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First Mover Advantages and Optimal Patent Protection

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First Mover Advantages and Optimal Patent Protection

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Patents or similar exclusive privileges have been awarded for many centuries to encourage invention and innovation. For early history, see Machlup (1958) and Kaufer (1988). Absent some barrier to competitive imitation such as patent rights, the underlying theory holds, competition might materialize so rapidly that the inventor-innovator is unable to recoup the investment made in effecting its innovation. In a pioneering theoretical contribution, William Nordhaus (1969) derived onditions showing the social welfare-maximizing life of patent gants. Virtually ignored in both the Nordhaus theory of patent protection and rationales underlying patent laws has been another thrust of the literature. Empirical studies have shown repeatedly that on average, but with notable exceptions, patent protection is a relatively unimportant requisite for business firms' investment in research, development, and innovation. Much more important in the average case are diverse non-patent advantages from being the first to commercialize a new product or process. Eliciting estimates from 25 British companies, Taylor and Silberston (1973) found that having all their patents subject to compulsory licensing at "reasonable" royalties would on average reduce the firms' research and development expenditures by only 8 percent. Surveying 100 U.S. companies, Edwin Mansfield (1986) reported that the weighted average number of inventions actually introduced by respondents that would not have been developed had *no* patent protection been available was roughly 14 percent.[1] See also Scherer et al. (1959, Chapter 12), Levin et al. (1987), Cohen et al. (2004), and Graham et al. (2009). This paper seeks to advance the theory of patent protection by quantifying approximations to the "first mover advantages" that sustain investment in invention and innovation without formal patent protection.

The Elementary Theory

The elementary logic underlying the grant of temporary but exclusive patent rights on *product inventions* is illustrated by Figure 1. The full market demand for a potential invention is D_1. The marginal cost of production (excluding front-end R&D costs) is assumed constant at C-MC. Marketing its product under monopoly conditions, the innovator equalizes marginal revenue (not shown) with marginal cost and sets price OA, earning a net profit before deduction of sunk R&D costs (more accurately called a quasi-rent) of AC per unit and a total quasi-rent given by rectangle ABEC. If this continues for a sufficiently long period, i.e., with patent protection, the discounted present value of the quasi-rents will cover and (the innovator hopes) exceed the original R&D investment, and the investment will prove to be profitable. But if others can readily imitate the innovator's product, demand will shift to D_2 in period 2 and D_3 in period 3 (arrows), etc., with quasi-rents shrinking to abeC in period 2 and a'b'e'C in period 3, etc. With such rapid entry, the discounted present value of quasi-rents could be less than the original R&D investment. If the would-be innovator foresees this, no R&D investment will be forthcoming. Again, patents inhibit imitative entry and hence encourage investment in research, development, and innovation.

If however the innovator enjoys non-patent first mover advantages,[2] competitive imitation may be delayed even in the total absence of patent rights. These are of several forms.[3]

For one, it takes time for would-be imitators to recognize the advantages of an innovation and quite possibly even more time to carry out their own developmental work needed to imitate successfully. In some cases, when the imitator can benefit from knowledge spillovers, that expense may be much less than the first mover's expense, but in other cases (such as developing new airliners) the imitator may have to spend as much and take as much time as the first mover did.[4]

Second, the innovator may be able to keep important details of its underlying technology secret, inhibiting imitation. This is more likely for process (i.e., internal cost-saving) innovations -- those analyzed by Nordhaus -- than for product imitations, but even for new products, non-obvious production tricks may have to be discovered and mastered.

Third, and very importantly, the first to market a new product often engrains in the minds of consumers an "image" of superiority -- that is, a product differentiation advantage -- allowing it to retain a substantial market share while charging prices substantially higher than those realizable by latecomers.[5]

Fourth, in industries such as aircraft, semiconductors, and solar converters, unit production costs fall with additional production and hence "learning by doing." The first mover begins progressing down its learning curve sooner than others and may therefore enjoy a substantial cost advantage over latecomers.[6]

Finally, economies of scale in production or marketing may require that a market be tightly oligopolistic, with only a few sellers contending for position, among other things through product innovation and differentiation. High R&D costs required for innovation may reinforce this structural condition. And with well-established marketing channels, the first mover can expect to retain preferential access to customers accustomed to patronizing particular sales representatives and/or retailers unless it falls significantly behind the product quality of rivals. In this case, a firm may be confident that when it innovates, it can at least retain a substantial share of the market after rivals imitate. However, it must also fear that if actual or potential rivals are the first innovative movers, they will capture, perhaps permanently, its own market share. In this case, characterizable as Schumpeterian "creative destruction" (Schumpeter 1942, Chapter 7), companies are impelled to invest in innovation by the threat of competition, whether or not patent protection can be anticipated.[7]

The Economic Theory of Optimal Patent Duration

The leading theory on how the duration of patent grants affects investment in research and development. and how patent lives can in turn be adapted to maximize a broader conception of social welfare, was originated by William Nordhaus (1969).[8] Nordhaus focuses on what is best called *process innovation*, that is, advances in technology reducing the cost of production (the MC line in Figure 1) and thereby increasing the size of the innovator's profit (rectangle ABEC in Figure 1). He calls inventions that merely reduce marginal cost without inducing an output expansion *run of the mill inventions*; those that also increase output are called *drastic inventions*. Nordhaus devotes no atttention to possible pre-patent-expiration competition among multiple firms to achieve cost reductions through invention. His assumption, to which counter-arguments will be recognized later, is analogous to what Edmund Kitch (1977) has called the *prospect theory of innovation*.

Nordhaus argues that the amount of cost reduction achieved is systematically and positively related through an *invention possibility function* to the amount of research and development conducted: the more R&D, the higher the percentage cost reduction. Given its invention possibility function, and given a payoff time structure determined by the government's patent life policy choice, that is, the period over which the inventor can exploit its invention without competition, firms are assumed to choose the amount of cost-reducing R&D that maximizes the discounted present value of their invention-dependent profits. Nordhaus shows that the longer the patent's life is, the more cost-reducing R&D will be induced, all else equal. In determining how long patents should have their exclusionary power, government policy-makers in turn are assumed by Nordhaus to choose a patent life that maximizes the invention's contribution to *social welfare*, including not only the profits achieved through cost reductions by the inventing firm but also increases in consumers' surplus realized during the life of the patent (only in drastic invention cases) plus those like triangle BGE in Figure 1 realized when patent protection ends and competition forces prices down to the new level of marginal cost.

Nordhaus' contribution was a pioneering clarification of relationships that had previously been visualized at best qualitatively and imprecisely. Compare e.g. Machlup (1958, pp. 66-73). It had, however, five significant limitations. First, it focused on cost-saving or process innovations which, available statistics showed, amounted to only about a fourth of all research and development expenditures incurred by American industries. The remaining three-fourths comprised R&D directed toward creating or improving *products* that would eventually be sold to consumers or other companies. To be sure, what for the inventing firm is a product (e.g., a computer-controlled lathe or a turbojet engine) may for the purchasing firm be a cost-reducing process, but the market dynamics, we shall see, are different.[9] Second, it assumed implicitly that patents were the only barrier to competitive imitation of inventions, ignoring the first mover advantages that were at the time beginning to be recognized as barriers to rapid imitation. Third, as is customary in mathematical economics, it focused on achieving optimal first-order conditions, with marginal private or social benefits being equalized to corresponding marginal costs. In so doing, it deemphasized the possibility that many alternative outcomes might be profitable for inventing firms and improve social welfare, even though they do not achieve a maximum maximorum. Fourth, by assuming a single inventor investing in new technology without recognizable technological rivals, it in effect accepted the prospect theory of invention and rejected the alternative and empirically plausible rent-seeking theory, with profoundly different implications for patent policy.[10] And fifth, it ignored the fact that invention is a cumulative process, and in particular, that how patent rights affect the use of an invention made at time t can significantly affect the further progress of technology at time t+n.[11]

This paper seeks to fill lacunae left by the first three of these Nordhaus assumptions. The fourth and fifth, requiring much richer and more diverse empirical foundations, are commended to others.

Theoretical Foundations

Our focus here is on product innovations. The most prominent attribute of product innovations is that they make products more attractive to consumers, shifting demand functions upward and outward, perhaps making it profitable to produce and market a product that, without the invention, would not have been commercially viable. Demand functions reveal the quantity of a given product that will be demanded at diverse alternative prices, *assuming*, as is conventional in partial equilibrium analyses, that the prices of other substitute or complementary products have adjusted to the availability of the product in question. Given this, we emphasize here the consequences for economic welfare within the immediate innovation-impacted product market, ignoring spillovers in possibly related product markets.

We assume that successful research and development shifts the relevant product's demand function upward so that it lies above marginal cost (whose level may also be affected by the invention project) and hence that profitable commercialization is possible. The model is illustrated at its simplest in Figure 2. We assume that marginal cost is constant per unit produced at level C-MC. Without invention, the relevant demand function is D_0, which lies at all points but the zero quantity value below marginal cost and hence leaves no possibility of profitable production. Invention shifts the demand function upward by CF (arrow), with the new demand function D_1 allowing profitable production. Assuming that the innovator has monopoly power in pricing its product, albeit taking into account the prices of potential substitute products, the innovator derives its marginal revenue function MR_1, chooses to market an output of OQ_M at price OA, and realizes a profit (strictly defined, quasi-rent) above its variable costs given by the rectangle ABEC. This profit is counted as a benefit from a broader society-wide perspective. But in addition, and in contrast to the Nordhaus run-of-the-mill case, sales of the new product yield to buyers a consumers' surplus measured by the dot-shaded triangle CS. The emergence of competition can have either or both of two effects. For one, imitators capture some of the innovator's sales, squeezing its demand function to the left and perhaps (depending upon demand elasticities) forcing the innovator to reset its price, leading to reduced profits. The assumption accepted here is that the innovator continues to have some monopoly power (i.e., under conditions of differentiated product oligopoly), so that it still faces a downward-sloping (though changed) marginal revenue function and can at least for a while after entry set a price above its marginal cost. Imitative rivals too are assumed to be differentiated product oligopolists tacitly cooperating, at least within limits, to set prices that maximize joint oligopoly profits. Second, the alternative assumption, implicitly accepted in the Nordhaus model, is that when patents or first mover advantages are lost, unrestrained price competition breaks out immediately and prices are driven all the way down to marginal cost MC. In this case, what was previously potential but lost consumers' surplus measured by triangle BGE (labelled DWL) in Figure 2 is transformed into actual consumers' surplus -- a measurable social gain. We will take this result as a benchmark in our analysis of socially optimal outcomes. At the same time, firms' quasi-rents are transformed into consumers' surplus on what is conventionally assumed to be a 1:1 basis.

In our model, the vigor of the innovator's product R&D effort determines (without stochastic variation, important in the real world) how far the innovator's demand function is thrust upward. What is needed then is an analogue to Nordhaus' invention possibility function. We focus on the resultant height of the demand function, leaving for exogenous simulations the demand function's slope and hence the breadth of the market. An intuitive rationale for this assumption is that product innovation affects consumers' willingness to pay, which is measured by a demand function's vertical dimension. The horizontal dimension is more closely related to the scope of the relevant market, which might arguably be said to be more exogenous than endogenous. Specifically, we assume that the demand function is shifted through product innovation from an intercept at point C in Figure 2, leaving sales intrinsically unprofitable, to an endogenous intercept point F, where F can vary from identity with C (if no R&D is performed) to five times OC (S = 5). Initial experiments assumed an exponential shift function $S = RD^k$, with k < 1 to imply diminishing marginal returns. This approximates the approach taken by Nordhaus with his invention possibility function. Those experiments, however, yielded implausibly high shift values and hence market sizes. Therefore, a quadratic approximation

(1) $S = 1 + .2784\ RD - .0049\ (RD)^2$

was used, with R&D outlays measured in two digits only, e.g., in thousands of dollars (or millions, for larger projects).[12] It is illustrated in Figure 3. Its maximum value is realized at R&D expenditures of roughly 28 (000), with S = 4.95 at that value.

