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ECONOMIC CONSEQUENCES OF A CHANGING LITIGATION ENVIRONMENT: THE CASE OF PATENTS

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ABSTRACT

A model of patent infringement is developed to analyze the relationship between litigation and aspects of the legal environment such as the probability that the patent is found valid, the size of legal fees and their allocation across agents. Potential challengers first decide whether to infringe and then the patentee decides whether or not to prosecute. The outcome of this game has a fundamental impact on the value of patent protection to a patentee. This model is then linked to a patent renewal model which explicitly incorporates the legal parameters of interest from the litigation game. Estimates of the renewal model allow the empirical estimation of the private value of a patent protection. Simulations are presented for Germany which show the quantitative impact of changes in the legal environment on the value generated by the patent system and hence the incentives created for innovation.

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The common rationale which underlies the maintenance of patent systems is that they redress a market failure: that difficulties in appropriating the returns to innovation lead to less than a socially optimal amount of investment being devoted to research and development (R&D)[1]. There is an extensive body of literature in economics which discusses the role of patents as an incentive mechanism. In more recent years, economists have begun using game theoretic models to investigate issues such as the impact of patents on the speed and diffusion of innovation (see Reinganum, 1989, for a survey). Often in this literature patents are treated as perfectly enforceable at zero cost. At the same time, a recent strand of investigation in the law and economics literature focuses directly on litigation and settlement in bargaining games. At issue is how the distribution of net benefits in a litigation setting is affected by the probability that the prosecution will win, by the legal costs of litigation, how those costs are allocated, and so on. Meurer (1989) applies this type of analysis to the case of patents in his theoretical investigation of how the characteristics of settlement equilibria and the likelihood of litigation, and hence the benefits received by a patentee from his innovation, are influenced by the legal environment.

The empirical literature in this area is much less developed. Despite the widespread belief that innovation is an important component of growth, and that intellectual property rights are an important mechanism to encourage innovation, we know almost nothing about the quantitative benefits generated

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[1] See Schiff, 1971, for a recounting of historical debates surrounding patent systems in many countries. This justification is also currently being pressed by proponents of stronger intellectual property rights in developing countries (e.g., Sherwood, 1990). Theoretical models have been devised which point to the possibility of patent races leading to overinvestment in R&D (e.g., Loury, 1979) but the empirical significance of this possibility has not been established.

by patent systems and how those benefits are distributed. Sample survey evidence provides some clues, particularly about the relative importance of patent protection to different industries, but with typical small sample and selection problems. Patent renewal data has been used to estimate the private value of patent protection for several countries on a population-wide statistical basis (see below, section two). However, previously these estimates have not taken into account the costs of litigation on the value of having a patent. This is a weakness, as the costs of litigation certainly do affect the value that inventors derive from patent protection. The most obvious sense in which this is true is in the substantial direct costs borne by firms in the form of legal expenses incurred defending patents which are actually litigated. These costs must be netted out of any benefits received. And they are not negligible. Lerner (1994) reports that, from July 1989 to June 1990, 1318 patent-related suits were initiated in the U.S. Federal court and approximately 3900 procedures within the U.S. Patent and Trademark Office. He estimates, based on historical costs, that these cases will involve legal expenditures of about one billion 1991 dollars - to be compared with expenditure on basic research of 3.7 billion by U.S. firms in 1991.

There are, however, other, less visible, avenues by which the legal environment impacts on the value of patent protection and thus on the incentives to devote resources to research and development. The first of these arises from the fact that when it is costly to prosecute infringements, some degree of infringement will be tolerated. As the expected costs of litigation rise, the level of infringement tolerated increases and the value of patent protection is correspondingly diminished. Consequently, as expected costs rise, patents will be renewed for a shorter period of time and less important innovations, those for which applying for a patent was of marginal value initially, will simply not be patented. Thus the benefit inventors derive from a patent system may be diminished by higher expected costs of litigation not only directly, if the legal expenses incurred defending those patents which are actually litigated increase, but also indirectly through their impact on the extent of patenting and on the value of all patents granted, whether they are litigated or not.

A second aspect of high litigation costs which is of concern is their influence on the areas in which a given level of R&D investment is directed, the types of innovations pursued, and the characteristics of firms which invest in research. Because these impacts are not neutral, they may lead to a socially wasteful use of that R&D investment which is forthcoming, imposing costs that spread far beyond the fees to patent attorneys. Certain aspects of this distortionary feature of patent systems have been recognized for a long time. For instance, it has long been thought that patent protection is more valuable for the protection of product innovations than for the protection of process innovations (e.g., Kuznets, 1962). This is both because secrecy is a more viable option for process innovations and because one can more precisely define, and therefore defend, claims to a product innovation. Similarly, patents are thought to protect innovations in some technological areas more effectively than in others (for survey evidence see Mansfield, 1986; and Levin, *et. al.*, 1987). The starkest example is those areas which are unpatentable, such as parmaceuticals and agricultural innovations in many countries. By raising the relative return to certain types of innovation, patent systems influence patterns of R&D investment.[2] In a recent paper using data on

[2] This aspect of patent systems may be a cost or a benefit depending upon appropriability conditions in the absence of patent protection. For example, to the extent that new product research is relatively underfunded in the absence of patent protection because products are subject to reverse engineering and imitation, a patent system may be beneficial in correcting the imbalance.

patenting and litigation by U.S. biotechnology firms, Lerner (1994) investigates a somewhat different distortion. He finds that those firms which have higher legal costs (proxied by low capitalizations and little litigation history) direct their research to areas of biotechnology which are less "crowded" and therefore less likely to provoke a prosecution for infringement. In particular, such firms avoid entering areas which are being pursued by firms with low litigation costs. Not only does this behavior alter the total amount of research directed at the various areas of biotechnology, but it also alters the types of firms which do R&D. Specifically, the need to defend patent rights raises the return to research performed by larger firms with big R&D divisions relative to that performed by small firms. If small firms are more 'innovative', making more innovations per R&D dollar[3], then this is an another indirect, yet potentially significant, cost of patent litigation.

There is a great deal of concern about the implications of patent litigation, particularly in the U.S. where it is widespread. U.S. patent reform in 1982 created a specialized appeals court to hear all Federal level patent cases (previously heard by district courts of appeals). This court as been considerably more "pro-patent" than the district courts. Between 1982 and 1990 it upheld 90 percent of infringement decisions by the lower court as opposed to 72 percent of non-infringement decisions. By contrast, in the two decades preceding 1982, the figures were 62 and 88 percent respectively (Lerner, 1994). One result has been a strengthening of patent protection in the U.S., which creates a larger incentive to invest in R&D. However, another result has been an increase in litigation and administrative proceedings over the

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[3] See Acs and Audretsch (1988) and the literature cited therein. Any studies of the relative R&D productivity of small vs. large firms is conditioned on distortions of the sort noted here.

past decade and claims that large firms have made use of predatory litigation to harm smaller competitors. Judging whether the balance is right is a hard problem. It is one that we cannot hope to address without some quantitative understanding of what incentives patent systems create and how policy reforms affect those incentives.

In the following section a two-stage game of infringement and prosecution is presented which highlights the ideas outlined above in a form which can be linked to a patent renewal model which is used in estimation. In the first stage of the game, potential competitors decide whether to infringe. In the second stage the patentee must decide whether or not to prosecute if infringement occurs[4]. This decision is determined, in part, by the costs of prosecution and section two presents evidence that a long litigation period may impose costs on a patentee over and above direct legal fees.

