, a privately developed first stage innovation may *not* be socially desirable for two reasons. First, if a patent race occurs, there may be wasteful duplication of R&D. I assume that only one firm develops the first stage innovation, thus excluding this possibility. Second, patent holdup allows parasitic behavior on the part of firm A—firm A may develop an innovation that is not socially desirable, but that is nevertheless profitable because it allows A to capture rents from firm B. As I show below, this possibility arises when firm B's innovation is technically independent of firm A's innovation.

This property of technical (in)dependence affects the calculation of social welfare. The literature on sequential innovation sometimes assumes that the first stage invention is *technically necessary* for second stage innovations to be discovered, that is, discoveries can occur only in a fixed sequence. Sometimes the first stage patent is described as a major "breakthrough" innovation and that subsequent improvements are minor, incremental innovation.

This is sometimes the case, but holdup also occurs when the second stage innovation is independent of the first—firm A can become the first stage innovator purely by a happenstance of timing. And indeed, nothing prevents a trivial first stage patent from holding up important second stage innovations; industry anecdotes provide ample evidence of such cases. For example, many people in the semiconductor industry argue that Texas Instruments' patent on encapsulating transistors in plastic has been used to extract rents on much more important subsequent innovations and that the encapsulation technique would likely have been developed after these other innovations, had it not been developed first.

Hence one cannot conclude that because two innovations occur in a sequence they *had* to occur in that particular sequence. It is very difficult to discern after the fact whether a second innovation is technically dependent on a prior innovation. Yet patent holdup can occur in both situations.

The significance of technical dependence for the calculation of social welfare can be seen formally. Let firm A's product have market value v_A, above whatever royalties and non-royalty benefits can be extracted from B. Let A's development cost be c_A. Given the above contracting solution, firm A's total benefit from B's development is

(8) $$x \equiv r^* + w \quad .$$

Now if the two innovations are technically independent, the first stage innovation is socially desirable whenever $v_A > c_A$. But firm A's profits are $v_A + x - c_A$, which may be positive even when $v_A < c_A$. This case represents "parasitic" holdup.

On the other hand, if innovation B technically requires innovation A, it is socially desirable to develop *both* innovations whenever

(9) $$v_A + v_B + w > c_A + c_B .$$

But from above, $r^* \leq v_B - c_B$ (individual rationality), so that the condition of positive profits for A, $v_A + x > c_A$, implies that (9) will hold. In other words, firm A is profitable only for socially desirable innovations; parasitic holdup does not occur with technical dependency. And clearly then, the strongest innovation incentives for A occur at the largest possible value of *x*, that is, the largest development costs, c_A, can be profitably incurred with the largest possible *x*.

Now patent strength affects *x* as can be seen from (7). Assuming $v_B > w$, for the domain where *ex post* licensing occurs, an increase in *s* increases *r** and *x*, and hence also increases the profits of firm A. The greatest profits can be achieved with the strongest possible patents, namely when *s* equals 1. Or,

> Proposition 2. Optimal patent strength under symmetric information. Assuming $v_B > w$ and assuming *ex ante* contracting occurs with a take-it-or-leave-it offer under full information, then profits for firm A will be greatest (over all feasible values of c_B) when *s* = 1. Furthermore, if all second stage innovations are technically dependent on previous innovations, this will be socially optimal.

This logic thus supports the analyses calling for the broadest patents, including Kitch's "prospect theory" of patents. This argument seems to rest on some rather strong assumptions, however. First, as long as some second stage innovations can be held up by *independent* first stage patents, then strong patents may give rise to socially sub-optimal parasitic R&D. Second, if *ex ante* contracts are negotiated with equal bargaining power instead of a take-it-or-leave-it offer, then it can be shown that maximum profits for firm A do not necessarily occur when *s* equals 1. And finally, this argument assumes full information. Below I show that even when sequential innovations are technically dependent and when firm A has all the bargaining power in *ex ante* negotiations, weak patents are socially optimal when cost information is private.[7]

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[7] Green and Scotchmer [1995] obtain the result that finite patent breadth is optimal when the value of the second innovation is uncertain and *ex ante* negotiations split the surplus.

III. A Model with Private Information on R&D Ability

A. Contracts with private information

Now assume that firm A does not know B's cost, c_B. Moreover, assume that A cannot accurately infer c_B after the fact.[8] Furthermore, for the moment I maintain the assumption that *ex ante* offers are take-it-or-leave-it offers. This prevents A from offering different licenses over time, allowing B to signal its cost.