Needless to say, even with a given demand intercept shift, markets can be of widely varying sizes. This arguably exogenous variability was taken into account by assuming demand functions to be linear in price, with equation P = 10S -(slope) Q and slopes dP/dQ varying from -.03 to -.07. Two such cases are illustrated in Figure 4. With linear demand and a given vertical intercept, the demand curves are iso-elastic, i.e., with the same price elasticity of demand for any given vertical level. This allows an assumption, simplifying calculation in computer simulations, that profit-maximizing prices are identical ($35 per unit in Figure 4) for linear demand functions with the same vertical intercept but varying slopes. The numerical assumptions to be sure determine the outcomes, and exploration with alternative parameter sets is encouraged. But the assumptions permit a wide range of circumstances to be investigated.

The Effect of Differing Patent Lives Revisited

For broad insight into how outcomes vary with alternative market parameters and patent lives, payoff matrices were calculated for three base cases: with demand slopes of -0.3, -0.5, and -0.7. In a preliminary stage, shift variables were determined as a function of R&D outlays varying by units from 1 to 35. For each R&D outlay and R&D-determined shift variable, profit-maximizing prices, quantities, and (given constant marginal cost of $10 per unit) price-cost margins were computed. The product of price-cost margins times profit-maximizing quantities yielded the annual quasi-rent following from any given R&D expenditure, assumed for simplicity to be constant over time with no exogenous growth or decline (an assumption varied later). For each possible patent life (by twos) from 4 years to infinity, the discounted present value of quasi-rents realized by the innovator was calculated. Patent lives were assumed to begin at year 0. Quasi-rents were assumed to begin flowing in at year 1, i.e., after a year's R&D and production setup. For each patent life, a discount factor associated with the years of sale under patent protection was applied to the annual quasi-rent estimate. The assumed discount rate was 12 percent per annum.[13] Following conventional assumptions (but inconsistent with the theory and evidence on first mover advantages to be addressed later), the calculations assumed that when patents expire, quasi-rents fall precipitously to zero and remain there subsequently. From the discounted present values so calculated, front-end research and development costs (multiplied from column (1) by 1000) were subtracted to yield the discounted present value from a year 0 vantage point of profits net of R&D outlays -- i.e., an indication of whether any given R&D expenditure was in the net present value-enhancing.

Tables 1 through 3 provide private payoff matrices computed under these assumptions. The first column (labelled "rand") contains alternative R&D expenditures (in thousands of dollars). The second column reports the annual quasi-rent (labelled "profit") resulting from each R&D expenditure, given the shift variable's impact on the demand curve's intercept value and the resulting profit-maximizing solution, and assuming marginal cost to be $10 per unit. The quasi-rent is assumed constant per year from the time of product introduction to the time of patent expiration, after which it plunges to zero. The remaining columns report discounted present profit values (with front-end R&D costs deducted) for various patent lives. In column (3), for example, the heading "dpvto4" indicates that the net discounted present values continuing only to a patent expiration at 4 years.

In Tables 1 through 3, the present value-maximizing R&D expenditure for any given patent life is indicated by a circle around the maximum DPV column value. Ranges of negative discounted present value are delineated by square brackets. Considering the latter first, we see that with all assumed market slope values, there are ranges of negative present values, the more so, the shorter the patent life. For the smallest assumed market (Table 3; slope= -.07), R&D outlays are uniformly value-reducing, i.e., unprofitable, through patent lives of eight years or less. For at least such "small-market" cases, substantial patent lives are needed to induce R&D investment. The circled values reveal that for all parameter values, DPV-maximizing R&D outlays increase moderately with longer patent lives, but then stabilize -- near a 12-year life for the largest simulated market and near 18 years for the smallest market. An indication of the underlying lucrativeness implied by the parameters is found by calculating the internal rate of return on the profit-maximizing R&D investment for a patent life of 16 years. With the largest market (slope = -.03), the internal rate of return at the DPV-maximizing invesment with patent life of 16 years is approximately 49 percent; for the intermediate case (slope = -.05), 27 percent; and for the smallest market (slope = -.07), 21.5 percent.[14] Obviously, for less lucrative cases, the internal rate of return is at least 12 percent over all payoff matrix cells with positive net present values.

Two main insights emerge at this preliminary stage. First, over a wide range of parameter values and patent lives, investment in research and development is profitable, even if not present value-maximizing. Second, R&D markets may fail totally -- i.e., no investment in R&D will be made -- if short patent lives are coupled with relatively small market spaces.

Constrained Social Welfare Maximization a la Nordhaus

What has been presented thus far is an analysis of how profitable R&D investments are from the perspective of private enterprises for various market parameters and patent lives. Now we ask, how do these results relate to the interests of the broader society in which firms operate? In other words, what constellation of parameters and choices maximizes social welfare? Social welfare here is measured by the discounted sum of surpluses from innovation realized by both the enterprises that provide the innovations and the consumers who utilize them. To explore this, we need a new kind of payoff matrix. Tables 1 through 3 focused on *private* payoffs only -- that is, the discounted present value of quasi-rent rectangles like ABEC in Figure 2 less the (undiscounted) value of R&D expenditures. To compute a social payoff matrix, we need a broader conception. Specifically, during the life of the patent, the gain is measured by the rectangle ABEC *plus* the triangle of consumers' surplus FBA in Figure 2. But after patents expire, values do not plunge to zero as assumed in Tables 1 through 3. Rather, the profit rectangle ABEC is converted into consumers' surplus as price competition drives prices down to marginal cost; triangle FBA continues to be realized by consumers (in industrial product cases, users) of the product; and in addition, triangle BGE (labelled DWL) now becomes consumers' surplus as lower prices induce increased consumption by previously under-served consumers. Given the linearity assumptions underlying our demand and cost analysis, the pre-patent-expiration surplus is exactly 1.5 times the innovator's quasi-rent, while the post-expiration surplus is 2.0 times the original innovator's quasi-rent. Each such surplus must, of course, be discounted to present value in the final reckoning, here by assumption at a constant 12 percent discount rate.

Tables 4-6 display these surpluses for three alternative demand slope cases. The bracketed items show that except for very low R&D outlays, social surpluses are uniformly positive across all patent lives. The rectangles around individual payoffs denote welfare-maximizing levels of R&D for each assumed patent life. One should not be surprised to see that they entail almost uniform R&D investments and that the discounted payoffs vary only moderately over diverse patent lengths. For the next insight, we ask again, what outcomes are discounted profit-maximizing for the *firms* that provide innovations? For each given patent life, the (social) payoff that maximizes the firm's discounted profits is circled, as in Tables 1 through 3. Here as before, we see that the profit-maximizing R&D outlays increase at least initially with longer patent lives. But now we advance to Nordhaus' ultimate test. He asks, *given* that firms respond in a profit-maximizing way to alternative government-imposed patent lives, what firm response maximizes social welfare? The mathematics for this constrained maximization problems are sufficiently complex that insights do not readily emerge without numerical analysis. To infer the solution, we begin with the circled social payoffs that correspond to profit-maximizing choices by firms and then read across the set of circled social payoffs to determine which firm optimum maximizes *social* value. For example, in Table 5, for the medium-size market, we see that social payoffs increase from 65,360 to 67,322 with a patent life extension from 6 to 8 years and then *decline* for longer patent lives! Thus, an eight-year patent life (marked by an asterisk at the circled payoff entry) maximizes social welfare in the Nordhaus sense for the assumed parameters. Comparing Tables 4-6, we find that welfare-maximizing patent lives a la Nordhaus increase systematically from six to eight to 14 years, the smaller the relevant market is. This is an important insight. We see also that the choices maximizing discounted private profits involve systematically lower R&D expenditures than those that maximize social welfare. This is the natural result of that fact that many of the benefits driving social welfare maximization are external to private company decision-makers.

How large is the difference between socially optimal and private profit-maximizing R&D outlays over varying market parameters? In Table 5, we see that private R&D expenditures at the social optimum are 22(000), or about 84.6 percent of the socially optimal R&D expenditure. Repeating this analysis for the alternative demand parameters assumed, we obtain the following percentages:

	Demand Slope	Private/Social R&D Percent
Smallest market	-0.07	88.0 %
Intermediate market	-0.05	84.6 %
Largest market	-0.03	88.9 %

These are for the R&D expenditure levels that maximize social welfare. A broader analysis is provided by Figure 5, which arrays private/social divergences over a range of patent lives from 4 to 20 years. With the largest market, i.e., demand slope = -0.03, the divergence is smallest. With smaller markets, the divergence rises, plummeting to zero -- that is, a complete R&D market failure -- for patent lives less than 6 years in the medium-sized market case and patent lives less than 10 years in the smallest market. The implication is that the patent system makes its strongest incremental contribution to sustaining innovation in relatively small markets -- those in which, it should be noted, the social gains from innovation are smallest.

Alternative First Mover Assumptions

We advance now to territory that remains unexplored. This paper takes off from the recognition that barriers other than patents impede rapid imitation of a first mover's commercialized invention. Not all of the first mover advantages articulated earlier can be treated analytically. We proceed by incorporating the following simplified assumptions.

To model recognition lags, secrecy, and the imitator's need to perform its own R&D, we test the effect of simple time lags ranging from two to four years following the innovator's product innovation date at year 1.

A second key assumption is that the innovator's loss of market share to imitators is not instantaneous, but because of the first mover's image and cost advantages, imitators' market penetration rates are constrained. We assume concretely that the innovator's market share decays exponentially at alternative rates of 10, 15, and 20 percent per year.

That rivals do not gain market position instantaneously with new products suggests a symmetric assumption, contrary to the naive assumptions underlying Tables 1 through 6, that first movers must also build up their patronage at an incremental rate rather than capturing the whole market in the first year after a new product's debut. Specifically, we assume for simplicity here that the first mover penetrates the relevant product market at the rate of 50 percent per annum, or more precisely, that the share of the market it does not capture, ignoring imitation, decays at the rate of e^{-pt}, where p is the 0.5 penetration coefficient and t is a running year variable with value of zero at the time of innovation.[15] Needless to say, this assumption disfavoring early year quasi-rents reduces the discounted present values of innovator profits by much more than those assumed in the analyses of Tables 1 through 3. Not surprisingly, trial analyses of first mover effects without this innovator penetration assumption (not reported here) yielded appreciably higher discounted innovator profits than those presented here. Analyses with the 0.5 penetration rate are emphasized here because of their greater believed realism.

Figure 6 summarizes the innovator market share implications of the alternative penetration and imitator erosion scenarios, assuming that imitation begins in year 3, the quickest of the three imitation lag scenarios. With no imitation, the innovator starting at the beginning of year 2 achieves 95 percent of its market potential after six years, i.e., in year 7. But erosion by imitators causes an increasing loss of innovator market position and leads within a decade to substantially atrophied innovator shares -- as low as three to eight percent within 20 years.

That patent-free imitation might within the life span of conventional patents (assumed absent in our first mover model) drive innovator market shares to very low values clashes with the notion that the first mover gains significant "image" advantages, permitting it to maintain premium prices indefinitely and to combine that product differentiation advantage with pricing strategies that impede competitive entry. This consideration underlies an additional set of simulations in which the first mover's retained market share is constrained not to fall below 30 percent. The 30 percent assumption was drawn from Bond and Lean (1977) and pioneering work done in the 1970s using rich data collected by the Strategic Planning Institute.

Tables 7 through 12 present the results of simulations embodying our first mover assumptions -- Tables 7 though 9 for varying demand slope assumptions, assuming no constraint on the market share rivals can capture, and Tables 10 through 12 with a 30 percent floor on the first mover's eventual market share. As with Tables 1 through 6, the first column of each table contains alternative R&D outlays "rand" (in thousands) and the second "profit" the resulting (constant) annual quasi-rent potential tapped by the innovator and its imitators.[16] The remaining column headings disclose years of delay between the innovator's product roll-out and the first year of imitation (e.g., in column (3), with imitation after two years, i.e., in the third year analyzed); and "ero..." reports the rate at which imitators erode the innovator's profit, e.g., in column (3), at a 10 percent annual rate. The numbers in those columns are discounted present values of innovator quasi-rents less front-end R&D costs. For each column, the maximum discounted present value entry is circled, and negative discounted present values are separated by square brackets.