The patent renewal model is presented in section three. This model is used to empirically estimate the value of protection to inventors using data

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[4] The model presented in section one is similar in spirit to that of Meurer (1989) in his investigation of the implications of litigation cost allocation rules, the probability of patent invalidity and antitrust policy on the likelihood of litigation in a symmetric information setting with a single potential challenger. In his model, the challenger moves first with a threat to initiate invalidity proceedings (another way in which validity can be questioned). Then the patentee makes a take-it-or-leave-it settlement offer and the challenger decides whether to accept it. Infringement as an option is assumed away and thus the credibility of the challenger's threat is at issue. The sequencing of moves makes the patentee the residual claimant of total returns. Since potential challengers can, in fact, always opt to infringe, thereby making their threats credible, it seems more appropriate to model the moves as presented here. This model is also more detailed with respect to the time dimension of litigation and multiple challengers, detail which is used when looking at the data in section 2 and in modelling the renewal decision in section 3.

from Germany[5] on the number of years that individual patents are kept in force by payment of the annual renewal fee. The use of renewal data to estimate patent value was pioneered by Pakes and Shankerman (1984) (see also Schankerman and Pakes, 1986; Pakes, 1986; Schankerman, 1991; and Sullivan, 1994, for an application to historical data). The basis of such models is the observation that a patentee will renew his patent in a given year only if the returns from doing so outweigh the costs. Given a parametric form for the (stochastic) evolution of returns over time and a renewal fee schedule, one can specify the percentage of those patents still in force which will be allowed to lapse in any given age, that is, the hazard rate. Parameter estimates are obtained by minimizing the distance between the observed hazard proportions and the hazard rates generated by the model.

The model used here (and developed in Lanjouw, 1993) differs from previous work in that it explicitly incorporates the fact that an inventor must be willing to defend his patent rights for those rights to be meaningful. The parameters of the model are direct counterparts of the factors identified in the law and economics literature as being important determinants of the value of the property right created by a patent. Thus the model permits simulation of the quantitative impact of changes in the legal environment (e.g., in legal costs, in the probability of rulings in favour of patentees, in the duration of cases) on the benefits generated by patent protection. In the fourth section simulations are presented which illustrate the magnitude of these changes. The final section concludes.

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[5] Throughout the paper, German and Germany refer to the Federal Republic of Germany, before re-unification.

Section 1: Is it Worth a Fight?

A profit-maximizing inventor is granted a patent and receives an annual profit of π^m_a from his innovation in the ath year (age) of protection if his patent is not infringed. There are N identical potentially infringing firms[6]. The patentee and each of the infringing firms receives a profit of $\pi^{(j)}_a$ in age a if j firms, in addition to the patentee, use the innovation[7] and π_a if all N potential competitors infringe. Thus if no one infringes, the return to having a patent for age a, r_a, is the *incremental* increase in profits, $\pi^m_a - \pi_a$. This increment may be a small part of the total profits derived from the innovation, depending on the characteristics of competition in the absence of protection. In the extreme, if there are no potential challengers then the returns to protection are zero, even if the innovation itself is hugely profitable. If the patentee allows j firms to infringe, his return to protection is $r_a(j) = \pi_a^{(j)} - \pi_a$. The total profit derived from the innovation is non-increasing in competition, that is, $d[(j+1)*\pi^{(j)}_a]/dj \leq 0$, so $dr_a(j)/dj \leq 0$. Protection becomes less valuable as the level of infringement increases. Profits may increase or decrease in age as the innovation is developed, marketed, and is subject to imitation or replacement by subsequent, superior innovations.

In order to keep a patent in force, a patentee must pay increasing

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[6] The number of potential infringing firms is treated as fixed and exogenously determined. However, in general a patentee may have other ways of dissuading other firms from using his innovation, such as brandname development, and his expenditure on other forms of deterrence would determine how many firms would enter in the absence of patent protection.

[7] Modelling additional increments of infringement as the entry of different firms is a convenience. The model can be recast slightly with j representing the *degree* of infringement - not necessarily by different firms as it is here.

annual renewal fees to the patent office. Increasing annual or semi-annual renewal fees are required in most countries. These are designated by c_a, $c_a >$ 0. Once a patent lapses it can not be reinstated.

Stochastic variables are in expectation given the information available at the time that actions are chosen. All agents are risk neutral and have common knowledge about the characteristics of the innovation and its market which may impinge on the current and future returns to patent protection. Consequently, they share expectations about all future values including the probability that the patent is valid. The information structure is very important in litigation bargaining models. In some contexts treated in the literature, such as personal injury or medical malpractice claims, asymmetry of information seems plausible. However, in the context of patent litigation the assumption of symmetric information seems most reasonable as all firms are likely to have similar access to market information and, by virtue of the disclosure requirement, all agents are informed about the innovation. In the following discussion, the age subscript on all profits and costs will be dropped to ease notation. The model does not explicitly incorporate a time discount factor, however, it should be understood that all values are in present value terms.

Each year[8] the potential competitors and the patentee play a two-staged game, until the point that an infringement occurs, or the patent lapses because it is not renewed, or the statutory term is reached (20 years in most countries). In the first stage the N potential challengers decide simultaneously whether or not to infringe, and in the second stage the patentee decides how to react. A second stage strategy for the patentee consists of a set of N

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[8] The model uses discrete rather than continuous time to accommodate the annual renewal fee schedule.

choices regarding whether to allow different numbers of infringements (j = 1 to N) to go on or to prosecute should they occur[9]. Only pure strategies are considered.

The following subsections first describe the expected payoffs to the patentee and potential competitors from their respective strategies, written for the game played at age one. Then the existence of a pure strategy subgame perfect equilibrium is established and the possible types of equilibria are characterized. The section concludes with a discussion of how the equilibrium outcome is likely to change as the legal environment is altered.

Prosecution

If a patentee has his patent infringed by j firms, and he chooses not to prosecute, his net return from patent protection is the incremental increase in profits from having the patent less the renewal fees:

$$\Sigma_1^{s(j)}[\pi^{(j)} - \pi - c] \qquad (1)$$

where the summation is over ages. s(j) is the expected number of years that the patent will be renewed when there are j firms in addition to the patentee using the innovation[10] and renewal decisions are made optimally (details are

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[9] The degree to which the costs of litigation increase in the number of infringers is assumed to be sufficiently low that the failure to include the selective prosecution of a subset of infringers in the patentee's strategy set is not restrictive.

[10] Two assumptions are implicit in this equation. The first is that if litigation does not occur in the first age it will not occur at all. As long as profit is falling in age, this would hold because the benefit of litigation would

in section 3).

If the patentee chooses to prosecute j infringements, he must incur total legal expenses, denoted $LF^p(j)$ where the superscript p refers to the patentee and a superscript c will refer to a challenger. If the patentee wins, some portion of his legal costs, lf(j), may be covered by the infringing firms, the portion depending on the rules of litigation cost allocation. For example, in the U.S., compensation for legal costs is granted only if infringement is deemed to be "willful" (35 U.S.C. & 284) or "exceptional" (35 U.S.C. & 285). In contrast, in Germany the losing party(s) is required to cover court costs and statutory legal fees for both sides (the English Rule). Of course, actual legal expenses may be higher than the statutory level.