Firm A only knows that c_B is drawn from a sample distributed according to a distribution function $F(\cdot)$. Assume that this cumulative distribution function is conditional on (1). That is, it excludes firms or projects that are not socially beneficial and cannot make profits. Also, assume that F is twice continuously differentiable, F is log-concave, $F(0) = 0$ and $F(v_B + w) = 1$.

In this environment, the firms will strike the same *ex post* licensing agreement as above, with royalty r_1, because this negotiation does not consider the sunk costs. But firm A may want to offer an *ex ante* contract.

As above, any *ex ante* contract is subject to an incentive compatibility constraint: no *ex ante* contract will be accepted that demands a higher royalty than r_1 because firm B can always get that royalty by waiting. It is helpful to temporarily ignore this constraint and consider what *ex ante* license A would like to offer. Once this is determined, the incentive compatibility constraint can be applied to determine whether it is binding or not.

In contrast to the symmetric information case, here A cannot offer an *ex ante* contract specifically tailored to firm B's cost. Firm A has no means of determining B's cost and hence no means of *discriminating* between a high cost B and a low cost B. Instead, firm A has to design an *ex ante* contract based on expected values of royalties and benefits. Assume that A is risk neutral so it wants to maximize its expected benefits. Now, if A charges royalty r, the expected benefit A receives is

(10) $$x(r) = (r + w)\, F(v_B - r)$$

since B will only accept this contract if $c_B < v_B - r$.

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[8] For example, costs cannot be inferred by observing the firm's *ex post* reported R&D spending. If costs could be inferred, an *ex ante* contract could be written specifying the royalty payment as a function of reported R&D spending. But unless firm A can monitor all the actual costs and effort, moral hazard arises: B can inflate the reported R&D. This is especially true because the total cost of innovating typically include large costs of adopting and implementing new technology that are not included in the R&D budget.

Firm A faces a tradeoff: as r increases, the possible royalty payment increases, but the probability of acceptance declines. It is straightforward to show that since F is log-concave, a unique interior solution exists

(11) $$r_0 = \arg\max_r x(r), \qquad -w < r_0 < v_B .$$

But will B accept this *ex ante* contract? That depends on the alternative royalty obtained from *ex post* bargaining (the incentive compatibility constraint). If $r_1 > r_0$, then B will prefer the lower royalty *ex ante* contract, accepting it as long as $c_B < v_B - r_0$. This situation is depicted in Figure 2.

On the other hand, if $r_1 \leq r_0$, then B will reject the *ex ante* contract. Instead, as long as $c_B < v_B - r_1$, B will develop its product and then negotiate an *ex post* license as in Figure 3. There are thus two solution regions depending on parameters. Note that the condition $r_1 \leq r_0$ is equivalent to $s \leq \tilde{s} \equiv r_0/(v_B - w)$. Limiting discussion to cases where $v_B > w$, the two regions may be described as: 1.) a region of relatively weaker patents where all contracts are *ex post*, $s \leq \tilde{s}$, and, 2.) a region of relatively stronger patents where all contracts are *ex ante*, $s > \tilde{s}$. Combining these two regions, the royalty offered is

(12) $$r^*(s) \equiv \min\left(r_1(s), r_0\right) = \min\left(s\,(v_B - w), r_0\right).$$

Furthermore, both regions have licensing failure. In the "weak patents" region, only $F(v_B - r_1) < 1$ percent of the firms will choose to enter. In the "strong patents" region, the portion of firms innovating is then $F\left(v_B - r_0\right) < 1$. Thus,

> Proposition 3. Efficiency under asymmetric information. Under asymmetric information, firm B may not enter even if $c_B < v_B + w$ and firm A offers an *ex ante* contract.

In the "weak patents" region, some second stage innovators, anticipating hold-up, will choose not to enter. In the "strong patents" region, some second stage innovators will also find the *ex ante* royalty too high, so they will still not enter.

Note that this failure occurs for cross-licenses, that is, cases where $w > 0$. Although cross-licensing does address certain transaction cost problems (as in Merges [1999] and Shapiro [2001]), it does not address the *ex post* hold-up problem. Cross-licenses may be written to cover already-developed patents (*ex post*) or prospective patents (*ex ante*).[9] But the optimal cross-license will include a “balancing royalty” paid to the owner of the more valuable patent portfolio (extant or prospective). Then an *ex post* cross-license is still subject to hold-up and hence insufficient incentives, and, with asymmetric information, not all *ex ante* contracts will be accepted.