With the largest of the three market size assumptions (Table 7; demand slope = -.03), all nine scenarios yield a substantial positive discounted present quasi-rent value. With the medium-size market (Table 8), this is also true, although for the shortest imitation lag (two years) and the fastest rate of penetration (.20), there is only one barely profitable R&D investment level yielding a tiny DPV of +1. Comparing the square brackets, we see that the range of unprofitable investment alternatives is smaller, the longer the imitation lag and the lower the imitator erosion rate. With the smallest of the assumed markets (Table 9), however, there is catastrophic R&D failure. No investment level is profitable with imitation beginning two years after innovation. With a three-year imitation lag, positive profits are found only with the lowest erosion rate of .10. A four-year imitation lag (i.e., under the heading "Imitation Year 5") is more successful, with positive profitability for .10 and .15 erosion rates even if not for the more rapid erosion at 20 percent. Clearly, market size, imitation lags, and erosion rates are critical to the success of first mover advantages in providing incentives alternative to the patent system.

Constraining the innovator's market share loss to imitators so that a minimum share of 30 percent is retained, consistent with the early pharmaceutical rivalry histories studied by Bond and Lean (1977), improves the incentive picture. This is shown in Tables 10 through 12. As in the unconstrained case of Table 7, all scenarios yield some positive discounted profit-maximizing equilibrium for the largest market (Table 10). In the analogue to the unconstrained Table 8 case, positive equilibria exist also across all parameter values in the medium-size market (Table 11), though with more generous margins above the zero-DPV R&D failure point. In the smallest market (Table 12), R&D failure occurs again with higher erosion rates and imitation lags of two and three years, but with a four-year imitation lag, positive equilibria are found for all three erosion rates. The effect of first mover advantages in allowing innovators to defend at least a minority share of their new markets through economies of scale, cost advantages, and the possibility of sustaining profitable price differentials contributes significantly to incentives for R&D investment.

Tables 13 and 14 summarize the impact of diverse first mover scenarios on the strength of R&D investment incentives. As a benchmark, we take the level of R&D investment that would maximize social welfare with 16-year patent lives, drawn from Tables 4, 5, and 6.

Table 13 focuses on 27 simulations, assuming no floor to the innovator's market share following imitation. Averaging across the nine outcomes for varying imitation lags and erosion rates, we find for the largest market that profit-maximizing R&D outlays with imitation are 90.1 percent of the social welfare-maximizing levels. For the medium-size market, they average 81.6 percent of the social optima. Averages conceal more than they reveal in the smallest of the three assumed markets. Six out of nine cases are failures, with no profitable level of R&D expenditure. For the remaining three cases, the average is 78.7 percent. Turning to Table 14, we see that a floor under the innovator's eventual market share improves outcomes slightly. For the largest market, the capped vs. social average is 91.6 percent; for the medium-size market, 85.1 percent. For the smallest of the three markets, there is also an improvement: five of the nine cases yield positive levels of R&D investment.

These averages reveal that first mover advantages fall short of yielding socially optimal levels of R&D investment. But the patent system is also an imperfect allocator. From Tables 4 through 6, we calculated that Nordhaus-optimal R&D investment levels are 88.9 percent of the social optimum in the largest of the three markets, 84.6 percent in the medium-size market, and 88.0 percent in the smallest market.[17] Over those three, the simple average is 87.2 percent. Ignoring the cases of R&D failure, the average across the three markets with first mover advantages substituting for patent protection and letting innovator market shares fall at most to 30 percent is 86.3 percent -- only one percent below the Nordhaus optima averages. We conclude at least tentatively, subject to confirmation with richer simulations, that incentive systems focused on first mover advantages do a quite tolerable job of allocating resources to research and development. Their principal weakness, at least by the assumptions underlying our analysis, is proneness to zero-R&D corner solutions, especially in small markets.

The incidence of innovation failure also suggests an interesting though less general insight. Out of the 54 simulations summarized by Tables 13 and 14, ten, or 18.5 percent, represent failures to invest at all in R&D because expected quasi-rents fall short of R&D costs over all alternative levels of R&D investment. This is not greatly at odds with Edwin Mansfield's (1986) finding, from hypothetical questions posed to 100 U.S. corporations, that in the total absence of patent protection, 14 percent of the innovations they actually commercialized would not have been made. In other words, first mover advantages alone would have provided insufficient incentive.

Discussion

The analysis presented here is at best a too long-delayed first step. Much more remains to be done. First mover advantages could be modelled in different and richer ways. And the basic model itself is highly simplified, focusing on a single clearly-designated inventor obtaining (or not obtaining) one patent, not hundreds or thousands, protecting an invention targeted toward a specific node in product characteristics space. A more complex and more realistic analysis could deal with innovators and presumed later movers with differentiated products, each occupying its own niche in product characteristics space.[18] The underlying mathematics would be more complex but in principle tractable, at least for a subset of economists excluding the author. Also needed is additional empirical work illuminating the various types of first mover advantages, their impact on the retention of market share and profits, and the rates at which both innovators and imitators penetrate their target markets. Levin *et al*. (1987), Cohen *et al*. (2004), and Graham *et al*. (2009) provide a start, but much more needs to be learned empirically.

A more important simplification here has been the assumption, following Nordhaus, that there is a single identifiable first mover whose invention, absent patent protection, is then imitated by one or more other firms. This scenario corresponds most closely to what Edward Kitch (1977) has called "the prospect theory of invention." In an alternative conception, changes in the forces of supply (i.e., the state of scientific and technological knowledge) and demand endogenously spur numerous firms to invest rivalrously in R&D in the hope of winning a preferred market position, perhaps protected by patents. The rivals' efforts may in the limiting case be so vigorous that the sum of R&D costs incurred by all participants equals or even exceeds the realizable pool of quasi-rents, so that in hindsight R&D investment approximates a zero-profit equilibrium. For a pioneering statement of this "rent-seeking" model, see Barzel (1968).[19] Re-analysis by McFetridge and Rafiquzzaman (1986, Table 1) revealed that when the implicit prospect assumption is replaced by a rent-seeking model, with R&D costs escalating to exhaust quasi-rents, the welfare-maximizing patent life over 32 sets of parameter values averaged 21.2 years following the strict Nordhaus assumptions and 0.8 years when rents are totally dissipated by competing inventors. Somewhere between these unrealistic extremes is the messier world of oligopoly, where investment in research and development is less a quest for protected niches in profitable product space than a Schumpeterian struggle for survival against market inroads by product-differentiating rivals.

Perhaps more serious a simplification is our neglect of uncertainty in assuming that the R&D investments supported are those with positive discounted present values. There is abundant research showing that R&D payoff projections are not only uncertain, but that the distribution of profit outcomes is quite skew, with a long thin tail containing the projects that ultimately yield the lion's share of returns.[20] Skewness in turn makes it difficult to use classical hedge strategies, that is, by supporting a portfolio of R&D projects. In the first mover simulations performed here (Tables 7 to 12), with only three alternative demand parameters, the innovator's DPV maxima ranged from zero (10 cases) to a maximum of 38,200, with a mean of 11,900, a median of 8,000, and a standard deviation of 12,400. This is skew, but not nearly as skew as the distributions studied by the author and Harhoff (2000). It is plausible that larger, well-established companies approach their R&D decisions with something at least approximating a portfolio mentality, expecting the less frequent good results to compensate or indeed over-compensate for the disappointments. This is less likely for smaller and especially startup ventures, but the behavioral consequences, though empirically fragile, could be surprising. Startups might be more risk-averse on average, requiring especially strong patent protection and/or first mover advantages to justify R&D investment decisions. But there is also reason to suppose that at least in the United States, small technological innovators are on average risk-lovers, taking long-shot investments that, if they could be quantified in advance, yield returns actuarily less than "normal." See Scherer (2001). What is certain is that both theories and policies on how R&D investments are motivated must take uncertainty into account.

Policy Implications

Given this standard economist's caveat that further research is needed, it might be premature to suggest policy implications. But the questions addressed here are important and almost totally ignored in past policy deliberations. Therefore, it is useful to sketch some directions in which policies might be adapted.

We begin from the widely accepted premise that all is not well in the realm of patent law and its administration.[21] Patents have proliferated without any evident increase in the rate of technological innovation; and patent litigation -- sometimes escalating to patent wars -- has imposed high costs upon participants, governmental adjudicative bodies, and technical progress. These problems suggest that fundamental policy changes should be seriously considered.

In view of evidence that non-patent first mover advantages often provide sufficient incentive for technological innovation even without patent protection, the logical step would be scaling back significantly the scope and duration of patent protection while retaining the possibility of long-lived patents for identifiable special cases. One starting point would be to limit grants for the protection of invention to short-term patents, like the German Gebrauchsmuster (petty patents), with streamlined granting procedures and effective lives limited to five years.[22] A five-year patent would both complement alternative first mover advantages and provide a brief lag in its own right -- a lag found important to improved profitability in Tables 7-9 as lags were increased from two to four years. The law could then identify two kinds of exceptions: a general class attempting to encompass the cases in which first mover advantages are systematically inadequate, and a special administrative procedure to grant longer-term protection when patent applicants provide persuasive evidence that conventional incentives are insufficient.

The most serious R&D failures, our analysis suggests, occur when markets are too small to support substantial R&D investments. Given the uncertainties that pervade R&D investment, identifying small-market exceptions administratively in advance is undoubtedly not feasible. A workable surrogate would be to limit full-term (i.e., 20 year) patent grants to unaffiliated independent inventors and companies with, say, fewer than 20 employees at the time of patent application.[23] Newness and smallness are presumably correlated with modest market prospects. A more fine-tuned but administratively feasible policy (using data like those employed in competition agencies' merger analyses) would withhold full-term patents only for firms with substantial (i.e., greater than 10 percent) market shares in Census-defined industries that are structured oligopolistically, i.e., in which the four leading sellers originate more than 40 percent of national market sales or value added. For such firms, established channels of distribution and brand images provide non-patent first mover advantages, and the threat of Schumpeterian creative destruction normally generates R&D incentives at least as potent as those offered by the prospect of a strong patent position contingent upon success.

Exceptions to these general presumptions could then be dealt with through expedited case-by-case administrative procedures. For example, applicants might seek extended protection by showing that (1) the costs of R&D are extraordinarily high compared to benchmarks in the relevant line of business;[24] (2) the underlying R&D is susceptible to quick replication at costs much lower than those incurred by the original inventor; (3) a full-term patent issuing from the relevant application will be licensed at "reasonable" royalties and without other restrictive provisions to all good-faith license seekers; and (4) (often accompanying (3)), that the underlying firm does R&D only and makes its profits by licensing the resulting technology to other manufacturers or users.[25] To be sure, administrative costs at the Patent Office would be increased by the need to adjudicate such petitions for exception. But if the default case is reduced to a Gebrauchsmuster-type patent, the Patent Office's costs of search to show that minimal standards of inventiveness are met and that patent issue is not barred by the existence of prior art -- functions that are both costly and error-prone -- could be reduced substantially.

These proposals are not intended to be anything like the last word on a long-controversial subject. Rather, they are articulated to stimulate debate on an important point that has been virtually ignored in past analyses -- the undeniable fact that non-patent first mover advantages serve an imitation-delaying function like that exercised by patents, permitting investors in invention and innovation to anticipate monetary rewards for their efforts that, even without patents, are sufficient to make the investments worthwhile.

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End Notes

1. The foregone invention counts are weighted by aggregate research and development expenditures in the surveyed industry groups.

2. The term probably originated in game theory.

3. This summary follows Scherer (1980), pp. 444-447.

4. Levin *et al*. (1987, p. 809) found that the R&D cost needed to duplicate a major *unpatented* new product exceeded 50 percent of the first mover's R&D in 86 percent of the surveyed industries.