If the patentee chooses to prosecute, the expected payoff from a successful prosecution of j infringements is:

$$\Sigma_{1s'}[\pi^m - \pi - c] - [LF^p(j) - lf(j)] \tag{2}$$

where s' = max{s(m), p} and p is the expected number of years required to resolve a suit. The max{} indicates that a patent will be renewed until the end of the litigation period even if the patentee would have chosen to let it lapse

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fall in age for both parties at any level of infringement. The second is that no additional infringement will occur in future ages. Since legal fees are constant, the benefit to a patentee of fighting infringements falls as the terminal age approaches and the number of years of remaining protection fall. Thus, in fact, he will likely allow a greater degree of infringement. Both of these implicit assumptions are relaxed in the model of section 3, and neither of them has any bearing in the special case of a single potential challenger which is the focus of much of this section.

in the absence of litigation[11]. The following section presents evidence that this matters, i.e, that s(m) is sometimes less than p.) The level of damages that the patentee expects to be paid by the infringing party(s) in the event that he wins just compensates him for his losses, giving him a profit of π^m. This is typically the objective when setting compensatory damages, which are based either on lost profits or reasonable royalties. Punitive damages are not normally granted although in the U.S. the proven damages may be trebled if they seem "inadequate". Implicit in equation (2) is the assumption that once a patent has been successfully defended, its validity has been established sufficiently that no further infringement will occur *as long as the patentee is willing to prosecute* (formally, equation (6), below, is negative for all j).

A successful prosecution is expected to occur with probability w, treated for the moment as independent of legal expenses. Below we will consider an alternative specification where the expected probability of winning is a function of the amount spent on the dispute by each side, i.e., w(LF^p, LF^c), with w the equilibrium outcome of a third-stage game in legal fees. The probability of winning is also treated as constant across patents within a technology group[12].

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[11] In Germany, if a patent is challenged before granting the patent application will only be granted after the suit is completed - requiring the payment of renewal fees throughout. Patents challenged later are likely to be renewed to lend weight to the prosecution.

[12] Given this assumption, w, which is the unconditioned (on litigation) probability of winning, corresponds directly to the percentage of litigated patents which are found valid. If one, more realistically, allows for a distribution of w over patents, then there is no direct empirical counterpart for the mean value of w . A patent's likelihood of being found valid influences whether it is litigated, causing the average patentee success rate among litigated patents to diverge from the unconditional mean (although, as noted by

The expected payoff to an unsuccessful prosecution of j infringements is:

$$\Sigma^{p}{}_{1}[\ \pi^{(j)} - \pi - c]\ \ - [LF^{p}(j) + lf(j)]. \qquad (3)$$

Note that infringement continues throughout the suit. In Germany, while a patentee has the right to request an injunction, they are rarely granted and often not sought as they put the patentee at risk of having to pay damages to his competitor if infringement is not upheld (see Sperber, 1980). An unsuccessful prosecution is expected to occur with probability (1-w).

Combining equations (2) and (3) we have the expected payoff to prosecution against j infringements:

$$\Sigma^{p}{}_{1}[(1-w)\pi^{(j)}+w\pi^{m} - \pi - c] + w\Sigma^{s'}{}_{p}[\pi^{m} - \pi - c]-[LF^{p}(j)-(2w-1)lf(j)] \qquad (4)$$

A patentee will litigate if equation (4) > equation (1). To highlight the issues of interest, we shall focus below on a situation where there is a single potential infringer, so N = 1 and $\pi^{(1)} = \pi$. In this case, equation (1) = 0 and the patentee will defend his patent against infringement whenever the expected payoff to prosecution,

$$\Sigma^{s'}{}_{1}[w(\pi^{m}-\pi) - c] + (1-w)\Sigma^{s'}{}_{p}c - [LF^{p}(1) - (2w-1)lf(1)], \qquad (5)$$

is positive.

Priest and Klein (1984), as the parties' uncertainty about w becomes large, case selection becomes more random). Waldfogel, 1993, discusses the literature on this point and derives estimates of w from a structural model of case selection.

Infringement

The expected net payoff to the jth potential infringer if he chooses to use the innovation, and if the patentee is expected to take action in response, is:

$$\Sigma^{p}{}_{1}\pi^{(1)} + (1\text{-}w)\Sigma^{s'}{}_{p+1}\pi - w\Sigma^{p}{}_{1}[\pi^{m}\text{-}\pi^{(1)}] - [LF^{c}(1)+(2w\text{-}1)lf(1)] \qquad (6)$$

if j = 1 and

$$\Sigma^{p}{}_{1}\pi^{(j)} - w\Sigma^{p}{}_{1}[(\pi^{m}\text{-}\pi^{(j)})/j] - [LF^{c}(j)+\{(2w\text{-}1)lf(j)/j\}]$$

if j > 1.

For the first infringer there are two potential benefits: returns during the suit and the possible invalidation of the patent. There is a discrete fall in the expected payoff to additional infringement once one firm is already infringing and will be engaged in litigation. This is because other firms can free-ride on the outcome of that litigation. If the infringing firm wins, the patent lapses and *all* firms can use the innovation at time p+1. The second to last term represents the share of the infringing firm in the damages suffered by the patentee over the course of the suit which are paid to the patentee if he wins. The final term is expected legal costs, where again compensation to the patentee, lf(j), is shared by the j infringers. In the case of a single potential infringing firm, the expected net payoff to challenge is,

$$\Sigma^{p}{}_{1}\ \pi + \Sigma^{s'}{}_{p+1}\ (1\text{-}w)\pi - w\Sigma^{p}{}_{1}[\ \pi^{m}\text{-}\pi\ ] - [LF(1)+(2w\text{-}1)lf(1)]. \qquad (7)$$

If the patentee is not expected to prosecute j infringements in the second stage then the expected net benefit is positive and the jth infringement occurs.

Equilibria

It is straightforward to establish that there is at least one subgame perfect equilibrium in pure strategies. Suppose that the patentee will fight a single infringement and that a single infringement is not optimal for a potential challenger given this response (equation (6) is negative). Then no infringement is an equilibrium. Suppose instead that equation (6) is positive for the first infringement. Then continue to $j=2$. If the patentee will not prosecute two infringements in the second stage (equation (4) is negative for $j=2$) continue to $j = 3$. Alternatively, if the patentee will prosecute two infringements and the second infringement is optimal nevertheless (equation (6) is positive for $j=2$) also continue to $j = 3$. If equation (6) is negative then stop. An equilibrium has been reached with $j-1$ infringements and prosecution depending on the patentee's optimal response to those infringements. If the process continues to N, then all potential competitors infringing is an equilibrium. (This procedure is analogous to the establishment of cartel stability with a finite number of firms, for example, in D'aspremont, *et. al.*, 1983.)

There are three possible types of pure strategy subgame perfect equilibria. Consider the case of a single potential challenger:

Equilibrium #1 - Equation (5) < 0.

The challenging firm begins using the innovation and is not prosecuted. Given a common knowledge assumption as to the optimality of defense, this will characterize the equilibrium whenever the patentee is unwilling to prosecute an infringement, i.e. whenever equation (5) is negative. With all potential competitors using the innovation, the patent no longer provides any protection so it will not be renewed.

This equilibrium may also be associated with the *initiation* of litigation by the patentee if one relaxes the common knowledge assumption to allow some uncertainty in the minds of potential challengers as to whether the patentee will follow through. This is termed nuisance or sham litigation, that is, litigation which is initiated in the expectation that the opposite party will settle (equation (7) is negative) and which is only profitable if they do settle (equation (5) is negative). A recent theoretical literature investigates the likelihood of litigation in a general asymmetric information setting which generates this type of behaviour (see Spier, 1994, and Cooter and Rubinfeld, 1989, for a survey).

