Market Structure and Innovation
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MARKET STRUCTURE AND INNOVATION*

GLENN C. LOURY

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I. INTRODUCTION

In the application of conventional economic theory to the regulation of industry, there often arises a conflict between two great traditions. Adam Smith's "invisible hand" doctrine formalized in the First Fundamental Theorem of Welfare Economics supports the prescription that monopoly should be restrained and competitive market structures should be promoted. On the other hand, Schumpeter, in his classic *Capitalism, Socialism and Democracy,* takes a dynamic view of the economy in which momentary monopoly power is functional and is naturally eroded over time through entry, imitation, and innovation. Indeed the possibility of acquiring monopoly power and associated quasi rents is necessary to provide entrepreneurs an incentive to pursue innovative activity. As Schumpeter put it, progress occurs through a process of "creative destruction." An antitrust policy that actively promotes static competition is not obviously superior to *laissez faire* in such a world.

This leads one to ponder what degree of competition within an industry leads to performance that is in some sense optimal. This question has been extensively studied in the literature concerning the relationship between industrial concentration and firm investment in research and development.[1] Both theoretical[2] and empirical[3] studies have suggested the existence of a degree of concentration intermediate between pure monopoly and atomistic (perfect) competition that is best in terms of R & D performance.

* The author has benefited considerably from discussion of this paper with Sanford Grossman, Mort Kamien, F. M. Scherer, and Nancy Schwartz, though he alone is responsible for any remaining inadequacies.

1. This literature was thoroughly reviewed by Kamien and Schwartz [1975].
2. See, for example, Scherer [1967b], Barzel [1968], and Kamien and Schwartz [1972, 1976]. Perhaps closer to the Schumpeterian tradition of evolutionary dynamics is the work of Nelson and Winter [1978] and Futia [1977]. A recent paper by Dasgupta and Stiglitz [1977] adopts an approach similar to that taken here.
3. Among the numerous studies consistent with this view are Mansfield [1963], Williamson [1965], and Scherer [1967a].

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Much of this literature has been a partial-equilibrium analysis, parameterizing industry structure in some way and then studying how an individual firm's behavior varies with the degree of industrial concentration. Noteworthy among these efforts is the work of Kamien and Schwartz [1972, 1976]. They study the optimal timing decision under rivalry for a firm contemplating the introduction of an innovation. The firm can reduce R & D costs by pursuing a longer lived development strategy, but only at the expense of increasing the probability that a rival will introduce the innovation first. In Kamien and Schwartz [1976] it is shown that more intense rivalry, characterized by an earlier expected date of rival introduction, will first elicit a greater R & D investment by the expected profit-maximizing firm, but will eventually cause the optimal intensity of innovative activity to decline. Thus, there is generally some intermediate degree of rivalry at which a firm's pursuit of R & D is most vigorous.

This approach to the problem, while highly suggestive, seems unsatisfactory for several reasons. As already noted, this is partial-equilibrium analysis, studying the behavior of an individual firm that views market conditions parametrically. In a given industry, however, every firm is the rival of every other firm. Thus, the likelihood of rival precedence depends on the R & D strategies chosen by other market participants, and cannot be treated as a parameter when analyzing changes in those decisions. Moreover, one cannot infer the change in aggregate innovative activity from the change in a single firm's investment intensity when rivalry has increased. The reason is that if greater rivalry means more firms are competing for the same prize, then a lower investment by each firm could well be outweighed by the increased number of firms. Finally, the policy relevance of these conclusions (concerning the impact of increased rivalry on R & D investments) is far from clear. Whether or not the greater investment in innovation, that more (or less) competition might bring forth, is actually in the social interest is an unanswered question. Thus, this approach does not provide a guide for antitrust policy.

This first point concerning the interdependency of firm investment strategies has been recognized for some time. An insightful earlier analysis by Scherer [1967b] studied the problem of firm R & D expenditures as a Cournot game. Each firm took account of other firms' investment intensities when formulating its optimal strategy, but believed that other firms' actions would be unaffected by its own decisions. Scherer found that symmetrically increasing the number of firms, and hence reducing the "representative" would-be innovator's initial market share, led to a greater marginal payoff to R & D investment for each firm. He could not, however, be sure that the overall profitability of the R & D project would remain nonnegative as the number of firms increased. He was quite correct in qualifying his conclusion that atomistic competition would provide the greatest incentive for innovative activity.

The present paper drawing on the work of Scherer and Kamien and Schwartz, formulates a model in which each firm invests in research and development under both technological and market uncertainty. Technological uncertainty arises from the assumed stochastic relationship between a firm's R & D investment and the time at which the innovation may be introduced by the firm. Market uncertainty is due to the fact that no firm can be sure when any of its rivals' R & D efforts will be successful. Firms are interdependent; the market uncertainty about a rival's introduction date faced by each firm is the result of rivals' investment decisions and the technologically uncertain relationship between those investments and the time of introduction of the innovation. Given the industry's market structure, equilibrium occurs when each firm's investment decision maximizes its expected discounted profits, subject to the other firms' R & D investment strategies being given. Rivalry is taken to be greater when the number of identical competing firms increases. The model is used to study the impact of market structure on R & D performance at both the firm and industry level, as well as the consequent effect on social welfare. Patent policy and antitrust considerations pertaining to ease of entry are examined as tools for improving industry performance.