5. Seminal contributions on this theme came from research with Strategic Planning Institute data. See Buzzell and Gale (1985), Buzzell and Farris (1977), and Robinson and Fornell (1985). See also Bond and Lean (1977) and Schmalensee (1982). On how first movers with an image or cost advantage can through strategic pricing impede the rate at which rivals enter their market, see Gaskins (1969), especially pp. 42-53; and more generally, Scherer (1980), pp. 232-243.

6. On how Intel used this advantage strategically, see Scherer (2011, pp. 50-54).

7. The theory of such R&D races can be traced back to Scherer (1967), which deliberately neglected the role of patent protection. That dominant firms often but not always respond with a lag to rival technological challenges is shown by the seven case histories presented in Scherer (2008), Chapter 44. See also Baldwin and Scott (1987) and Christenson (1997).

8. A much earlier, more qualitative but prescient contribution was by Sir Arnold Plant (1933). A geometric interpretation of the Nordhaus theory is offered in Scherer (1972).

9. On the flow of technologically advanced products to become processes in purchasing industries, see Scherer (1982).

10. See Barzel (1968) and McFetridge and Raffiquzzaman (1986).

11. See e.g. Merges and Nelson (1990) and Scotchmer (1991).

12. In Scherer (1972), I suggested more inflected cubic or in one case linear dogleg invention possibility functions.

13. Nordhaus (1969, p. 81) assumes a discount rate of 20 percent. A lower rate was chosen here mainly because an expert panel retained by the U.S. Office of Technology Assessment (1993, pp. 267-283) found 12 percent to be an empirically-supported risk-adjusted real discount rate for research-intensive pharmaceutical firms.

14. The calculations were done assuming finite annual discount terms (e.g., $(1/(1+r)^t)$ rather than the e^{-rt} term used in computing the column values for various patent lives.

15. The combination of penetration and imitator erosion coefficients mirrors the approach taken in Scherer (1967), equation [7].

16. It is assumed that imitators' products do not enlarge or reduce the size of the quasi-rent pool; e.g., because the number of imitators is small enough to retain a joint profit-maximizing oligopoly. Note a key difference between Tables 1 through 6 and those here: the actual innovator quasi-rents here from which discounted present values calculated are not the total market potential, but only that part of the potential tapped and/or retained by the innovator.

17. Note that within the range of Nordhaus-optimal values, socially optimal R&D levels remain essentially constant (subject to rounding error attibutable to considering only integer values) across a wide range of patent lives, including our 16-year benchmark.

18. See Scherer (1980, pp. 393-398) for the author's own survey of a literature pioneered by others. A significant methodological contribution is Hausman *et al*. (1994).

19. For applications to pharmaceutical R&D revealing dramatic differences in implications, depending upon whether prospect or rent-seeking model assumptions are followed, see Scherer (2004) and Scherer (2010, pp. 562-569).

20. The pioneering empirical analysis was Mansfield et al. (1968, Chapter 3). Evidence on skewness is presented inter alia in Scherer and Harhoff (2000).

21. See U.K. Commission (2002), U, S. National Research Council (2004), Jaffe and Lerner (2004), and Bessen and Meurer (2008).

22. Needless to say, given the 20-year patent mandate incorporated in the 1994 TRIPS Treaty of Marrakesh, the change would have to be world-wide and not confined to a single nation. But if the negotiators for TRIPS got the balance wrong in the first place, their choices should indeed be reversed. Compare Michael Ryan (1998).

23. It would be necessary to restrain "sham" transactions, e.g., when a large firm finances the R&D of small entities and then acquires the resulting patents with their full-term rights.

24. For guidance, see Levin *et al*. (1987, p. 809).

25. Classic examples in famous U.S. patent rights law include radio circuit designer Hazeltine Research (*Automatic Radio v. Hazeltine Research*, 339 U.S. 827 (1950)); and glass bottle machinery designer Hartford-Empire (*U.S. v. Hartford-Empire Co. et al*., 323 U.S. 386 (1947)). Licensing practices would presumably continue to be subject to competition policy rules.