This equilibrium (equation (5) $<$ 0) could also be associated with litigation which is actually carried through if one were to allow for multiple patents. As it stands, the model treats each patentee as innovating only once, which suffices to illustrate the points of concern here. However, if a patentee expects to have a series of patents then he might find it advantageous to defend even in situations where it would not be optimal in a one-shot game in order to establish a reputation as an aggressive defender of his property rights and lower the probability of infringements of future patents. This strategy can be supported either by a random time horizon or by uncertainty in the minds of potential infringers as to the payoffs of the patentee (e.g., Kreps and Wilson, 1982). The expectation of repeated innovations, and of a long and uncertain time horizon, are much higher with a firm as opposed to an individual patentee so one would expect firms to be more aggressive in defense of their patents for this reason alone (that is, quite apart from lower legal costs.)

Equilibrium #2 - Equation (5) > 0 and Equation (7) < 0.

The patent is renewed and no litigation occurs. The patentee would defend himself against infringement (equation (5) is positive) and the potential infringer does not find it worthwhile to challenge him knowing this to be the case (equation (7) is negative).

Equilibrium #3 - Equation (5) > 0 and Equation (7) > 0.

The infringement occurs and the patent is litigated.

With pre-litigation bargaining, equilibrium #3 could be associated with a settlement between the parties where the infringing firm is licensed by the patentee to use his innovation[13]. If licensing contracts can be constructed which maintain monopoly returns, then settlement effects the distribution but not the total value derived from patent protection. If licensing contacts are restricted, for example because of antitrust regulation, then the total value falls. The distribution of surplus hinges on the form of the bargaining process. In either case, the returns generated are distributed away from the patentee/inventor to the infringing firm and thus the role of patent protection as an incentive mechanism is diminished.

Comparative Statics

What, then, are the predicted impacts of changes in the legal environment surrounding patent protection on the value generated by the patent

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[13] A study of German patentees conducted by the U.S. Department of Energy (1982) found that more than a third of suits were settled out of court.

system as an incentive to R&D investment? What are the implications of differences in legal costs across firms?

Costs of litigation can change in a number of ways. Clearly the direct legal costs may vary, as may the portion that the losing party must cover. As appears to have happened in the past decade in the U.S., the attitude of the courts towards patent protection can also change, altering the probability that a patentee will win when prosecuting an infringement. The average duration of a suit may vary over time, particularly if there is a jump in the number of suits leading to a backlog in the courts. In this model, these aspects of the legal environment are captured by the variables LF, lf, w, and p.

As the costs of defending a patent against infringement rise, holders of less valuable patents will no longer be willing to defend them and they will be allowed to lapse. Defense becomes more costly if there is a fall in the probability that the court will decide in the patentees favour, w. Considering equation (4), we see that defense becomes more costly as LF^p rises. A fall in lf also raises the expected cost of defense if the probability of winning is greater than fifty percent (the empirically relevant case).

A longer litigation period has an ambiguous effect on the costs borne by a patentee. As discussed under equilibrium #1, renewal of a patent requires that the patentee be willing to defend it against N infringements. Thus the current benefit of having a patent plus the net returns over a prospective litigation period must be greater than the renewal fee. For those patents initially on the margin of being renewed, as the litigation period increases, the expected net returns over the period fall and they will no longer be renewed. In total fewer patents are renewed. On the positive side, further infringements are deferred during a suit which makes a longer litigation period attractive to the patentee, particularly if legal fees are substantial. However, the negative impact increases in p while the positive impact falls, so, while the effect is ambiguous at lower levels of p, it is likely to be negative as litigation is increasingly drawn out. This is reinforced if legal fees are higher for a longer running suit.

Potential competitors find infringement more costly as legal fees, LF^c, rise, and as lf rises if the probability that the patentee wins is greater than fifty percent (see equation 6). If the patentee becomes more likely to win, an increase in w, infringement becomes more costly. The expected length of a suit has a positive effect on infringers since it delays the entrance of further competition, unless, as noted above, legal fees are increasing in p.

Thus, with an increase in legal fees, or a fall in w or lf (assuming w > .5), the first equilibrium applies to more patents and they will be allowed to lapse. With a fall in legal fees, the third equilibrium, that with litigation, becomes more likely and the first equilibrium less so. More patents will be renewed and more will be litigated. As w or lf increases, equilibrium #1 becomes less likely in favor of the second and to a lesser extent the third equilibrium. More patents will be renewed and, in the case of multiple competitors, less infringement will be tolerated (see below).

Similar results hold when one generalizes the analysis to j potential infringing firms where output and prices are described by a Cournot equilibrium with $\pi^{(j)} > \pi$ for $j < N$. The equilibria for this situation are more complex to characterize because the expected net benefit of fighting infringement (equation 4 - equation 1) as a function of j can take on many forms (not necessarily monotonic in j) depending on the specification of the functions LF(j) and $\pi^{(j)}$. In a similar way, the expected return to challenges (equation 6) may take on various forms as a function of j. Since the points of interest can be illustrated in the single challenger case, the general case will not be explored in detail here. However, there are two types of results which do not arise in the single challenger case and which bear mentioning.

The first arises when the net benefit of fighting infringement is increasing in the number of infringing firms. In particular, if we make the reasonable assumption that LF' ≥ 0, LF'' ≤ 0, that is that there are economies of scale in the number of infringements[14], then it is easy to devise examples where the patentee will fight large numbers of infringers but will tolerate the existence of a few. As the costs of prosecution increase, the amount of infringement tolerated increases. The result then is a lowering of the value of protection offered by non-litigated patents. Lerner (1994) notes a number of cases of patentees pursuing damages for past infringements with the shift to a more pro-patent (higher w) stance in the U.S. courts. These are infringements that they had tolerated during a period when the courts were less supportive of patentees.

In the general case one can also show that, where litigation does occur, it involves fewer infringing firms when the costs of infringement rise. The intuition for this result is that the benefit of having an oligopoly over the period of the suit may be worthwhile if the costs of the suit are low (or the period long). However, as costs rise or the period shortens, a firm considering infringement will only be interested if there is less competition in the use of the innovation.

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[14] The story of Refac Technologies, related by Besen and Raskind (1991), is indicative. The company acquired 5% ownership rights in a multitude of software patents related to spreadsheets in exchange for agreeing to prosecuting infringement suits. It filed some 2,000 suits as a result.

What are the implications of differences across firms in the costs of legal services? Consider a three-stage game where in the third stage firms engaged in an infringement suit decide how much to invest in legal fees. Given the benefit that they expect to receive from winning, their choices will be determined by the effectiveness of legal expenditure in altering the outcome of the suit, i.e., $w = w(LF^p, LF^c)$, with $w_1' \geq 0$, $w_1'' \leq 0$ and $w_2' \leq 0$, $w_2'' \geq 0$. Suppose that initially both the patentee and the infringing firm have high legal costs and the equilibrium levels of legal fees yield w^H. Now suppose that the patentee is instead faced by an infringing firm with low legal costs. One way to say this is that for the same legal fees, LF^c, the low cost infringer gets more effective services - that is, a lower w. Because its legal expenditure is more effective, the low cost challenger is also likely to have a higher equilibrium level of expenditure on legal fees, lowering w yet further. As a result, patentees with high legal costs are more likely to drop their patents when faced by low legal cost infringers. This diminishes their expected returns and discourages them from pursuing innovations in areas where low legal cost firms are active.

Section 2: The Costs of Delay

This section looks directly at the hazard rate data for evidence concerning the costs imposed on patentees by an extension of the litigation period, p.