Similar arguments also apply to other contractual arrangements. A patent pool can be thought of simply as a cross-license where additional licenses are offered to third parties. This changes the interpretation of v_B and *w*, but does not change the basic conclusion. A research joint venture can be viewed as a form of *ex ante* contract; under asymmetric information the terms establishing a joint venture might not be accepted even though development would be socially desirable. Also, *ex ante* mergers and acquisitions face the same information problem in determining an acquisition price.

B. Second best social welfare

Patent strength affects the nature of contracts formed and these in turn affect efficiency. Beginning in the weak patent region, consider what happens generally as patents are strengthened. An increase in *s* causes r_1 to increase. This decreases the probability that firm B will enter, $F(v_B - r_1)$. The expected value of non-royalty benefits, $w\,F(v_B - r_1)$, will likewise decline. However, as r_1 increases, $x(r_1)$ approaches its maximum (at r_0), so expected royalties, $r_1\,F(v_B - r_1)$, must increase, more than offsetting the loss of non-royalty benefits.

Eventually, *s* will equal $\tilde{s}$ and r_1 will equal r_0 at the boundary of the strong patent region. This is the highest royalty rate charged and so firm B will have the weakest innovation incentives. On the other hand, at this point, firm A will have the strongest incentives—expected benefits, $x(r_1)$, are at the maximum, although non-royalty benefits are at their minimum. Further increases in *s* have no effect since r_0 is independent of *s*. Simple calculation generates the following:

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[9] Some cross-licenses are both *ex ante* and *ex post* because they cover both existing patents and prospective technologies. For example, in the semiconductor industry cross-licenses that are based on already-developed patent portfolios may also include a provision to cross-license patents that are developed in the same field for a given period into the future. However, since such agreements do not typically adjust royalties to account for *specific* prospective patents, these agreements do not convey the efficiency benefits of *ex ante* licenses and can be characterized as *ex post* for the purposes here.

> Proposition 4. Statics under asymmetric information. Assuming $v_B > w$, in the weak patent region ($s \le \tilde{s}$) as patent strength, s, increases, expected royalties increase, expected non-royalty benefit to A decrease and total expected benefit to A, x, increases. In the region $s > \tilde{s}$, further increases in s have no effect on these variables.

Thus patent strength is a policy instrument, at least in the weak patent region. A social planner is faced with a tradeoff in this zone: stronger patents increase incentives for firm A, but they decrease incentives for firm B. A risk neutral social planner wants to set patent strength to maximize expected social welfare. However, the social planner lacks private information about development costs for both A and B, so this solution will be second best. For consistency, I assume that A's development cost, c_A, is also drawn independently from distribution $F(\cdot)$.

As above, I wish to present the case most favorable to first stage innovation and to strong patents, so I assume that the second innovation technically depends on the first. Firm A's entry is then necessary for any innovation and this occurs when $v_A + x(r^*) > c_A$. Then expected social welfare is a function of patent strength

$$
\begin{aligned}
U(s) = {} & E\left[v_A - c_A \;\middle|\; v_A + x(r^*(s)) > c_A\right] \\
& + E\left[v_B + w - c_B \;\middle|\; v_B - r^*(s) > c_B \;\;\&\;\; v_A + x(r^*(s)) > c_A\right]
\end{aligned} \tag{13}
$$

The first expectation is the net social benefit of firm A's product conditional on firm A choosing to enter. A's decision to enter depends on the expected benefits to be received from B, given the optimal contract. (Since A's decision is made prior to B's, A's decision does not depend on the actual realization of benefits received, only the *expected* benefits.) The second expectation is the net social benefit of B's product conditional on B *and* A entering, based on the optimal contract. This last condition captures the technical dependency. From this definition follows

> Proposition 5. Second best optimal patent strength for division of profit. As long as $v_B > w$ and F is non-degenerate, the socially optimal patent strength, $\hat{s}$, occurs in the interior of the "weak patent" region, $\hat{s} < \tilde{s}$, where only *ex post* licensing is used. This is true even when the first innovation is required to produce the second innovation.
>
> Proof: see Appendix.

Figure 4 shows an example of the welfare function U. In the strong patent region, U is independent of s. In the weak patent region, the social planner experiences a trade off between incentives for A and incentives for B. In simple terms, the optimal patent strength assigns incentives to B that are above their minimum level and incentives to A that are below their maximum level. This situation only occurs in the weak patent region. Note that without the assumption of technical dependency, the optimal patent strength is even weaker.