Figure 1

How Imitation Can Reduce the Innovator's Profit

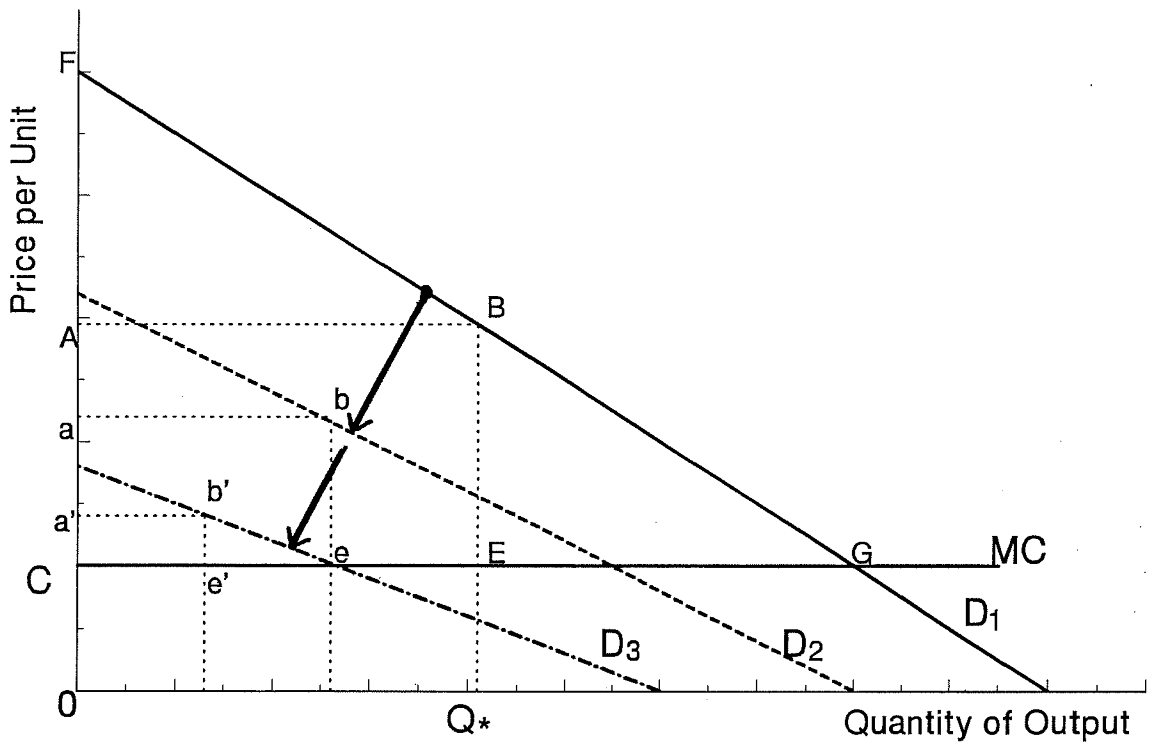

Figure 2

How Innovation Shifts Product Demand Functions Outward

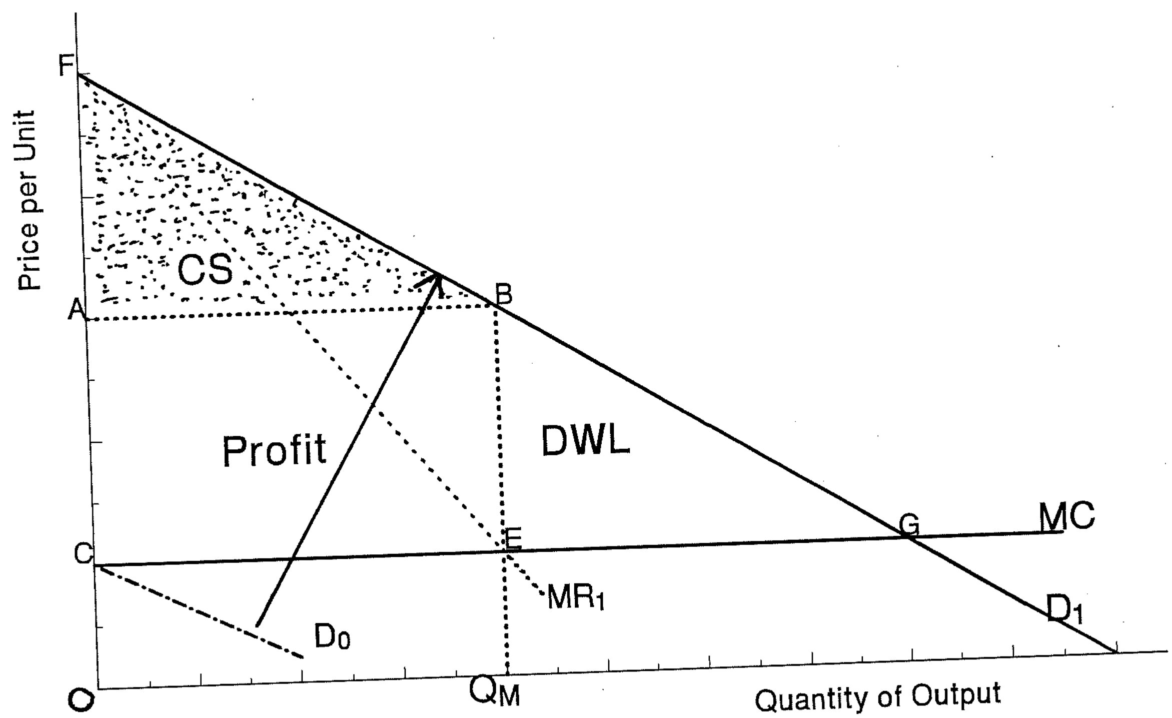

Figure 3

Relationship of Demand Shift Factor to R&D Expenditure

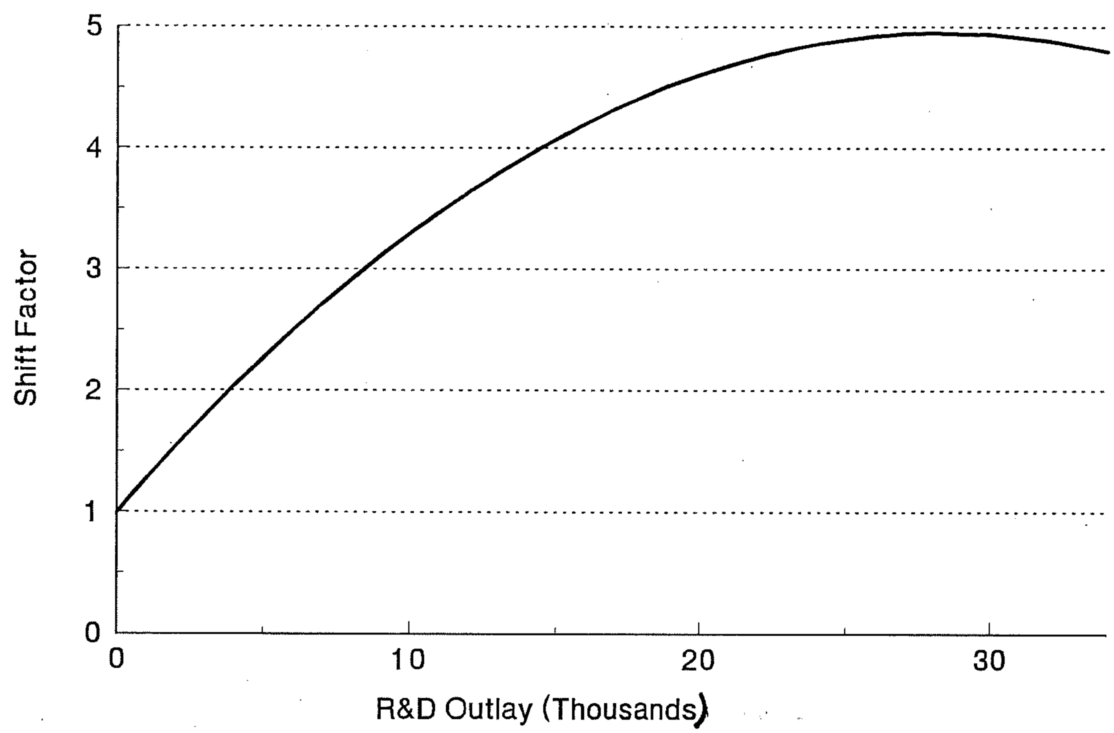

Figure 4

Graph of Demand and Cost Functions

Shift Factor = 4

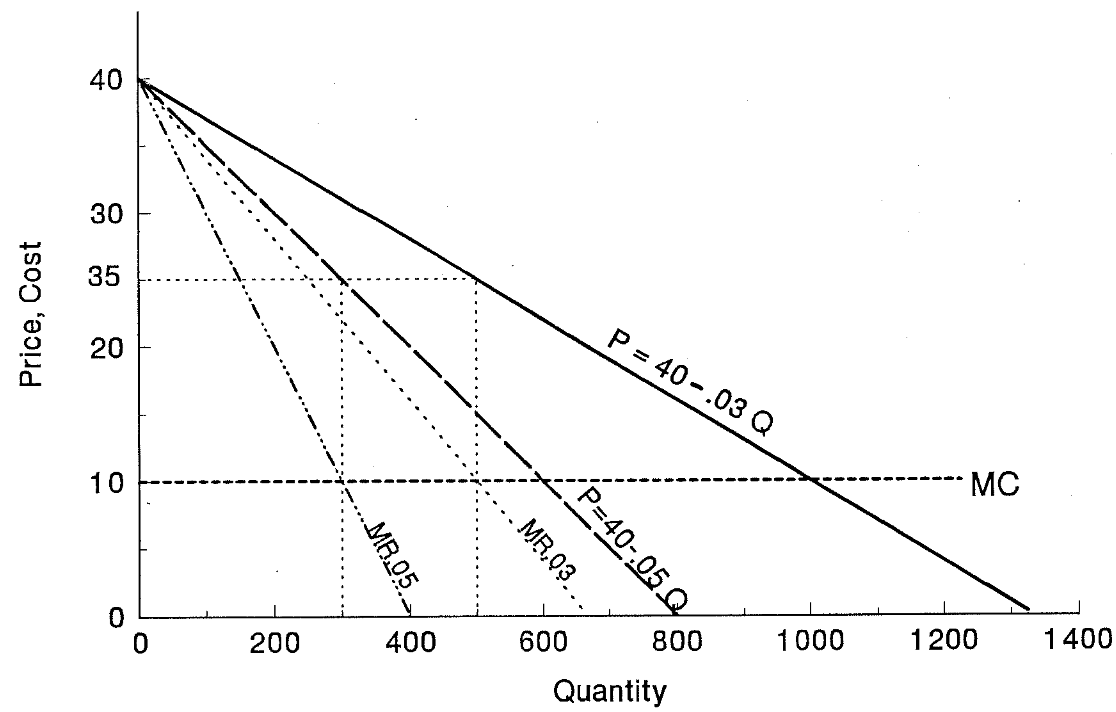

Figure 5
Private R&D Optima as Percent of Social Optima
for Varying Patent Lives (in Years)

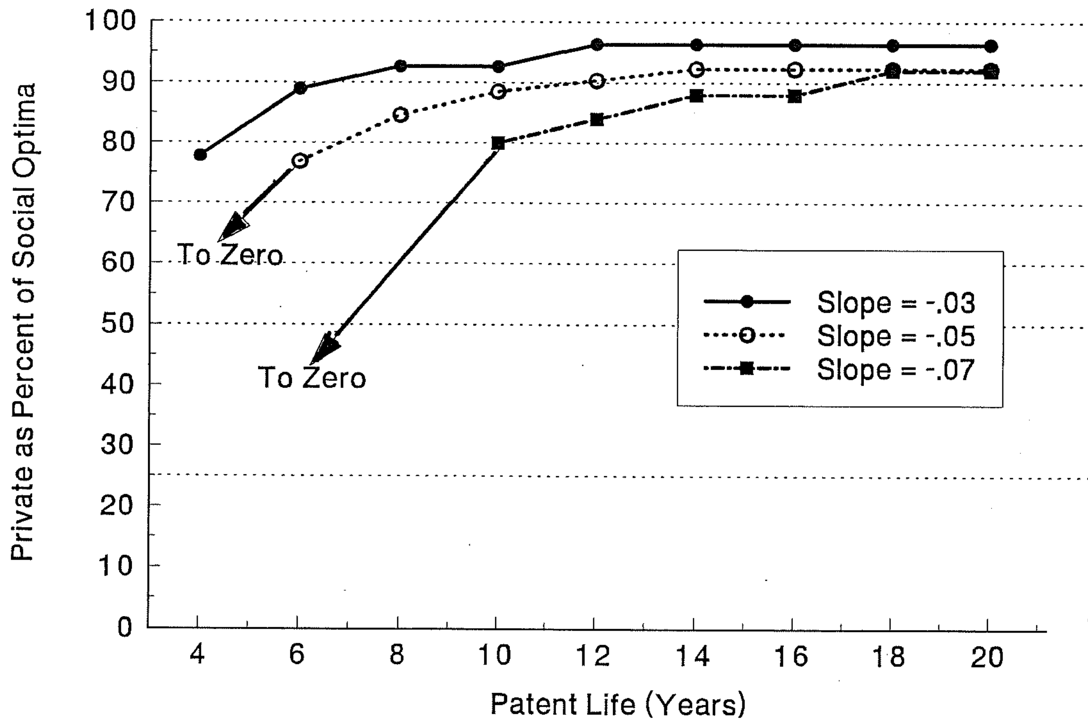

Figure 6

Innovator's Market Share under Alternative Imitation Scenarios

Innovator Captures Market at 50 Percent Annual Rate

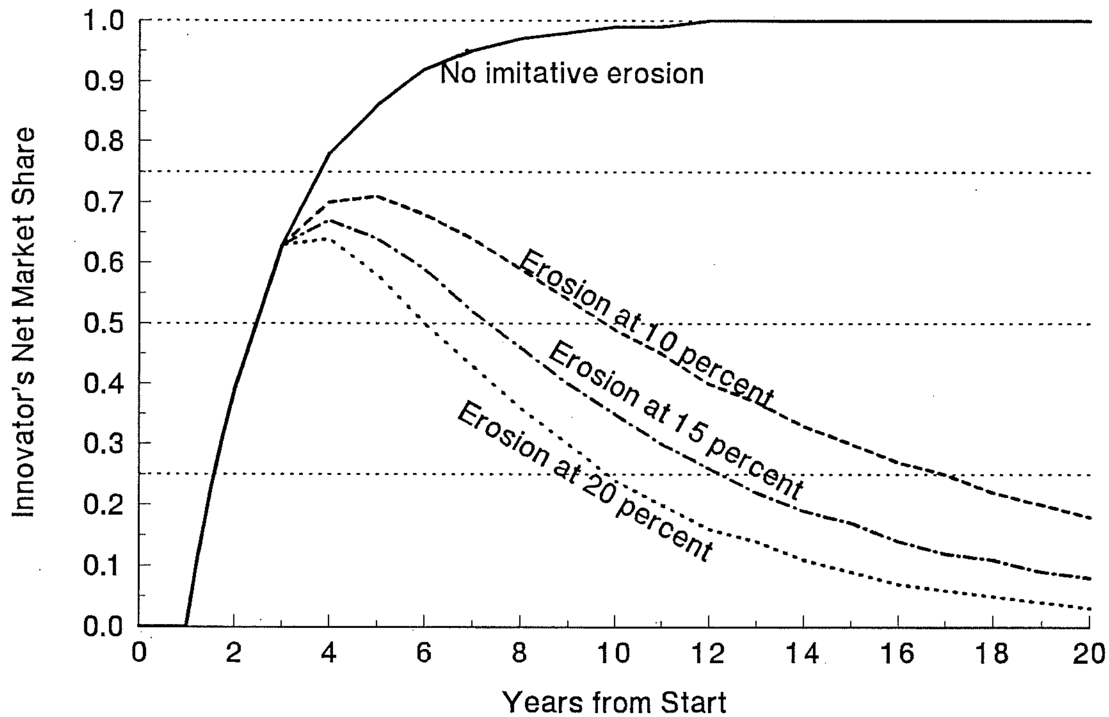

Table 1

Private Payoff Matrix for Diverse Patent Lives

Demand Function P = 10S - .03Q (Large Market)

rand	profit	dpvto4	dpvto6	dpvto8	dpvto10	dpvto12	dpvto14	dpvto16	dpvto18	dpvto20
1	62	-861	-792	-738	-696	-662	-636	-615	-599	-586
2	240	-1463	-1198	-990	-826	-697	-596	-516	-454	-404
3	522	-1835	-1261	-810	-454	-175	45	217	353	460
4	893	-2005	-1022	-249	359	837	1213	1509	1742	1925
5	1343	-1999	-521	641	1555	2275	2840	3285	3636	3911
6	1860	-1844	203	1812	3079	4075	4859	5475	5960	6341
7	2433	-1563	1113	3219	4876	6179	7204	8010	8644	9143
8	3052	-1181	2176	4817	6894	8529	9814	10826	11621	12247
9	3705	-720	3357	6564	9086	11071	12632	13860	14826	15586
10	4385	-201	4624	8419	11405	13754	15601	17054	18198	19097
11	5082	356	5947	10345	13805	16527	18668	20352	21677	22719
12	5787	931	7297	12306	16246	19345	21783	23701	25209	26396
13	6492	1506	8648	14267	18687	22164	24899	27050	28742	30073
14	7189	2064	9974	16196	21091	24941	27970	30353	32227	33701
15	7872	2590	11251	18064	23423	27639	30956	33564	35617	37230
16	8533	3068	12456	19841	25651	30221	33816	36644	38869	40618
17	9167	3484	13569	21503	27744	32654	36516	39554	41944	43823
18	9767	3825	14572	23025	29675	34906	39022	42258	44805	46807
19	10329	4081	15445	24385	31418	36950	41302	44725	47418	49535
20	10848	4240	16175	25564	32949	38759	43329	46925	49753	51976
21	11319	4292	16746	26542	34248	40311	45079	48830	51781	54102
22	11739	4230	17145	27305	35297	41584	46529	50420	53480	55886
23	12104	4046	17362	27838	36078	42561	47660	51671	54827	57308
24	12411	3733	17387	28129	36579	43226	48455	52568	55804	58348
25	12659	3286	17213	28169	36787	43567	48900	53095	56395	58990
26	12844	2701	16833	27949	36694	43574	48985	53242	56590	59223
27	12967	1975	16242	27465	36293	43238	48701	52998	56379	59037
28	13026	1106	15437	26711	35579	42555	48043	52360	55755	58426
29	13020	93	14417	25686	34550	41523	47008	51323	54717	57386
30	12949	-1065	13182	24390	33206	40142	45597	49889	53265	55919
31	12815	-2365	11734	22826	31550	38414	43813	48060	51401	54028
32	12618	-3806	10077	20997	29587	36346	41661	45843	49132	51719
33	12359	-5384	8214	18911	27325	33944	39151	43247	46469	49002
34	12041	-7095	6153	16574	24771	31221	36293	40284	43423	45891
35	11666	-8933	3901	13998	21940	28188	33103	36969	40010	42401