The data set is a random sample of over 20,000 German patents in 4 technology areas (computers, pharmaceuticals, combustion engines, textiles) from those which were applied for or in force during the period 1955-1988. The data contains information on the age of the patent at the time of granting and the number of years that each patent was renewed. Over the period of the data, the German Patent Office used two granting procedures. Before October, 1968, an examination for patentability was automatically initiated after application. Currently, applicants have 7 years to request and pay for a full examination. Details of the data set and a summary of the two regimes, fees and legal protection are in Appendices I and II.

The data do not indicate which patents have been infringed and prosecuted. However, challenges may also occur before the granting of a patent via opposition proceedings (see Lanjouw, 1992b, for details). Thus the age of granting can be used to make inferences about challenges by noting that those patents which have *not* been subject to a challenge are granted 3 months after a successful examination, while those which have been challenged may be granted many years later. In particular, under the early regime, when examination could not be delayed, it may reasonably be assumed that patents granted longer after application are more likely to have been through a challenge than those granted soon after application. Under the current regime this is less clear, so this section focuses on data from the earlier period.

The implications of a lengthy period of opposition proceedings (litigation period) can be seen in the following simple example. A group of patents generates initial returns to protection $r_1 = \pi_1^m - \pi_1$, distributed $f(r_1)$, which decay at a known constant annual rate, δ (so $r_a = r_1 e^{-\delta(a-1)}$). Patents which are on the margin of being renewed have an expected value of zero so marginal patents which are engaged in opposition proceedings must begin to yield negative net annual returns (that is, $\pi_a^m - \pi_a - c_a < 0$) at some point during the period to offset positive returns received at the beginning of the period. If not in the midst of a challenge, such patents would stop being renewed at that point (s(m), the optimal stopping point in the absence of litigation, < p).

However, because obtaining the positive returns at the beginning of the opposition proceedings is contingent on winning the challenge, the patents are renewed to granting (fn 11). At this point, the patents are dropped. As a result, the hazard rate for challenged patents just after granting, the "post-grant hazard", includes those patents which would have been dropped in that age regardless of having been challenged *plus* those which would have been dropped earlier if not for the need to continue p years in order to gain benefits contingent on winning. Labelling the hazard probability for patents which have not just been granted the "distant-grant hazard" we have,

Proposition 1: (Challenge Effect) *The post-grant hazard probability for a given age for a group of challenged patents will be greater or equal the distant-grant probability for the same age.*

Before turning to the data for evidence of challenge effects in the post-grant hazard rates, another factor which may alter these hazard rates must be considered. Costs related to granting are quite high in Germany relative to renewal fees for the early ages (see Appendix II). For this reason they can exercise a selection effect on the hazard rates of recently granted patents. Using the previous example, note that because returns are declining in age, if current net returns are zero then they will never be positive in the future. Ignoring the issue of litigation, this means that the minimum level of returns which will lead to renewal in age a is $r_a = c_a$, the renewal fee. A patentee will request a full examination and pay the publication cost if and only if net returns over the examination period plus expected future returns contingent on being granted are greater than these costs. This puts a floor on the returns generated by patents which go through the granting procedure (a floor which is high relative to c_a in the early ages). Proposition 2 follows.

Proposition 2: (Selection Effect) *Ceteris paribus, as a result of high granting costs, the post-grant hazard probability for a given age is less than or equal the distant-grant hazard probability for the same age.*

The empirical data are summarized in Figure 1, which displays the ratio of post-grant to distant-grant hazards, with details in Table 1. The first column of the table contains post-grant hazards and the second column contains the average hazard for a given age taken over those patents granted in age-2 or earlier (the distant-grant hazards).[15] The third column, that shown in Figure 1, is the ratio of post-grant to distant-grant hazards. The first region in Figure 1 corresponds to grant ages too early for a challenge to have occurred and the third region to grant ages where a challenge almost surely did occur.

Because of the selection effect, the only reason for post-grant drops in the early ages is a quite dramatic fall in returns in the age after granting. Thus, Table 1 reveals that the probability that an innovation is discovered to have little value in the early ages is 4.5 to 7.6% per year. Apart from its independent interest, this should be borne in mind when interpreting the ratios in column three (and Figure 1). Age specific obsolescence contributes to post-grant and distant-grant hazards equally. In looking for evidence of litigation and selection effects, it is differences in the incremental hazards, over and above non-renewals due to obsolescence, which are relevant. For example, suppose that there is a probability of becoming obsolete of .05 in age 15.

[15]The hazards were calculated in two stages. First a weighted average over technology, country (and in column 2, cohort) groups was calculated for each year and then an unweighted average was taken over years. This ensures that years are given the same weight in both sets of hazards. The procedure was used to avoid biases due to the combination of a truncated sample and systematic year effects such as trend falls in the real renewal fee schedule.

Figure 1

The Ratio of Post-grant to Distant-grant Hazards

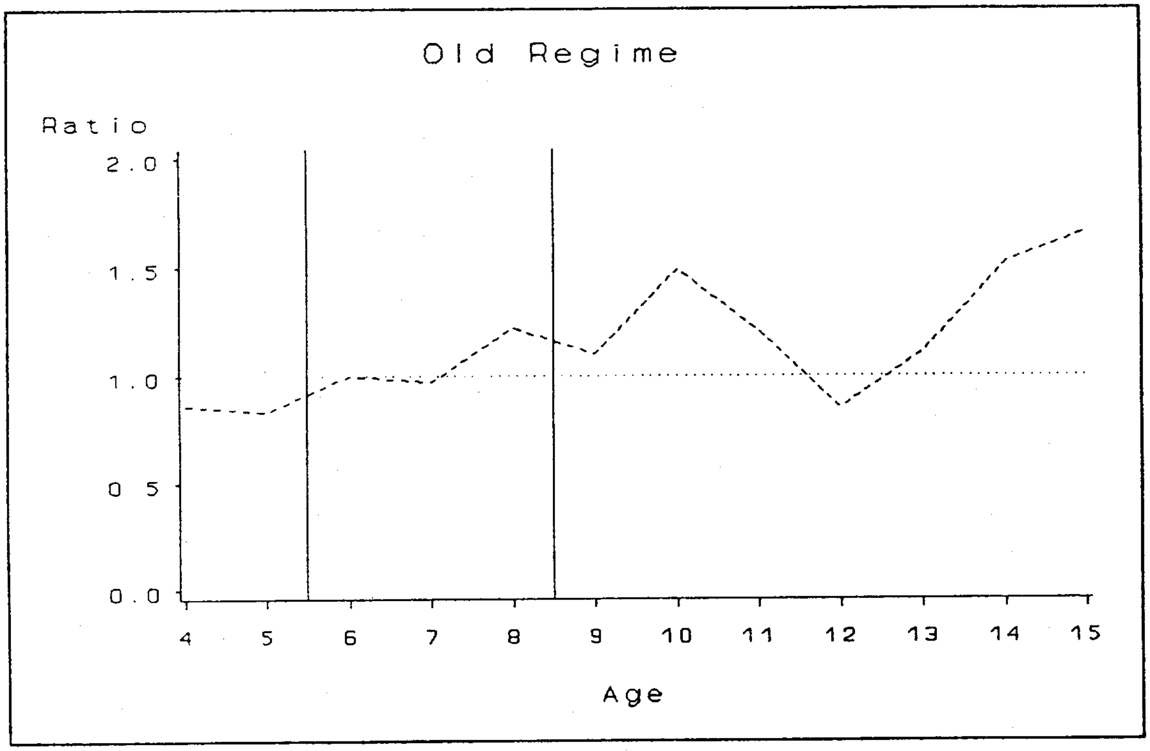

Table 1

Post-Grant vs Distant-Grant Hazards

Age	Post-grant Hazard[1] (1)	Distant-grant k=2 to (age-2)[2] (2)	Ratio (1/2) (3)
3	.045 (.006)		
4	.060 (.007)	.069 (.008)	.86 (.14)
5	.076 (.008)	.091 (.007)	.83 (.10)
6	.111 (.011)	.111 (.007)	1.00 (.12)
7	.108 (.013)	.111 (.007)	.97 (.13)
8	.147 (.017)	.120 (.007)	1.22 (.16)
9	.157 (.020)	.142 (.009)	1.10 (.16)
10	.201 (.025)	.135 (.008)	1.49 (.20)
11	.160 (.023)	.132 (.010)	1.21 (.20)
12	.153 (.029)	.179 (.013)	.85 (.17)
13	.188 (.030)	.169 (.008)	1.11 (.18)
14	.285 (.033)	.188 (.030)	1.52 (.19)
15	.261 (.011)	.157 (.006)	1.66 (.10)