II. THE MODEL

Imagine a world in which n identical firms compete for the constant, known, perpetual flow of rewards V that will become available only to the first firm that introduces an innovation. Assume for the moment indefinite patent protection so that belated innovators get no net rewards. A variable patent life will be studied later as a policy tool. Assume further that firm i, by making a contractual commitment to R & D with an implied present value of cost x_i, in effect purchases a random variable $\tau(x_i)$, which represents the uncertain date at which the R & D project will be successfully completed. This commitment is assumed binding so that the costs of carrying out an investment project may be taken as known at the initial moment, independent of subsequent developments.[4] Moreover, assume the following

4. This assumption is weakened in Lee and Wilde [1978], modifying some of the results presented below.

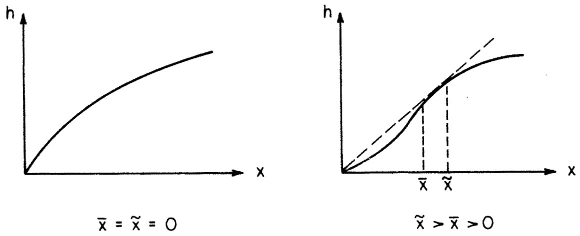

FIGURE I

technological relationship:

$$\text{(1)} \qquad \operatorname{pr}[\tau(x_i) \leq t] = 1 - e^{-h(x_i)t}.$$

That is, $\tau(x_i)$ is exponentially distributed with an expected time of introduction given by

$$\text{(2)} \qquad E\,\tau(x) = h(x)^{-1}.$$

Thus, by making an investment valued presently at x, the firm "produces" the constant, perpetual, instantaneous probability $h(x)$ that the innovation will be ready for the market at any subsequent moment. That is, $h(x)dt$ is the constant probability that if the innovation is not ready at time t, it will be ready at time $t + dt$, where dt is an infinitesmal increment of time. Let $C(\cdot)$ be the inverse of $h(\cdot)$, satisfying $C(h(x)) \equiv x$. Then $C(h)$ is the present value of costs that must be incurred to produce for all time the instantaneous probability of introduction h.

Here we take $h(\cdot)$ to be twice continuously differentiable, strictly increasing, satisfying

$$\text{(3)} \qquad h(0) = 0 = \lim_{x \to \infty} h'(x)$$

and

$$h''(x) \gtreqless 0 \quad \text{as} \quad x \lesseqgtr \bar{x},$$

with $\bar{x}$ possibly equal to zero. Equation (3) expresses the assumption that while there may be an initial range of increasing returns to scale in the R & D technology, diminishing returns are encountered eventually. Let $\tilde{x}$ denote the point where $h(x)/x$ is greatest (see Figure I).

To express the ith firm's *market uncertainty* regarding the time at which any rival will introduce the innovation, define $\hat{\tau}_i$ as the random variable representing this unknown date. If firms' expectations are rational (i.e., correct) as we shall assume, then $\hat{\tau}_i$ is related to the behavior of other firms by

$$\hat{\tau}_i = \min_{1 \leq j \neq i \leq n} \{\tau(x_j)\}. \tag{4}$$

Let us assume now that there are no externalities in the R & D process (no theft of trade secrets for example), so that the random variables $\tau(x_i)$, $i = 1, \ldots, n$, may reasonably be taken as independent. Then

$$\mathrm{pr}[\hat{\tau}_i \leq t] = 1 - \exp\left(-t \sum_{i \neq j} h(x_j)\right) = 1 - e^{-a_i t}, \tag{5}$$

where

$$a_i \equiv \sum_{i \neq j} h(x_j),$$

and a_i is taken as constant by the ith firm. Let the rate at which firms discount future receipts be r. At any time $t \geq 0$ the ith firm earns a revenue flow V in the event that $\tau(x_i) \leq \min(\hat{\tau}_i, t)$. This is so because in order to earn the reward flow at t a firm must have introduced the innovation previously. Moreover, it must also be the case that no other firm "beat it to the market" with the innovation. Integrating the joint density of $(\tau(x_i), \hat{\tau}_i)$ over the relevant region, we have

$$\begin{aligned} &\mathrm{pr}[\tau(x_i) \leq \min(\hat{\tau}_i, t)] \\ &= e^{-a_i t}(1 - e^{-h(x_i)t}) + a_i \int_0^t (1 - e^{-h(x_i)s})\, e^{-a_i s}\, ds \\ &= \frac{h(x_i)}{a_i + h(x_i)}(1 - \exp(-t[a_i + h(x_i)])). \end{aligned} \tag{6}$$