This general result depends only on general characteristics of the distribution F and does not assume a specific distribution. Note, however, that as the variance of this distribution declines, $\hat{s}$ approaches $\tilde{s}$. For a degenerate distribution, these two values are equal.

Thus not only can *ex ante* licensing fail to occur under asymmetric information; excluding work-for-hire development contracts, it *only* occurs when patents are sub-optimally too strong, generating insufficient incentives for second stage firms in general.

C. Other considerations

These results were obtained under some strong assumptions, so I briefly consider how well *ex ante* licensing may work to prevent holdup under other possible assumptions. First, I assumed above that *ex ante* negotiations occurred under time pressure and, for that reason, they took the form of a single offer from firm A. Without time pressure, firm A may not be able to credibly commit to a single offer. If firm B does not accept the offer during the first negotiating period, then firm A might be better off trying a second, lower offer. As in the sequential bargaining literature, firm A would offer a series of declining royalty offers, allowing firm B to signal its cost.

However, in general, firm A's discounted *ex ante* royalties in this case will be less than in the case of a single offer. This will reduce the range of the "strong patents" regime—firm A will now prefer *ex post* licensing for some values of $s > \tilde{s}$ where A formerly preferred *ex ante* licensing. Indeed, for the sequential bargaining models that support the Coase conjecture, as the discount factor approaches 1, firm A's *ex ante* royalties approach 0, so firm A will always prefer *ex post* contracts.

Also, this paper, like Green and Scotchmer [1995], only considers a simple model of division of profit between two firms. Clearly, if imitation costs are low or if the product space permits close substitutes, then either or both firms may have competitors and this may alter consideration of licensing.[10] These complications may change the effect of patent strength, and so the results are not necessarily valid in a more general setting. Nevertheless, arguments for broad patents based on an optimistic assessment of *ex ante* licensing do not hold in this basic setting.

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[10] See Gallini [1984], Scotchmer [1996] and Maurer and Scotchmer [2002] for models that include some such considerations.

Two other considerations may limit ex ante licensing (see Rai, 1999, 2001). First, transaction costs may be large. With complex technologies it is often difficult to determine which patents a product may infringe (especially a product that has not yet been developed). Texas Instruments' lawyers often spend a year studying a firm's patents before beginning licensing negotiations [Grindley and Teece, 1997]. Of course, transaction costs also affect *ex post* negotiations, but their relative impact is much larger for *ex ante* negotiations because the success of the innovation is not known *ex ante*.

This can be seen as follows. The model above assumes that the value of innovation B, v_B, is deterministic. This simplifying assumption does not affect the results above, but it does affect consideration of transaction costs. Suppose, instead, that the probability that B's innovation is successful is p and transaction costs are T. Then if firm B anticipates an *ex post* license negotiated with conditional royalty r, its expected profit is $p\,(v_B - r - T) - c_B$. However, the expected profit from an *ex ante* negotiation is $p\,(v_B - r) - T - c_B$. Thus if the probability of success, p, is 10%, the relative impact of transaction costs is *ten times higher* in *ex ante* negotiations. A similar calculation affects firm A's profits. These transaction costs may thus exceed expected joint profits, ruling out a profitable *ex ante* licensing arrangement.

A second problem is that firm B faces a degree of moral hazard in *ex ante* negotiations. Firm A may learn enough information during negotiations to develop the product itself, denying all profits to B. This may exacerbate any transaction cost problems, effectively imposing large expected negotiating costs on B.

Thus *ex ante* licensing does not solve hold-up problems in general and the arguments supporting broad patents need to be reconsidered in regard to asymmetric information.

IV. Empirical Evidence

This section summarizes evidence from a variety of sources on both the extent of *ex ante* licensing and on changes in licensing associated with the strengthening of patents during the 1980's. This evidence suggests that industries with cumulative innovation behave consistently with the model under asymmetric information and *ex ante* licensing is not significant in some of these industries.

First, if the assumption of symmetric information holds, then *ex ante* licensing should occur quite often in industries with cumulative innovation and should comprise a substantial portion of all patent licenses. Caves et al [1983] estimated that patent holders capture about 40%

of the rents from their patents. That is, *s* was approximately 40% in the late 70's and may be higher now (see below). If one assumes that the domain of R&D projects exhibits diminishing returns, so that more projects have high cost-benefit ratios than have low cost-benefit ratios, then the mass of projects will be concentrated toward the right in Figure 1. Then one would expect *at least* 40% of second stage innovators to obtain *ex ante* licenses under symmetric information.