Notes:

1) In columns 1 and 2 the hazard for a given age a is calculated in two stages. First an average over technology, country and cohort is obtained for each year, weighted by the sample size. Second, the unweighted average over years is calculated.

2) Estimated standard errors are in parentheses. Because technology, country, cohort and grant age groups are independent, variances at each stage are calculated as sums of the variances of the constituent hazard estimates weighted by the relevant coefficients.

3) The variance of the ratio in column 3, (h_1/h_2), is calculated using a Taylor expansion:
$\text{Var}\,(h_1/h_2) \cong [1/(h_2)^2][\text{Var}(h_1)] + [h_1/(h_2)^2][\text{Var}(h_2)]$.

Subtracting .05 from the hazards in columns one and two, the ratio in column three would increase, from 1.66 to 1.97. In general, a positive probability that innovations will become obsolete hides differences and brings the ratio towards 1.

The pattern of hazards is clearly in accordance with the propositions. In the early ages the post-grant hazards are lower than the distant-grant hazards and the ratio is less than one[16]. In the middle ages, where the expected net effects are ambiguous, the empirical net effects are also mainly zero. In the later ages post-grant hazards tend to be the same or higher indicating challenge effects and the length of the period, p, clearly matters. When the challenge takes three or four years to resolve (age of grant k = 8), about 3 percent would have dropped earlier and suffer negative returns as a result. When p rises to nine or ten years, about 11 percent would have dropped earlier.

What is surprising, and informative, is that these numbers are not larger. For example, if patents granted in age 8 had the same distribution of value as those granted earlier, then one would infer from the distant-grant hazards that 28 percent of them should have preferred to drop earlier. One explanation for this discrepancy is that opposition proceedings are launched against the most valuable patents. However, chi-square tests fail to find differences in hazard proportions across grant-age groups, indicating that challenged and unchallenged patents are the same given that the patentee renews through granting (see Lanjouw, 1992b, for details). A second explanation is that patent applications with lower expected value are allowed

[16] The fact that the selection effect bites (the ratio below 1) indicates that there are a substantial number of patentees making marginal decisions. This fact is crucially important to the ability to actually estimate renewal models successfully.

to lapse in the face of opposition. Thus this breakdown of the hazard proportions reveals not only negative net returns being suffered by patentees in the later years of opposition proceedings, but also indicates that a substantial fraction of threatened applications are simply dropped.

Section 3: The Patent Renewal Model

If we ignore for the moment the issue of litigation, the value of renewing a patent in any age has three components. It is equal to the returns to protection for that age, $r_a = \pi_a^{(j)} - \pi_a$, where j is the level of infringement tolerated, plus the expected value of the option to continue renewing in the future and minus the renewal fee, c_a. Let $\bar{r}_a$ be the minimum level of returns in age a which will lead to renewal. Then $\bar{r}_a$ is defined implicitly by:

$$V(a, r_a) = r_a + \beta\theta E[V(a+1) | r_a, c, \omega] - c_a = 0 \quad (8)$$

with

$$\bar{r}_a = 0 \text{ iff}$$
$$V(a, r_a = 0) \geq 0,$$

where $1-\theta$ is the probability of obsolescence, $1-\beta$ is the real discount rate (set to .05), ω is a vector of parameters and $E[V(a+1) | .]$ is the expected value of the patent in a+1 conditional on current returns and the vector of parameters, ω, assuming optimal future decisions.

At the time of renewal for age a, patentees are assumed to know with certainty their returns from patent protection in age a. They are uncertain about the future evolution of their own returns. However, they know with certainty the probability distribution over all future events, conditional on their current returns. This conditional probability density function is modelled as:

$$r_a = \max\{ z, (1-\delta)r_{a-1}\}$$

where $r_0 = 0$, δ is depreciation and z is a draw from an exponential density:

$$q_a(z) = [\exp\{-((z/\sigma_a)+\gamma)\}] / \sigma_a.$$

$\gamma \geq 0$ and σ_a is modelled as $\phi^{a-1}\sigma$ with $\phi \leq 1$. The parameter γ determines the size of the density mass at $(1-\delta)r_{a-1}$ and thus the gestation period before a patent generates a strictly positive return. The functional dependence of r_a on the level of infringement is not explicit. However, in the absence of a favourable draw, returns depreciate at a constant annual rate of δ. One reason for this is an increase in the amount of infringement tolerated with age (see fn 10). Returns may also depreciate in age because new innovations may arise which can compete with the older one. "Inventing around" is an oft remarked phenomenon. Alternative forms of protection may be developed rendering patent protection less valuable. Obsolescence, which occurs with probability $1-\theta$, is defined as a permanent fall to a level of returns such that the patent will not be renewed, even in the midst of an infringement suit.

Introducing the possibility of litigation alters the decision rule. If a patentee will not prosecute N infringements then they will occur. His patent becomes valueless as $r_a(N) = \pi_a - \pi_a = 0$ and it will be allowed to lapse (Equilibrium #1). Thus renewal requires a willingness to prosecute N infringements. $\bar{r}_a$ is now the minimum level returns such that equation (4) is positive with $j = N$. Suppose that the expected period of litigation, p, is three years, as most suits in Germany are completed within that period (U.S. Department of Energy, 1982). Then, $\bar{r}_a$ in a model incorporating the fact that a patentee must be willing to prosecute N infringements[17] is the unique r_a which solves the equation:

$$V(a,\ r_a) =$$

$$w\theta^2 r_a + w\beta\theta^2 E[VL(a+1)\,|\,r_a] - c_a - \beta\theta c_{a+1} - (\beta\theta)^2 c_{a+2} - 2(1-w)[LF(N)] = 0 \qquad (9)$$

with

$$\bar{r}_a = 0 \text{ iff}$$

$$V(a,\ r_a = 0) \geq 0.$$

$E[VL(a+1)\,|\,.]$ denotes the expected value of future protection when two years rather than three remain before resolution of a suit[18]. Costs over the prospective litigation period must be paid while benefits are received only with probability w. Patents which drop because they are revoked after failing to

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[17] As discussed in section one, potential litigants may settle with the patentee agreeing to license his innovation. While this may affect the distribution of patent value, it does not have any effect on the estimation of that value using renewal data. The reason is that even if the returns generated by patent protection go to the licensee(s), it still remains the patentee's decision whether to renew. As long as the decision rule remains positive the patent is generating positive returns and a licensee will pay sufficient royalties, at least equal to the renewal fee, to encourage the patentee to renew. In effect, the same decision rule applies, with royalties replacing renewal costs, and is acted upon by the licensee.