Table 2

Private Payoff Matrix for Diverse Patent Lives

Demand Function P = 10S - .05Q (Medium-Size Market)

rand	profit	dpvto4	dpvto6	dpvto8	dpvto10	dpvto12	dpvto14	dpvto16	dpvto18	dpvto20
1	37	-916	-875	-843	-817	-797	-782	-769	-760	-752
2	144	-1678	-1519	-1394	-1296	-1218	-1158	-1110	-1072	-1043
3	313	-2301	-1957	-1686	-1473	-1305	-1173	-1070	-988	-924
4	536	-2803	-2213	-1749	-1385	-1098	-872	-694	-555	-445
5	806	-3199	-2313	-1615	-1067	-635	-296	-29	181	347
6	1116	-3506	-2278	-1313	-553	45	515	885	1176	1405
7	1460	-3738	-2132	-868	125	907	1522	2006	2387	2686
8	1831	-3909	-1894	-310	937	1917	2689	3296	3773	4148
9	2223	-4032	-1586	338	1852	3043	3979	4716	5296	5752
10	2631	-4121	-1226	1052	2843	4252	5361	6233	6919	7458
11	3049	-4187	-832	1807	3883	5516	6801	7812	8606	9232
12	3472	-4242	-421	2584	4948	6807	8270	9421	10326	11038
13	3895	-4296	-11	3360	6012	8098	9739	11030	12046	12844
14	4314	-4361	384	4118	7055	9365	11182	12612	13736	14621
15	4723	-4446	750	4838	8054	10584	12574	14139	15370	16338
16	5120	-4559	1074	5505	8991	11733	13890	15587	16922	17971
17	5500	-4710	1342	6102	9847	12793	15110	16933	18367	19494
18	5861	-4905	1543	6615	10605	13744	16213	18155	19683	20885
19	6198	-5151	1667	7031	11251	14570	17181	19235	20851	22122
20	6509	-5456	1705	7338	11770	15256	17998	20155	21852	23186
21	6791	-5824	1647	7525	12149	15787	18648	20899	22669	24061
22	7043	-6262	1487	7583	12378	16150	19118	21452	23288	24732
23	7262	-6773	1217	7503	12447	16337	19396	21803	23696	25185
24	7447	-7360	833	7278	12347	16336	19473	21941	23882	25409
25	7595	-8028	328	6902	12072	16140	19340	21857	23837	25395
26	7707	-8779	-300	6370	11617	15744	18991	21545	23554	25134
27	7780	-9615	-1055	5679	10976	15143	18421	20999	23028	24622
28	7815	-10536	-1938	4827	10147	14333	17626	20216	22254	23856
29	7812	-11544	-2950	3812	9130	13314	16605	19194	21231	22832
30	7770	-12639	-4090	2634	7924	12085	15359	17933	19959	21552
31	7689	-13819	-5359	1296	6530	10649	13888	16436	18441	20017
32	7571	-15083	-6754	-201	4953	9008	12197	14706	16680	18232
33	7415	-16430	-8272	-1853	3195	7167	10291	12748	14682	16202
34	7225	-17857	-9908	-3655	1263	5133	8176	10570	12454	13935
35	6999	-19360	-11659	-5601	-836	2913	5862	8181	10006	11441

Table 3

Private Payoff Matrix for Diverse Patent Lives

Demand Function P = 10S - .07Q (Small Market)

rand	profit	dpvto4	dpvto6	dpvto8	dpvto10	dpvto12	dpvto14	dpvto16	dpvto18	dpvto20
1	27	-940	-911	-888	-870	-855	-844	-835	-828	-823
2	103	-1770	-1656	-1567	-1497	-1442	-1398	-1364	-1337	-1316
3	224	-2501	-2255	-2061	-1909	-1789	-1695	-1621	-1563	-1517
4	383	-3145	-2724	-2392	-2132	-1927	-1766	-1639	-1539	-1461
5	576	-3714	-3081	-2582	-2191	-1882	-1640	-1449	-1299	-1181
6	797	-4219	-3342	-2652	-2109	-1682	-1346	-1082	-874	-711
7	1043	-4670	-3523	-2620	-1910	-1352	-913	-567	-295	-81
8	1308	-5078	-3639	-2507	-1616	-916	-365	68	409	677
9	1588	-5451	-3704	-2330	-1248	-398	271	798	1212	1537
10	1879	-5800	-3733	-2106	-826	180	972	1595	2085	2470
11	2178	-6133	-3737	-1852	-369	798	1715	2437	3005	3451
12	2480	-6458	-3729	-1583	106	1434	2479	3301	3947	4456
13	2782	-6783	-3722	-1314	580	2071	3243	4165	4890	5460
14	3081	-7115	-3725	-1058	1039	2690	3988	5009	5812	6444
15	3374	-7461	-3749	-829	1467	3274	4696	5814	6693	7385
16	3657	-7828	-3804	-639	1851	3810	5350	6562	7516	8266
17	3929	-8221	-3899	-498	2177	4281	5936	7238	8262	9068
18	4186	-8646	-4040	-417	2433	4675	6438	7826	8917	9775
19	4427	-9108	-4237	-406	2608	4979	6844	8311	9466	10373
20	4649	-9611	-4496	-472	2693	5183	7142	8683	9895	10848
21	4851	-10160	-4823	-624	2678	5277	7320	8928	10193	11187
22	5031	-10758	-5223	-869	2556	5251	7370	9038	10349	11381
23	5187	-11409	-5702	-1212	2320	5098	7284	9003	10355	11419
24	5319	-12114	-6262	-1658	1963	4812	7053	8816	10202	11293
25	5425	-12877	-6908	-2213	1481	4387	6672	8470	9885	10997
26	5505	-13699	-7643	-2878	870	3818	6137	7962	9397	10525
27	5557	-14582	-8467	-3657	126	3103	5444	7286	8735	9874
28	5583	-15526	-9384	-4552	-751	2239	4591	6441	7896	9041
29	5580	-16531	-10392	-5563	-1764	1225	3576	5425	6880	8024
30	5550	-17599	-11493	-6689	-2911	62	2400	4239	5686	6823
31	5492	-18727	-12685	-7931	-4192	-1250	1064	2884	4316	5441
32	5408	-19916	-13967	-9286	-5605	-2708	-430	1362	2772	3881
33	5297	-21164	-15336	-10752	-7146	-4309	-2077	-322	1059	2145
34	5161	-22469	-16791	-12325	-8812	-6048	-3873	-2163	-818	240
35	5000	-23828	-18328	-14000	-10597	-7919	-5812	-4155	-2852	-1827

Table 4

Social Payoffs for Diverse Patent Lives

Demand Function P = 10S -.03Q (Large Market)

rand	profit	dpvto4	dpvto6	dpvto8	dpvto10	dpvto12	dpvto14	dpvto16	dpvto18	dpvto20
1	62	-148	-183	-210	-231	-247	-261	-271	-279	-285
2	240	1286	1154	1050	968	903	853	813	782	757
3	522	4126	3840	3614	3436	3297	3187	3100	3032	2979
4	893	8203	7712	7325	7021	6782	6594	6446	6330	6238
5	1343	13352	12613	12032	11575	11215	10932	10710	10535	10397
6	1860	19417	18393	17588	16955	16457	16065	15757	15515	15324
7	2433	26247	24908	23855	23027	22376	21863	21460	21143	20893
8	3052	33698	32020	30699	29660	28843	28200	27695	27297	26984
9	3705	41634	39596	37993	36731	35739	34958	34344	33861	33481
10	4385	49924	47512	45614	44121	42947	42023	41297	40725	40276
11	5082	58444	55648	53449	51719	50358	49288	48446	47783	47262
12	5787	67076	63893	61388	59418	57869	56650	55691	54937	54343
13	6492	75709	72138	69329	67119	65380	64013	62937	62091	61425
14	7189	84239	80284	77173	74726	72801	71286	70095	69158	68421
15	7872	92568	88238	84831	82152	80044	78385	77081	76055	75248
16	8533	100605	95911	92218	89313	87028	85231	83817	82704	81830
17	9167	108265	103222	99255	96135	93680	91749	90230	89035	88095
18	9767	115470	110097	105870	102545	99930	97872	96254	94980	93979
19	10329	122148	116466	111996	108480	105714	103538	101826	100480	99421
20	10848	128235	122268	117573	113881	110975	108690	106893	105479	104367
21	11319	133672	127445	122547	118694	115663	113278	111403	109927	108767
22	11739	138406	131949	126869	122873	119729	117257	115312	113781	112578
23	12104	142394	135735	130498	126377	123136	120586	118581	117003	115763
24	12411	145595	138768 *	133397	129172	125848	123234	121177	119559	118287
25	12659	147978	141014	135536	131227	127837	125171	123073	121423	120126
26	12844	149517	142451	136893	132520	129081	126375	124247	122572	121256
27	12967	150193	143060	137448	133034	129561	126830	124681	122991	121662
28	13026	149993	142828	137191	132757	129269	126525	124367	122669	121333
29	13020	148912	141750	136116	131684	128197	125455	123297	121600	120265
30	12949	146950	139827	134223	129815	126347	123619	121474	119786	118458
31	12815	144115	137065	131519	127157	123725	121026	118902	117232	115918
32	12618	140419	133478	128018	123723	120344	117686	115595	113950	112657
33	12359	135884	129085	123737	119530	116220	113616	111568	109957	108691
34	12041	130535	123912	118701	114602	111378	108841	106846	105277	104043
35	11666	124408	117991	112942	108971	105847	103390	101457	99936	98741

Table 5

Social Payoffs for Diverse Patent Lives

Demand Function P = 10S - .05Q (Medium-Size Market)

rand	profit	dpvto4	dpvto6	dpvto8	dpvto10	dpvto12	dpvto14	dpvto16	dpvto18	dpvto20
1	37	-489	-510	-526	-538	-548	-556	-563	-567	-571
2	144	-28	-108	-170	-219	-258	-288	-312	-331	-346
3	313	1276	1104	968	862	778	712	660	620	587
4	536	3322	3027	2795	2613	2469	2356	2268	2198	2143
5	806	6011	5568	5219	4945	4729	4559	4426	4321	4238
6	1116	9250	8636	8153	7773	7474	7239	7054	6909	6795
7	1460	12948	12145	11513	11016	10626	10318	10076	9886	9736
8	1831	17019	16012	15220	14596	14106	13720	13417	13178	12991
9	2223	21381	20158	19196	18439	17844	17375	17007	16717	16489
10	2631	25955	24507	23369	22473	21769	21214	20778	20435	20166
11	3049	30667	28989	27670	26632	25815	25173	24668	24270	23958
12	3472	35446	33535	32033	30851	29922	29190	28615	28162	27806
13	3895	40226	38083	36398	35072	34029	33208	32563	32055	31656
14	4314	44944	42570	40704	39236	38081	37172	36457	35895	35453
15	4723	49541	46942	44899	43291	42027	41032	40249	39633	39149
16	5120	53964	51146	48931	47188	45817	44739	43890	43223	42698
17	5500	58160	55133	52754	50881	49408	48250	47338	46621	46058
18	5861	62083	58858	56323	54328	52758	51524	50553	49789	49188
19	6198	65690	62279	59598	57488	55829	54523	53496	52688	52053
20	6509	68942	65360	62544	60329	58586	57215	56136	55288	54621
21	6791	71804	68067	65129	62817	60998	59567	58442	57557	56861
22	7043	74244	70369	67322 *	64924	63038	61554	60387	59469	58747
23	7262	76237	72241	69099	66627	64682	63152	61949	61002	60258
24	7447	77757	73660	70438	67904	65909	64341	63107	62136	61373
25	7595	78787	74608	71322	68737	66703	65103	63844	62854	62076
26	7707	79311	75070	71736	69113	67049	65425	64148	63144	62354
27	7780	79316	75035	71669	69021	66937	65298	64009	62995	62198
28	7815	78797	74496	71115	68455	66362	64715	63420	62402	61601
29	7812	77748	73449	70070	67411	65319	63673	62379	61360	60560
30	7770	76171	71895	68534	65890	63809	62172	60885	59872	59076
31	7689	74069	69838	66512	63895	61836	60216	58942	57940	57151
32	7571	71452	67286	64011	61434	59407	57812	56557	55571	54795
33	7415	68331	64250	61042	58518	56532	54970	53742	52775	52015
34	7225	64722	60747	57621	55162	53227	51705	50508	49566	48826
35	6999	60645	56794	53766	51383	49509	48034	46875	45962	45245