But this does not appear to be the case in cumulative industries such as semiconductors and computers. Major licensors, such as Texas Instruments and Hewlett Packard, do not include special consideration of *ex ante* contracts in their licensing program nor do they calculate lower royalties for licensees who have not yet developed new technology [Grindley and Teece, 1997]. Texas Instruments' policy explicitly renegotiates licenses every five years to accommodate *ex post* innovations developed in the interim. Nor do venture capitalists in semiconductors regularly advise their firms to seek out licenses *before* their technology is developed. Instead, they usually encourage their firms to accumulate patent portfolios as rapidly as possible to be in a stronger bargaining position when possible licensors come calling.[11]

More formal evidence comes from a study of announced licensing deals and alliances, including joint ventures, by Anand and Khanna [2000]. They found that only 17 out of 314 contracts in SIC 36 (mostly in the electronic components and accessories industry) and only 9 out of 158 contracts in SIC 35 (mostly in the computer industry) covered technologies not yet developed. That is, only 5.4% and 5.7% of the licenses were *ex ante*, respectively. Only in SIC 28, including biotech, were many contracts (22.6%) written *ex ante*. Although Anand and Khanna's sample might under-represent *ex ante* licenses, the extent of *ex ante* licensing cannot be nearly as great as implied by the symmetric information model except in SIC 28.[12] And some of the *ex ante* licensing that does take place may actually be for work-for-hire development contracts as opposed to true patent licensing that might be subject to hold-up.

Thus in some important industries known for cumulative innovation, *ex ante* licensing simply does not appear to occur very often. This is consistent with the model of asymmetric information and weak patents. Moreover, in industries in SIC 28, known for stronger patent protection [Levin et al, 1987, Cohen et al, 2000], *ex ante* licensing does occur more frequently, consistent with the model.

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[11] Based on the author's experience and conversations with leading venture capitalists.

[12] I assume that within these broad 2-digit industries the values of *s* vary across individual product markets, but are higher on average within SIC 28. Only the upper tail of the distribution of *s* will use *ex ante* licenses.

Another sort of evidence derives from the strengthening of patents that occurred during the mid-1980's. Legal scholars have noted a sharp change in the legal environment for patents following the creation of the Court of Appeals for the Federal Circuit in 1982. A series of decisions strengthened the rights of patent holders by interpreting scope more broadly, making it more difficult to challenge patent validity, granting preliminary injunctions and large damage awards, and, in general, increasing plaintiff success rates [Kortum and Lerner, 1998, Lanjouw and Lerner, 1996, Lerner, 1995, Merges, 1997]. This shift has been specifically noted in the semiconductor industry [Grindley and Teece, 1997, Hall and Ziedonis, 2001, Hunt, 1996].

Consistent with theory, some evidence suggests that an increase in royalty rates has accompanied this strengthening of patents. Texas Instruments is well known as an aggressive enforcer of patent rights. Texas Instruments' royalty income as a percentage of world semiconductor sales grew from an average of 0.34% during 1986-90 to 0.55% from 1991-95, a 62% increase in the average royalty rate.[13] This suggests a similarly large increase in s.

According to the symmetric information model, such a large increase in patent strength should substantially increase innovation incentives for initial innovators while leaving second-stage innovation incentives unchanged. Such a change should increase industry and firm R&D intensity (R&D to sales ratio), as more costly first stage projects become profitable. On the other hand, with asymmetric information, declining incentives for second stage innovation offset the greater incentives for first stage innovation. Depending on the initial patent strength, average R&D intensity might increase modestly, remain unchanged or even decrease.

In fact, R&D intensity declined for both firms and the industry as a whole at the same time patent strength and royalties increased (see Figure 5). Using NSF figures for SIC 367, industry R&D intensity declined from an average of 8.2% for 1986-90 to 7.5% for 1991-95. Using Compustat data for a continuous panel of 70 public firms, R&D intensity declined from 9.5% in the late 80's to 8.7% in the early 90's, reversing an earlier increasing secular trend.[14] Even Texas Instruments scaled back R&D spending from 7.9% of sales in the late 80's to 6.9% in the early 90's as its royalty income grew handsomely (far exceeding the earlier R&D expenditures that generated the royalties). Thus the large increase in royalties does not appear to have increased

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[13] Royalty figures from Grindley and Teece [1997]; world semiconductor sales from the Semiconductor Industry Association [2001]. The timing of these figures suggests a lag between the legal decisions and their effect on royalties. This is not surprising, given the strong industry norms regulating licensing behavior described by Grindley and Teece.