[18] This renewal rule incorporates the assumptions that obsolescence arriving either in a+1 or a+2 will lead to non-renewal and that, barring obsolescence, an infringement will be prosecuted through the future 2 years. Although realized returns in a+1 and a+2 may be less than their expectation in a, the bulk of legal fees will have to be paid even if a suit is abandon in midstream so both c_a (and c_{a+1}) and legal fees are sunk costs. It seems plausible to assume that these sunk costs are large enough relative to the distance between the worst news about the value of continuing and the expectation at age a that the patentee would continue.

win a suit, rather than as a consequence of the specified renewal rule, are only .02% of the sample so this distinction can be ignored (see also fn. 16).

Equation (9) incorporates the fact, noted in section one, that, in Germany, attorneys' fees and court costs are borne by the losing side so lf = LF. Their levels are set by statute and are linked to the damage inflicted on the patentee - as measured by lost profits. The size of total legal fees depends on the value of the patent protection and the duration of the process. Since the value of protection increases in competition, this means that legal fees are increasing in j as assumed in section one. Data from several sources (e.g., Berkenfeld, 1967; Bohlig, 1987; Korner, 1984) indicates that the total legal fees increase approximately linearly in damages:

$$LF(j) = \alpha_0 + \alpha_1 [\pi^{(m)} - \pi^{(j)}]$$

with OLS estimates of $\hat{\alpha}_0 = 12{,}612$ and $\hat{\alpha}_1 = .20$ (1975 DM, estimated standard errors of 5001 and .02 respectively, $R^2 = .89$). Legal fees may be higher than the statutory level with, in a third-stage game in legal expenditures, the equilibrium level of fees chosen by each agent increasing in the benefit that he expects from winning. This could present a problem in specifying the legal costs that a patentee expects to incur if an infringement is prosecuted. The problem does not arise here, however, because all that is of importance in the decision rule is the equilibrium legal fees for those on the *margin* of renewing. It suffices to assume that $w(LF^p, LF^c)$ is sufficiently convex in LF^p that marginal patents do not bring forth expensive legal battles and that non-marginal patents do not become marginal.

Section 4: Estimation & Simulation Results

Because the model is analytically intractable, parameter estimates were obtained for each technology group using a weighted simulated minimum distance estimator (details in Lanjouw, 1993). Table 2 presents parameter estimates for the combustion engine and pharmaceutical technology groups. Estimates for pharmaceuticals use only data from cohorts 1967-1980 because the patent law was amended to allow the patenting of pharmaceutical product in addition to process innovations beginning in 1967. Estimates for pharmaceuticals from the earlier period, as well as for the textile and computer technology groups, are in Lanjouw (1993). The size and distribution of patent values implied by the parameter estimates for combustion engines and pharmaceuticals, calculated for cohort 1975, are found in the first column of Tables 3a and 3b, respectively, under the heading "Base". All value distributions are generated using 15,000 simulated patents.

Both groups of patents have value distributions which are very skewed. Engine patents have a relatively high probability of being valuable, with a mean of 50,488 DM[19], and patentees learn quickly about their prospects (γ is small). However, they are relatively difficult to defend and lose value quickly over time. The high obsolescence rate alone, at 12%, would leave only one-third of engine patents surviving through age 10. Pharmaceutical patents, on the other hand, are lower valued, with a mean of 32,357 DM, which is due to the high gestation lag and the large percentage of patents which never generate positive value (15.1%). This may seem surprising in light of the importance placed on patenting by surveyed

[19] All monetary values are in 1975 Deutchmarks which are approximately equal to 1988 U.S. dollars.

Table 2

Parameter Estimates[1]

	Engines		Pharmaceuticals	
w	.860	(.0049)	.99	(.0013)
ϕ	.598	(.0169)	.383	(.0199)
δ	.065	(.0013)	.063	(.0007)
θ	.880	(.0057)	.924	(.0025)
γ	.070	(.0083)	.598	(.0041)
σ	9534.4	(624.9)	8072.0	(559.3)
size of:				
sample	3958		1831	
simulation	7916		5493	
MSE[2]	.0049		.0011	

Notes:

1) Estimated standard errors are in parentheses.

2) MSE is calculated as the weighted sum of squared residuals divided by 356, the number of cohort/age cells in the data.

Table 3a
Simulated Value Distributions for Cohort 1975
Combustion Engines

Simulation	(Base)[1]	(2)	(3)	(4)	(5)	(6)	(7)
Variables - (Bold are changes from Base level)							
p - suit length	3 years	3 years	3 years	3 years	3 years	**1 year**	3 years
w - win probability	.86	**.99**	**.50**	.86	**.50**	.86	.86
LF - legal fees	Base	Base	Base	**2*Base**	**2*Base**	Base	Base
δ - depreciation	.065	.065	.065	.065	.065	.065	**.130**
Value Distributions[2]							
Mean	50,488 DM (4,573)	50,738 DM	41,013 DM	49,864 DM	28,351 DM	49,724 DM	38,863 DM
Percentile:							
50% (median)	33,639 DM (3,314)	34,065 DM	18,010 DM	32,923 DM	10,915 DM	32,887 DM	25,204 DM
75	68,188 (6,126)	68,639	57,918	67,687	23,954	67,761	52,705
99.9	415,396 (34,979)	415,319	410,778	415,396	399,289	415,396	289,437
Percentage with Value ≤ 0	8.8%	8.9%	9.6%	8.8%	9.8%	8.9%	8.8%

Notes: 1) 'Base' refers to parameter values estimated from the renewal model and other data. The other cases are selected changes.
2) Values, in 1975 DM, are net of annual renewal and administration fees, as well as application, examination and publication costs faced by the 1975 cohort (assuming examination at age 7 and publication at age 9). Calculations use 15000 simulation draws. Estimated standard errors for the value (vper) estimates calculated using a Taylor approximation: $vper(\hat{\omega}_N) \approx vper(\omega_0) + \Gamma(\omega_0)'(\hat{\omega}_N - \omega_0)$. Gradient matrices $\Gamma(\omega_0)$ are approximated with central finite difference gradients calculated at $\hat{\omega}_N$.

Table 3b
Simulated Value Distributions for Cohort 1975
Pharmaceuticals

Simulation	(Base)[1]	(2)	(3)	(4)	(5)	(6)	(7)
Variables - (Bold are changes from Base level)							
p - suit length	3 years	3 years	3 years	-	3 years	**1 year**	3 years
w - win probability	.99	**.75**	**.50**		**.50**	.99	.99
LF - legal fees	Base	Base	Base		**2*Base**	Base	Base
δ - depreciation	.063	.063	.063		.063	.063	**.126**
Value Distributions[2]							
Mean	32,357 DM (2,550)	30,136 DM	23,136 DM	-	15,761 DM	32,347 DM	23,480 DM
Percentile:							
50% (median)	13,840 DM (1,355)	10,115 DM	3,700 DM	-	3,657 DM	13,865 DM	9,513 DM
75	41,993 (3,261)	39,824	22,754	-	11,956	41,993	27,468
99.9	365,054 (26,158)	365,054	360,947	-	350,722	365,054	218,238
Percentage with Value ≤ 0	15.1%	21.5%	23.4%	-	23.4%	16.5%	15.3%

Notes: 1) 'Base' refers to parameter values estimated from the renewal model and other data. The other cases are selected changes.
2) Values, in 1975 DM, are net of annual renewal and administration fees, as well as application, examination and publication costs faced by the 1975 cohort (assuming examination at age 7 and publication at age 9). Calculations use 15000 simulation draws. Estimated standard errors for the value (vper) estimates calculated using a Taylor approximation: $vper(\hat{\omega}_N) \approx vper(\omega_0) + \Gamma(\omega_0)'(\hat{\omega}_N - \omega_0)$. Gradient matrices $\Gamma(\omega_0)$ are approximated with central finite difference gradients calculated at $\hat{\omega}_N$.

pharmaceutical firms. However, because pharmaceutical product innovations must undergo government health agency testing they cannot readily be kept secret so are patented early in the development process when less is known about whether they are worth protecting. Pharmaceutical patents are almost sure to be found valid (w=.99) if challenged.