Table 6

Social Payoffs for Diverse Patent Lives

Demand Function P = 10S - .07Q (Small Market)

rand	profit	dpvto4	dpvto6	dpvto8	dpvto10	dpvto12	dpvto14	dpvto16	dpvto18	dpvto20
1	27	-635	-650	-661	-670	-677	-683	-687	-691	-733
2	103	-592	-648	-693	-728	-756	-777	-794	-808	-971
3	224	54	-69	-165	-241	-301	-348	-385	-415	-771
4	383	1230	1019	854	724	621	540	477	427	-185
5	576	2865	2549	2300	2104	1950	1828	1733	1658	736
6	797	4893	4455	4110	3838	3625	3457	3325	3221	1943
7	1043	7249	6675	6224	5869	5590	5370	5197	5062	3389
8	1308	9871	9152	8586	8141	7790	7515	7298	7128	5028
9	1588	12701	11827	11140	10600	10174	9840	9577	9370	6819
10	1879	15682	14649	13835	13196	12692	12296	11985	11740	8721
11	2178	18762	17564	16622	15880	15297	14838	14477	14194	10694
12	2480	21890	20526	19453	18609	17945	17422	17011	16688	12702
13	2782	25019	23489	22285	21338	20592	20006	19545	19183	14710
14	3081	28103	26409	25075	24026	23201	22552	22042	21640	16687
15	3374	31101	29246	27786	26638	25734	25023	24464	24025	18600
16	3657	33974	31963	30380	29136	28156	27386	26780	26303	20423
17	3929	36686	34525	32825	31488	30435	29608	28957	28445	22127
18	4186	39202	36900	35089	33664	32543	31661	30967	30421	23690
19	4427	41493	39058	37143	35636	34450	33518	32784	32207	25088
20	4649	43530	40973	38961	37379	36134	35154	34384	33778	26302
21	4851	45289	42621	40522	38870	37571	36549	35745	35113	27313
22	5031	46746	43980	41803	40090	38743	37683 *	36849	36194	28104
23	5187	47884	45031	42786	41021	39631	38539	37679	37003	28663
24	5319	48684	45759	43457	41647	40222	39102	38220	37527	28975
25	5425	49134	46151	43803	41956	40503	39360	38462	37754	29033
26	5505	49222	46195	43813	41939	40465	39305	38393	37675	28827
27	5557	48941	45885	43480	41588	40099	38929	38008	37283	28352
28	5583	48284	45214	42798	40898	39403	38227	37302	36574	27603
29	5580	47249	44180	41766	39866	38372	37196	36272	35544	26579
30	5550	45837	42785	40383	38494	37008	35839	34919	34196	25281
31	5492	44050	41030	38653	36783	35313	34156	33245	32530	23709
32	5408	41895	38921	36581	34740	33292	32153	31257	30552	21869
33	5297	39380	36467	34175	32371	30953	29837	28959	28269	19767
34	5161	36516	33678	31445	29688	28306	27219	26364	25692	17411
35	5000	33318	30569	28405	26704	25365	24311	23483	22831	14812

Table 7
Payoff Matrix with Penetration and Imitation Lags

Demand Function P = 10S - .03Q (Large Market)

		Imitation Year 3			Imitation Year 4			Imitation Year 5		
rand	profit	im2ero10	im2ero15	imero20	im3ero10	im3ero15	im3ero20	im4ero10	im4ero15	im4ero20
1	62	-737	-780	-809	-716	-754	-781	-697	-731	-755
2	240	-985	-1150	-1263	-904	-1053	-1154	-830	-963	-1054
3	522	-799	-1157	-1401	-623	-945	-1165	-463	-751	-949
4	893	-230	-844	-1262	70	-482	-859	344	-149	-488
5	1343	669	-254	-883	1121	291	-276	1533	791	282
6	1860	1852	573	-298	2477	1328	543	3047	2020	1316
7	2433	3270	1598	459	4088	2586	1559	4835	3491	2570
8	3052	4881	2783	1355	5907	4022	2735	6843	5158	4003
9	3705	6642	4094	2360	7888	5599	4035	9024	6978	5575
10	4385	8512	5496	3445	9986	7277	5427	11331	8909	7249
11	5082	10453	6958	4580	12161	9022	6877	13720	10913	8989
12	5787	12428	8449	5741	14374	10799	8357	16148	12952	10761
13	6492	14404	9940	6903	16586	12576	9837	18578	14992	12534
14	7189	16348	11405	8041	18765	14324	11290	20970	16999	14277
15	7872	18230	12817	9134	20876	16014	12692	23291	18943	15963
16	8533	20022	14154	10161	22890	17619	14018	25508	20795	17564
17	9167	21697	15394	11104	24779	19116	15248	27590	22527	19057
18	9767	23231	16515	11945	26515	20482	16360	29511	24116	20418
19	10329	24603	17501	12668	28076	21696	17337	31244	25539	21629
20	10848	25793	18334	13258	29440	22739	18161	32767	26775	22668
21	11319	26781	18998	13702	30586	23595	18818	34058	27807	23521
22	11739	27553	19481	13988	31499	24248	19294	35099	28616	24172
23	12104	28093	19771	14107	32162	24686	19578	35875	29190	24607
24	12411	28391	19857	14050	32564	24897	19660	36370	29516	24817
25	12659	28436	19732	13809	32692	24873	19531	36574	29583	24790
26	12844	28220	19389	13379	32539	24605	19184	36478	29384	24521
27	12967	27738	18822	12755	32098	24088	18616	36075	28913	24004
28	13026	26986	18029	11934	31365	23319	17822	35360	28166	23234
29	13020	25960	17008	10916	30338	22295	16801	34331	27140	22211
30	12949	24663	15759	9700	29017	21018	15553	32988	25837	20934
31	12815	23096	14285	8288	27405	19489	14081	31335	24257	19406
32	12618	21264	12588	6684	25506	17712	12387	29376	22407	17630
33	12359	19171	10673	4890	23327	15692	10477	27117	20291	15612
34	12041	16828	8549	2915	20876	13439	8357	24569	17919	13360
35	11666	14244	6223	764	18166	10960	6037	21744	15301	10884

Table 8

Payoff Matrix with Penetration and Imitation Lags

Demand Function P = 10S - .05Q (Medium-Size Market)

		Imitation Year 3			Imitation Year 4			Imitation Year 5		
rand	profit	im2ero10	im2ero15	im2ero20	im3ero10	im3ero15	im3ero20	im4ero10	im4ero15	im4ero20
1	37	-842	-868	-885	-830	-853	-868	-818	-839	-853
2	144	-1391	-1490	-1558	-1342	-1432	-1492	-1298	-1378	-1432
3	313	-1679	-1894	-2041	-1574	-1767	-1899	-1478	-1651	-1769
4	536	-1738	-2107	-2357	-1558	-1889	-2115	-1394	-1690	-1892
5	806	-1598	-2152	-2530	-1327	-1825	-2165	-1080	-1525	-1830
6	1116	-1289	-2056	-2579	-914	-1603	-2074	-571	-1188	-1610
7	1460	-838	-1841	-2524	-347	-1249	-1865	101	-705	-1258
8	1831	-271	-1530	-2387	344	-786	-1559	906	-105	-798
9	2223	385	-1143	-2184	1133	-241	-1179	1815	587	-255
10	2631	1107	-702	-1933	1992	366	-744	2799	1346	349
11	3049	1872	-225	-1652	2897	1013	-273	3832	2148	993
12	3472	2657	269	-1355	3824	1680	214	4889	2972	1657
13	3895	3442	764	-1058	4752	2346	702	5947	3795	2321
14	4314	4209	1243	-775	5659	2995	1174	6982	4600	2967
15	4723	4938	1690	-520	6526	3608	1615	7975	5366	3578
16	5120	5613	2093	-303	7334	4172	2011	8905	6077	4138
17	5500	6218	2436	-137	8067	4670	2349	9754	6717	4634
18	5861	6739	2709	-33	8709	5089	2616	10507	7270	5051
19	6198	7162	2901	1	9246	5418	2802	11147	7724	5377
20	6509	7476	3000	-45	9664	5643	2897	11660	8065	5601
21	6791	7669	2999	-179	9952	5757	2891	12035	8284	5713
22	7043	7732	2889	-407	10100	5749	2777	12260	8370	5703
23	7262	7656	2663	-735	10098	5612	2547	12325	8314	5565
24	7447	7435	2314	-1170	9938	5339	2196	12222	8109	5290
25	7595	7062	1839	-1714	9615	4924	1719	11945	7750	4874
26 ←	7707	6532	1233	-2373	9123	4363	1111	11487	7231	4313
27	7780	5843	493	-3147	8459	3653	370	10845	6548	3602
28	7815	4991	-382	-4039	7619	2791	-507	10016	5700	2741
29	7812	3976	-1395	-5050	6603	1777	-1519	8999	4684	1727
30	7770	2798	-2544	-6180	5410	611	-2668	7793	3502	560
31	7689	1458	-3829	-7427	4043	-707	-3951	6401	2155	-757
32	7571	-42	-5247	-8790	2504	-2173	-5368	4825	644	-2222
33	7415	-1697	-6796	-10266	796	-3784	-6914	3070	-1025	-3833
34	7225	-3503	-8471	-11851	-1074	-5537	-8585	1142	-2848	-5584
35	6999	-5453	-10266	-13541	-3100	-7424	-10377	-953	-4819	-7469

Table 9

Payoff Matrix with Penetration and Imitation Lags

Demand Function P = 10S - .07Q (Small Market)

		Imitation Year 3			Imitation Year 4			Imitation Year 5		
rand	profit	im2ero10	im2ero15	im2ero20	im3ero10	im3ero15	im3ero20	im4ero10	im4ero15	im4ero20
1	27	-887	-906	-918	-878	-895	-906	-870	-885	-895
2	103	-1565	-1636	-1684	-1530	-1594	-1637	-1499	-1556	-1595
3	224	-2056	-2210	-2315	-1981	-2119	-2214	-1913	-2036	-2121
4	383	-2384	-2648	-2827	-2256	-2492	-2654	-2138	-2350	-2495
5	576	-2570	-2966	-3235	-2377	-2732	-2975	-2200	-2518	-2736
6	797	-2635	-3183	-3556	-2367	-2859	-3196	-2122	-2563	-2864
7	1043	-2598	-3315	-3803	-2248	-2892	-3332	-1928	-2504	-2899
8	1308	-2479	-3379	-3990	-2040	-2847	-3399	-1638	-2361	-2856
9	1588	-2296	-3388	-4131	-1762	-2743	-3413	-1275	-2152	-2753
10	1879	-2066	-3358	-4238	-1434	-2595	-3388	-858	-1896	-2607
11	2178	-1806	-3303	-4323	-1074	-2419	-3338	-406	-1608	-2433
12	2480	-1531	-3236	-4396	-697	-2229	-3275	64	-1306	-2245
13	2782	-1255	-3168	-4470	-320	-2038	-3212	534	-1003	-2056
14	3081	-993	-3112	-4554	42	-1861	-3161	987	-714	-1881
15	3374	-758	-3078	-4657	376	-1708	-3132	1411	-453	-1730
16	3657	-562	-3076	-4788	668	-1591	-3135	1789	-230	-1615
17	3929	-415	-3117	-4955	906	-1521	-3179	2111	-59	-1547
18	4186	-329	-3207	-5166	1078	-1507	-3274	2362	50	-1535
19	4427	-312	-3356	-5428	1176	-1559	-3427	2534	89	-1587
20	4649	-374	-3571	-5746	1189	-1683	-3645	2615	47	-1713
21	4851	-522	-3858	-6127	1109	-1887	-3935	2597	-82	-1919
22	5031	-763	-4222	-6576	929	-2179	-4302	2472	-307	-2212
23	5187	-1102	-4669	-7096	642	-2563	-4752	2233	-632	-2596
24	5319	-1546	-5204	-7692	242	-3043	-5288	1874	-1064	-3078
25 ←	5425	-2098	-5829	-8367	-274	-3625	-5915	1390	-1607	-3661
26	5505	-2762	-6547	-9123	-911	-4312	-6635	777	-2263	-4347
27	5557	-3540	-7362	-9962	-1672	-5105	-7450	33	-3037	-5141
28	5583	-4434	-8273	-10885	-2557	-6006	-8362	-845	-3928	-6042
29	5580	-5445	-9282	-11893	-3569	-7016	-9370	-1858	-4939	-7052
30	5550	-6572	-10388	-12985	-4706	-8135	-10477	-3004	-6069	-8171
31	5492	-7815	-11592	-14162	-5969	-9361	-11679	-4284	-7318	-9397
32	5408	-9172	-12891	-15421	-7354	-10694	-12977	-5696	-8682	-10730
33	5297	-10640	-14282	-16761	-8859	-12131	-14367	-7235	-10160	-12166
34	5161	-12216	-15764	-18179	-10481	-13669	-15846	-8898	-11748	-13702
35	5000	-13895	-17333	-19672	-12214	-15302	-17412	-10681	-13442	-15335