[14] The NSF data are for company-funded R&D performed in the U.S. relative to U.S. sales [NSF, 2001]. The Compustat data are for worldwide R&D to worldwide sales for U.S. public companies whose main business is in SIC 367 (electronic components and accessories).

R&D incentives overall. Similar patterns are observed if one looks separately at different groups of firms, including an unbalanced panel and balanced panels of large firms (by sales), small firms, and new firms (results not shown). Hunt [1996] explores this phenomenon in depth, considers other factors that might affect R&D, and reaches a similar conclusion.

This finding is also consistent with another observed change in licensing practice accompanying the stronger patents. As Grindley and Teece [1997] report, licenses began emphasizing royalties at the expense of reciprocal benefits associated with cross-licensing. In the asymmetric model with weak patents, an increase in patent strength reduces the value of reciprocal benefits to first stage innovators and simultaneously increases royalty income. Hunt [1996] obtains econometric evidence supporting this shift. He analyzes the market value of public semiconductor firms, separating the effect of each firm's own R&D and the spillover effects of other firms' R&D. He finds that the late 80's exhibited an increase in the value of own-R&D but this was offset by a simultaneous decrease in spillover effects.

In summary, this evidence is difficult to reconcile with the view that hold-up problems are effectively resolved through *ex ante* licensing in industries with cumulative innovation. Instead, many of these industries hardly use *ex ante* licensing and, as a result, greater R&D intensity has not followed from stronger patents.

V. Conclusion

This analysis suggests skepticism regarding the ability of *ex ante* licensing to solve hold-up problems in cumulative innovation. With asymmetric information about development costs, the *ex ante* licenses offered are limited or non-existent. Then hold-up prevents second stage innovators with socially valuable products from entering the market. And empirical evidence suggests that some key industries with cumulative innovation, such as computers and electronics, do, in fact, use *ex ante* licenses only infrequently. Other evidence suggests that the semiconductor licensing practice fits the model of asymmetric information with *ex post* hold-up.

Some researchers have argued in favor of broad patents or greater patent strength, under the assumption that *ex ante* licensing will resolve hold-up problems. If second stage innovators are assured adequate incentives, the argument goes, then patents should be designed to maximize incentives for first stage innovators.

But here, too, my results counsel caution. With private information about development costs, second stage entry is not assured and patent policy must achieve a balance between incentives for first and second stage innovators. As the analysis shows, this second-best balance may be achieved with relatively weak patents.

Appendix

Proof of Proposition 5

Using the definition in the text,

$$U(s) = \int_0^{v_A+x} (v_A - c)\, F'(c)\, dc \; + \; F\big(x + v_A\big) \int_0^{v_B - r^*} (v_B + w - c) F'(c)\, dc$$

where, $x = x\big(r^*(s)\big)$ and $r^* = r^*(s)$. As discussed in the text, $U'(s) = 0$ for $s > \tilde{s}$. For $s \le \tilde{s}$, $U'(s)$ is in general nonzero and is discontinuous at $s = \tilde{s}$. Designate the derivative from the left (*s* increasing) as $U'^L(s)$. Note that if $U'^L(\tilde{s}) < 0$, then a greater social welfare can be achieved in the region $s \le \tilde{s}$ than anywhere in the region $s > \tilde{s}$. In other words, the social optimum must occur in $s \le \tilde{s}$. The remainder of the proof demonstrates that this condition does, in fact, apply.

In the region $s \le \tilde{s}$, $r^* = s\,(v_B - w)$ so that

$$\frac{d\,r^*}{d\,s} = v_B - w \quad \text{and} \qquad U'^L(s) = \frac{d\,U}{d\,r^*}(v_B - w).$$

Note that by (11) the first order maximizing condition implies

$$\left.\frac{d\,x(r)}{d\,r}\right|_{r=r_0} = 0 = \left.\frac{d\,x(r^*)}{d\,r^*}\right|_{s=\tilde{s}}.$$

From this and the envelope theorem, it follows that

$$U'^L(\tilde{s}) = -\,F\big(x(r_0) + v_A\big)(r_0 + w)\, F'\big(v_B - r_0\big)(v_B - w) < 0, \quad \text{for } v_B > w.$$

This means that the socially optimal royalty rate must be less than r_0 and hence must occur in the region where $s \le \tilde{s}$.