Columns 2 and 3 of Tables 3a and 3b show the impact on patent value of changes in w, the (unconditional) probability that a patent would be found valid by the court if it were to be challenged. Bold print at the top of the tables indicates values which have been changed. At high levels of w, the impact of changes is fairly negligible. Going from the actual level of w for engine patents of .86 up to .99 increases mean value by 250 DM and, for pharmaceuticals, a move from .75 to .99 changes mean value by just 221 DM (elasticities of .11 and .27 respectively). However, moving in the other direction, the mean value per patent falls substantially if the probability that the patentee wins drops down to fifty percent. Pharmaceuticals lose almost a third and engines almost a half of their initial value, and the percentage of pharmaceutical patents which generate no returns jumps to 23.4%.

The fourth and fifth columns of Tables 3a and 3b indicate the impact of increases in legal fees, LF, on the value of patent protection - *before* netting out the total legal fees actually paid by patentees. In other words, these costs in terms of patent value are over and above the direct expense of higher legal fees. Not surprisingly, the impact of higher fees on the value received by patentees depends largely on whether or not they expect to win litigation suits. Thus, the mean value of an engine patent falls 624 DM if legal fees are doubled at the actual level of w. However, if the likelihood of winning is only .5, then a doubling of legal fees leads to an additional 12,662 DM fall in value, from 41,013 to 28,351 DM (column 5). For pharmaceuticals, if w = .5, then a doubling of legal fees causes the mean value to drop from 23,136 to 15,761 DM for a fall of 7,375 DM.

Moving from the current, "English", cost allocation rule to the American rule, where each agent pays his own legal expenses, is equivalent in this model to an increase in legal fees, with the impact depending on the probability that a patent will be found valid. For engine patents such a change in procedure would lead to a 20% fall in mean value (not displayed) - again *before* adjusting for the increase in total legal expenses actually paid by patentees. For pharmaceutical patents, the effect would be a dramatic loss of over half of mean value. The reason is that, with an almost certain expectation of winning, pharmaceutical patentees derive particular benefit from a loser pays allocation rule. Under this rule, pharmaceutical patentees prosecuting the infringement of a marginal patents (with lf=LF) can expect to pay no legal fees at all. As a result, a change in the cost allocation rules would hit them hard.

Column 6 demonstrates the ambiguous nature of changes in the length of litigation. For both types of patents, shortening the period of litigation from three years to one year actually decreases the value of patent protection by a small amount. Here the loss of the infringement dissuading impact of litigation over a longer litigation period more than offsets the positive impact of not needing to renew through a litigation period in order to enjoy returns.

The final column displays the effect on patent value of tolerating more infringement. This enters the model, not totally comfortably, as a change in the annual rate of depreciation in returns, δ. Although the reason that a patentee would be willing to tolerate more infringement is linked to changes in the other parameters which would cause value to fall yet further, the simulation looks at the effect of changes in δ in isolation. The effect here is marked - a doubling of δ, to about 13% annually, leads to a fall in value of 11,625 DM and 8,877 DM in the value of engine and pharmaceutical patents, or 23% and 36% falls, respectively. And unlike the other changes examined here, an increase in the tolerance of infringement has a large impact on higher valued patents. (Note the drop in value of the 99.9th percentile patent.)

To put these changes in patent value in perspective it should be emphasized that these impacts are felt by all patents, whether litigated or not, so that even fairly small changes can represent substantial sums in the aggregate. For example, there were 21,515 patents granted in Germany in 1975 including all technology areas. The simulation results show that a drop in w to .5 and a doubling of statutory legal fees leads to a fall in the mean value per patent by about 20,000 DM. This would represent a loss of about 400 million DM *per year* in the value generated by the patent system *even if no patents were ever actually prosecuted.*

Section 5: Final Comments

The patent value estimates and simulations indicate that those characteristics of the litigation process which have been highlighted in theoretical models as determining the distribution of benefits between agents are, in fact, empirically important. In particular, because all patentees must cope with the possibility of infringement, the aggregate impact of changes in the costs of litigation, the rules determining their allocation, or the tenor of the courts, can be substantial. And this is on top of any changes in the sums paid out in legal fees.

The results presented here were for the purposes of illustration and to get a rough gauge on the importance of certain policy variables in determining the effectiveness of patent protection. In principle, however, this type of analysis could be done to evaluate the impact of proposed policy reforms. More and more countries are computerizing their patent offices and most countries make information on patenting and renewals public (with an access cost). This opens up the possibility of estimating more finely differentiated models, for instance with respect to technologies, firm size, type of inventor, etc. Importantly, most countries also currently charge increasing annual or semi-annual renewal fees - a crucial requirement in estimating a renewal model. So the data is there. Such an analysis would also require the formulation of renewal models which are sensitive to the legal environment of the country under consideration. Here further developments in our understanding of the litigation bargaining game will be useful, in pointing towards more appropriate ways to specify the payoffs faced by patentees when making a decision whether to renew. Given our current state of ignorance concerning the empirical benefits of patent systems, research in this direction could be a way forward.

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Appendix I

Characteristics of the Data

Total Sample Size	20,235 patents
Percentage of Total Patents Granted (1953-1980)	3.5 %
Country Groups - by nationality of the owner	Western Europe
United States	
	Japan
Technology Groups	Computers Textiles Engines Pharmaceuticals
Range of Years	
Western Europe and United States	1953-1988
Japan	1963-1988
Range of Cohorts	
Western Europe and United States	1953-1980
Japan	1963-1988
First Annual Fee due for age	3
Maximum Age	
1953-1976	18
1977-	20

Mean Sample Size[1]

	Western Europe	United States	Japan
Computers	102	86	67
Textiles	102	38*	34*
Engines	102	48*	40*
Pharmaceuticals	80	37*	40*

Note:
1) An asterisk indicates that the technology/country/cohort cell samples are equivalent to the entire population of granted patents for every cohort covered.

Appendix II

Patenting Procedure, Fees and Legal Rights

Stage	Fees[20]	Legal Rights
Old Regime - until October, 1968		
Application examination follows without request	Application fee 100DM	No rights to an injunction and compensation at the discretion of the patent office
Decision to Grant	Publication fee 100DM plus cumulated annual fees	Rights to claim an injunction and to full compensation.
3 month opposition period for opposition challenges		
Granting	Annual renewal fees 100DM age 3 to 2900DM age 20	
Current Regime		
Application Preliminary examination follows without request	Application fee 75DM	
First publication	Annual renewal fees (continuing) 75DM age 3 to 2200DM age 20	No rights to an injunction and compensation at the discretion of the patent office
Request for full examination (by age 7)	Examination fee 325DM	
Decision to grant	Publication fee 100DM	Rights to an injunction and to full compensation
3 month opposition period for opposition challenges		
Granting	Annual renewal fees	

[20]Figures are approximate levels of the indicated fee in 1975 Deutchmarks (=.95 1988 US dollars).