Table 10

Payoff Matrix; Minimum Innovator Share of 30%

Demand Function P = 10S - .03Q (Large Market)

		Imitation Year 3			Imitation Year 4			Imitation Year 5		
rand	profit	im2ero10	im2ero15	imero20	im3ero10	im3ero15	im3ero20	im4ero10	im4ero15	im4ero20
1	62	-726	-755	-772	-706	-733	-748	-689	-712	-726
2	240	-942	-1054	-1119	-868	-968	-1028	-799	-890	-944
3	522	-706	-948	-1090	-544	-763	-892	-396	-593	-710
4	893	-72	-486	-730	205	-169	-391	458	122	-78
5	1343	907	285	-82	1324	761	427	1705	1199	898
6	1860	2182	1319	812	2758	1979	1517	3286	2585	2169
7	2433	3702	2574	1910	4457	3437	2832	5147	4230	3685
8	3052	5423	4008	3175	6369	5090	4332	7234	6085	5402
9	3705	7299	5581	4570	8448	6895	5975	9499	8103	7274
10	4385	9290	7256	6060	10650	8811	7722	11893	10241	9259
11	5082	11354	8998	7611	12930	10800	9537	14371	12457	11319
12	5787	13455	10771	9193	15249	12823	11386	16890	14710	13415
13	6492	15556	12545	10774	17569	14847	13235	19410	16964	15511
14	7189	17623	14290	12328	19853	16839	15053	21892	19183	17574
15	7872	19626	15976	13829	22067	18768	16812	24300	21335	19572
16	8533	21535	17578	15251	24182	20604	18485	26602	23387	21476
17	9167	23323	19072	16571	26166	22323	20046	28765	25312	23260
18	9767	24964	20435	17770	27993	23899	21472	30763	27084	24897
19	10329	26436	21646	18828	29639	25309	22743	32568	28677	26365
20	10848	27717	22687	19728	31081	26534	23839	34158	30071	27642
21	11319	28789	23540	20453	32299	27554	24742	35509	31245	28711
22	11739	29635	24192	20989	33275	28354	25438	36604	32182	29554
23	12104	30240	24628	21326	33994	28920	25913	37426	32867	30157
24	12411	30593	24838	21452	34441	29239	26156	37961	33286	30507
25	12659	30682	24812	21359	34607	29301	26156	38197	33429	30594
26	12844	30499	24543	21039	34482	29098	25907	38125	33286	30410
27 ←	12967	30039	24026	20488	34060	28624	25403	37737	32852	29949
28	13026	29296	23256	19703	33336	27875	24640	37030	32123	29206
29	13020	28270	22233	18681	32308	26850	23616	36000	31095	28180
30	12949	26961	20956	17423	30976	25548	22331	34649	29771	26871
31	12815	25370	19427	15931	29344	23972	20788	32978	28151	25281
32	12618	23502	17651	14209	27415	22125	18991	30993	26240	23415
33	12359	21364	15633	12261	25196	20016	16946	28701	24046	21279
34	12041	18964	13381	10096	22698	17651	14660	26113	21577	18881
35	11666	16314	10904	7722	19931	15041	12143	23239	18845	16233

Table 11

Payoff Matrix; Minimum Innovator Share of 30%

Demand Function P = 10S - .05 Q (Medium-Size Market)

		Imitation Year 3			Imitation Year 4			Imitation Year 5		
rand	profit	im2ero10	im2ero15	im2ero20	im3ero10	im3ero15	im3ero20	im4ero10	im4ero15	im4ero20
1	37	-835	-853	-863	-824	-840	-849	-813	-827	-836
2	144	-1365	-1432	-1472	-1321	-1381	-1417	-1280	-1334	-1366
3	313	-1624	-1769	-1854	-1527	-1658	-1735	-1438	-1556	-1626
4	536	-1643	-1892	-2038	-1477	-1702	-1835	-1325	-1527	-1647
5	806	-1455	-1829	-2049	-1206	-1543	-1744	-977	-1281	-1461
6	1116	-1091	-1608	-1913	-745	-1213	-1490	-428	-849	-1099
7	1460	-579	-1256	-1654	-126	-738	-1101	288	-262	-589
8	1831	54	-795	-1295	621	-146	-601	1141	451	41
9	2223	780	-251	-858	1469	537	-15	2100	1262	764
10	2631	1574	354	-364	2390	1287	633	3136	2145	1556
11	3049	2413	999	167	3358	2080	1322	4223	3074	2392
12	3472	3273	1663	716	4350	2894	2032	5334	4026	3249
13	3895	4133	2327	1265	5341	3709	2741	6446	4979	4107
14	4314	4974	2974	1797	6312	4503	3432	7535	5910	4944
15	4723	5776	3586	2297	7241	5261	4087	8580	6801	5743
16	5120	6521	4147	2750	8109	5963	4691	9561	7632	6486
17	5500	7194	4643	3143	8900	6594	5228	10459	8388	7156
18	5861	7779	5061	3462	9596	7139	5684	11258	9050	7738
19	6198	8262	5388	3697	10184	7586	6046	11941	9607	8219
20	6509	8630	5612	3837	10649	7920	6303	12495	10043	8585
21	6791	8874	5724	3872	10980	8133	6446	12906	10347	8827
22	7043	8981	5715	3794	11165	8213	6463	13163	10510	8933
23	7262	8944	5577	3596	11196	8152	6348	13256	10520	8894
24	7447	8756	5303	3271	11065	7943	6094	13177	10372	8704
25	7595	8409	4887	2815	10765	7581	5694	12919	10057	8357
26 ←	7707	7900	4326	2224	10289	7059	5144	12475	9572	7846
27	7780	7223	3616	1493	9636	6374	4442	11843	8912	7170
28	7815	6378	2754	622	8802	5525	3584	11018	8074	6324
29	7812	5362	1740	-391	7785	4510	2570	10000	7057	5308
30	7770	4177	574	-1546	6586	3329	1399	8789	5863	4123
31	7689	2822	-743	-2841	5206	1983	73	7387	4490	2769
32	7571	1301	-2209	-4275	3649	475	-1405	5796	2944	1249
33	7415	-382	-3820	-5843	1918	-1191	-3033	4021	1228	-433
34	7225	-2221	-5571	-7542	19	-3010	-4804	2068	-654	-2271
35	6999	-4212	-7457	-9367	-2041	-4975	-6714	-56	-2693	-4260

Table 12

Payoff Matrix; Minimum Innovator Share of 30%

Demand Function P = 10S - .07Q (Small Market)

		Imitation Year 3			Imitation Year 4			Imitation Year 5		
rand	profit	im2ero10	im2ero15	im2ero20	im3ero10	im3ero15	im3ero20	im4ero10	im4ero15	im4ero20
1	27	-882	-895	-902	-874	-885	-892	-867	-877	-883
2	103	-1547	-1594	-1623	-1515	-1558	-1583	-1485	-1524	-1547
3	224	-2017	-2120	-2181	-1947	-2041	-2097	-1884	-1968	-2018
4	383	-2316	-2494	-2598	-2198	-2358	-2453	-2089	-2233	-2319
5	576	-2468	-2735	-2892	-2290	-2531	-2674	-2126	-2343	-2472
6	797	-2493	-2863	-3081	-2246	-2580	-2778	-2020	-2320	-2499
7	1043	-2413	-2897	-3181	-2090	-2527	-2786	-1794	-2187	-2420
8	1308	-2247	-2854	-3210	-1842	-2390	-2715	-1471	-1963	-2256
9	1588	-2014	-2751	-3184	-1522	-2188	-2582	-1072	-1670	-2025
10	1879	-1733	-2604	-3117	-1150	-1938	-2405	-617	-1325	-1746
11	2178	-1419	-2429	-3024	-744	-1657	-2198	-126	-947	-1434
12	2480	-1091	-2241	-2917	-321	-1361	-1977	382	-552	-1108
13	2782	-762	-2052	-2811	101	-1065	-1756	890	-158	-781
14	3081	-447	-1876	-2716	509	-783	-1548	1383	222	-468
15	3374	-160	-1724	-2645	886	-528	-1366	1843	572	-183
16	3657	87	-1609	-2607	1221	-312	-1220	2258	881	62
17	3929	282	-1540	-2612	1500	-147	-1123	2614	1134	255
18	4186	414	-1527	-2669	1712	-43	-1083	2899	1322	385
19	4427	473	-1580	-2787	1846	-10	-1110	3101	1434	442
20	4649	451	-1705	-2973	1892	-57	-1211	3211	1460	419
21	4851	339	-1911	-3234	1843	-191	-1396	3219	1391	305
22	5031	130	-2203	-3575	1690	-419	-1669	3117	1222	95
23	5187	-182	-2588	-4003	1427	-748	-2037	2898	944	-218
24	5319	-602	-3069	-4520	1047	-1183	-2504	2556	552	-639
25	5425	-1136	-3651	-5132	547	-1728	-3075	2085	42	-1173
26	5505	-1785	-4338	-5840	-78	-2386	-3754	1483	-591	-1823
27	5557	-2554	-5131	-6647	-831	-3161	-4541	745	-1348	-2593
28	5583	-3444	-6032	-7555	-1713	-4053	-5440	-129	-2232	-3482
29	5580	-4455	-7042	-8565	-2725	-5064	-6450	-1142	-3244	-4494
30	5550	-5588	-8161	-9675	-3867	-6193	-7572	-2293	-4383	-5626
31	5492	-6841	-9388	-10886	-5138	-7440	-8804	-3580	-5649	-6879
32	5408	-8213	-10720	-12196	-6536	-8803	-10146	-5002	-7039	-8250
33	5297	-9701	-12157	-13602	-8058	-10278	-11594	-6556	-8551	-9737
34	5161	-11300	-13693	-15101	-9700	-11864	-13145	-8237	-10181	-11336
35	5000	-13008	-15326	-16690	-11458	-13553	-14795	-10040	-11923	-13042

Table 13

Analysis of First Mover R&D Incentives

First Mover's DPV-Maximizing R&D Outlays as Percentage of Social Benefit-Maximizing Outlay

Social Optimum Computed with 16-Year Patent Life
First Mover Enters Market at 50 Percent Rate

Case 1: Large Market (Demand Slope = -.03)

Erosion Rate	Imitator Begins Entry at Year	3	4	5
.10		92.6%	92.6%	92.6%
.15		88.9	88.9	92.6
.20		85.2	88.9	88.9

Case 2: Medium-Size Market (Slope = -.05)

	3	4	5
.10	84.6%	86.5%	88.5%
.15	78.9	80.8	84.6
.20	73.1	76.9	80.8

Case 3: Small Market (Slope = -.07)

	3	4	5
.10	0	80.0%	80.0%
.15	0	0	76.0
.20	0	0	0

OK

Table 14

Analysis of First Mover R&D Incentives

First Mover's DPV-Maximizing R&D Outlays as
Percentage of Social Benefit-Maximizing Outlay
Social Optimum Computed with 16-Year Patent Life
First Mover Enters Market at 50 Percent Rate
First Mover's Minimum Market Share Capped at 30%

Case 1: Large Market (Demand Slope = -.03)

Erosion Rate	Imitator Begins Entry at Year 3	4	5
.10	92.6%	92.6%	92.6%
.15	88.9	92.6	92.6
.20	88.9	90.7	92.6

Case 2: Medium-Size Market (Slope = -.05)

	3	4	5
.10	84.6%	88.5%	88.5%
.15	80.8	84.6	88.5
.20	80.8	84.6	84.6

Case 3: Small Market (Slope = -.07)

	3	4	5
.10	76.0	80.0%	84.0%
.15	0	0	80.0
.20	0	0	76.0