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Figure 1. Licensing under Symmetric Information

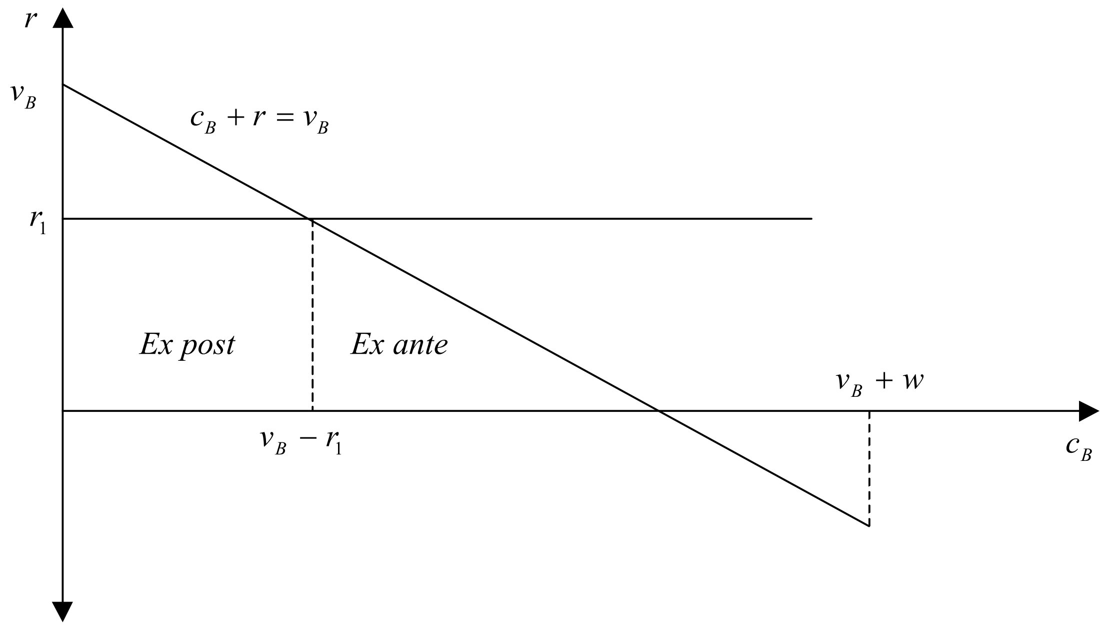

Figure 2. Licensing under Asymmetric Information with Strong Patents

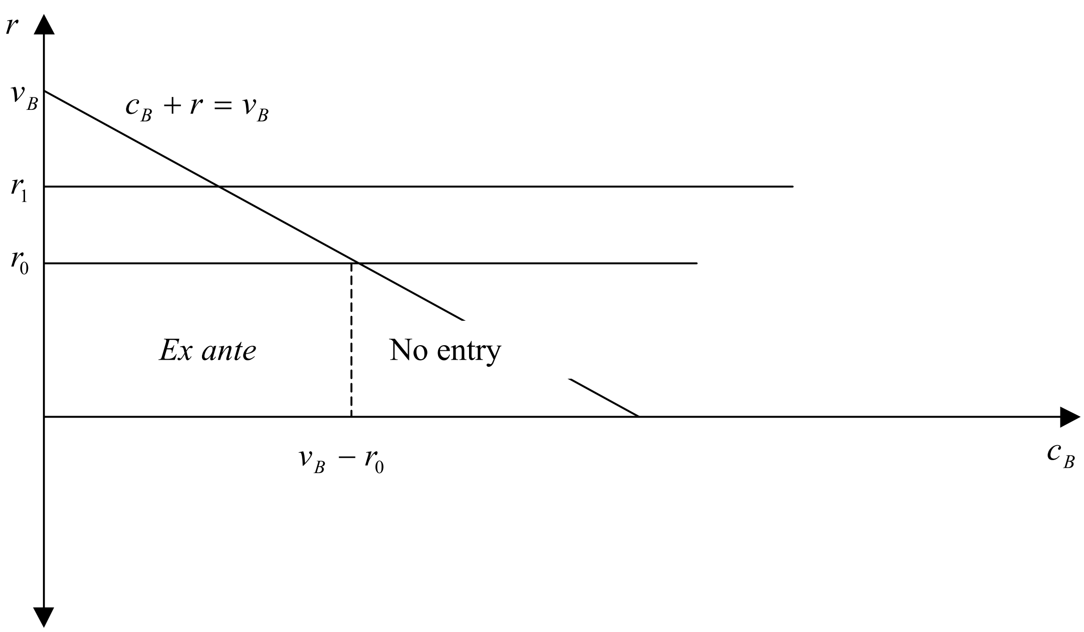

Figure 3. Licensing under Asymmetric Information and Weak Patents

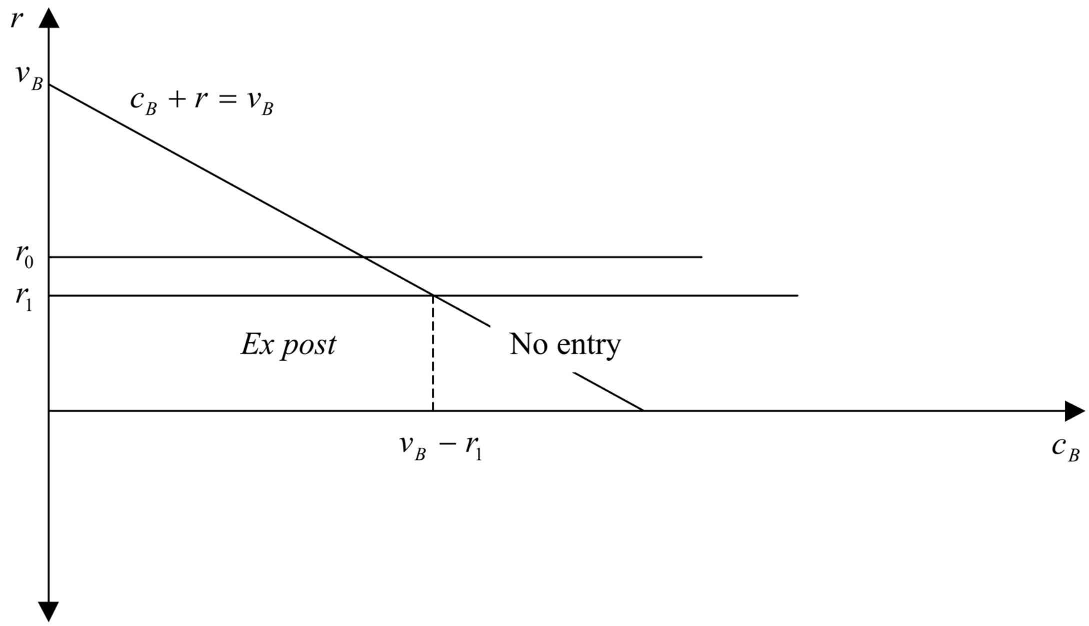

Figure 4. Social Welfare as a Function of Patent Strength

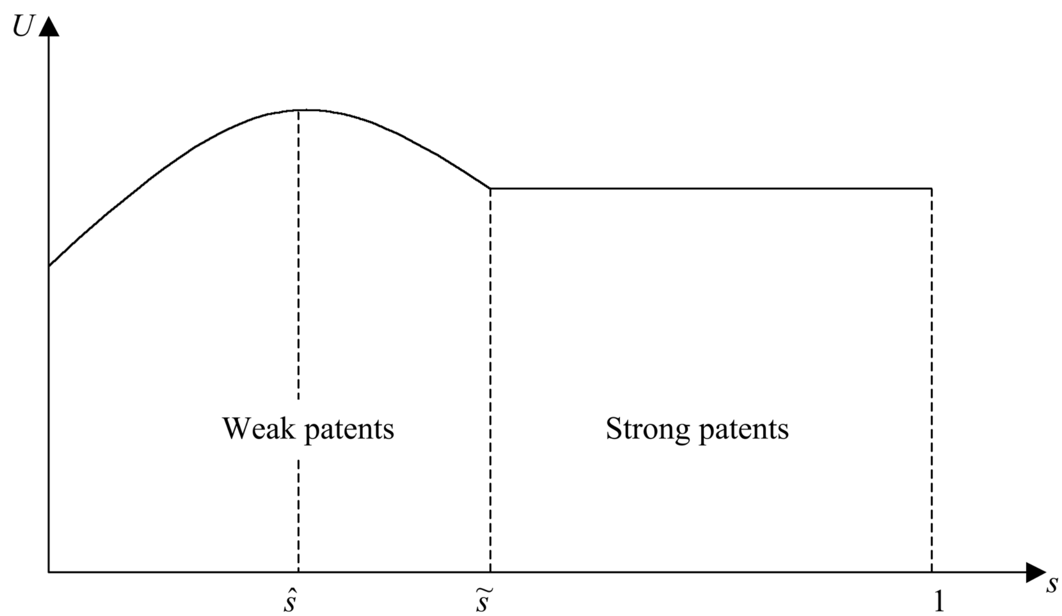

Figure 5. R&D Intensity in Semiconductors
Sources: NSF [2001], Compustat.