Assuming that the ith firm chooses x_i, given a_i, r, and V to maximize expected discounted profits, it must solve the following problem:

$$\max_x \left\{\frac{Vh(x)}{r(a_i + r + h(x))} - x\right\} \equiv \max_x \Pi(a_i, x; V, r). \tag{7}$$

From our assumptions (3) it is clear that a global maximum will exist as long as expected profits are nonnegative at some $x > 0$. We shall assume this to be true for $a_i = 0$ (i.e., in the absence of rivalry), and deduce below further conditions assuring the nonnegativity of profits at a solution to the first-order condition for (7) when $a_i > 0$. This assumption is not restrictive, for the problem would not be interesting if innovation were unattractive even in the absence of rivalry.

It follows that necessary conditions for $\hat{x}$ to be an interior solution to (7) are (omitting the subscript for firm i)

$$\frac{h'(\hat{x})\,(a+r)}{(a+r+h(\hat{x}))^2} - \frac{r}{V} = 0, \tag{8}$$

and

$$h''(\hat{x})\,(a+r+h(\hat{x})) - 2h'(\hat{x})^2 \leq 0. \tag{9}$$

Equation (8) defines $\hat{x} = \hat{x}(a,r,V)$ implicitly. $\hat{x}$ is the expected profit-maximizing investment in research and development for a firm which presumes that the instantaneous probability of rival introduction is a. $\hat{x}$ is the function whose properties are studied in Kamien and Schwartz [1976]. Note from (8) and (9) that $\hat{x}$ is increasing in V and decreasing in r, as one would expect. Now the symmetry of our firms dictates that, in equilibrium, they pursue the same investment strategies. Moreover, since their expectations are rational and each is investing x^* in equilibrium, we must have for each firm that $a = (n-1)h(x^*)$, or from (8)

$$x^* = \hat{x}((n-1)h(x^*), r, V). \tag{10}$$

Equation (10) implicitly defines the equilibrium level of firm R & D investment $x^* = x^*(n,r,V)$. We note that an equilibrium exists as long as R & D is profitable in the absence of rivalry.[5] Notice also that we define equilibrium relative to a fixed market structure; entry is considered in the following section. For now, we examine the impact of greater rivalry on a firm's innovative activity by studying the dependency of x^* on n.

Before pursuing this, however, we shall first examine why a partial-equilibrium analysis of this problem gives misleading results. As noted, the method previously employed was effectively to calculate $\partial\hat{x}/\partial a$, concluding that greater rivalry stimulates R & D activity if $\partial\hat{x}/\partial a > 0$. Now it is easily seen from (8) and (9) that $\partial\hat{x}/\partial a \gtreqless 0$ as $h(\hat{x}) \gtreqless a + r$. Consult Figure II. There are two cases: (i) $h^{-1}(r) \geqq \hat{x}(0,r,V)$ or (ii) $h^{-1}(r) < \hat{x}(0,r,V)$. Case (i) implies that greater rivalry always reduces investment. Moreover, since it is clear that $\lim_{a\to\infty} \hat{x}(a,r,V) = 0$, the only possible pattern in case (ii) is that indicated in the figure—namely that investment is a single peaked function of the

5. That is, one can show that an x^* exists which solves (10) as long as $\hat{x}(0,r,V) > 0$. However, for sufficiently large n profits may be negative at such a solution. We address this problem below when long-run industry equilibrium is considered.

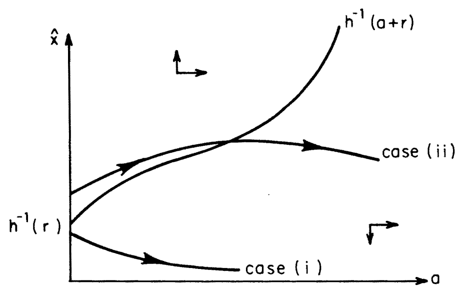

FIGURE II

degree of rivalry, increasing initially but eventually declining thereafter.

Now these are precisely the conclusions reached by Kamien and Schwartz. Yet these results do not stand once rival behavior is made endogenous. For when $n \geq 2$, $\partial\hat{x}/\partial a$ is necessarily negative *at any equilibrium.* One then has the following proposition:

PROPOSITION I. As the number of firms in the industry (i.e., the extent of rivalry) increases, the equilibrium level of firm investment declines.

Proof. Regarding n as a continuous variable, totally differentiate (10) to find (for $n \geq 2$) that

$$\frac{\partial x^*}{\partial n} = \frac{\partial\hat{x}/\partial a\, h(x^*)}{1-(n-1)h'(x^*)\partial\hat{x}/\partial a} < 0.$$

Q.E.D.

Thus, we have found the implication of profit maximization, rational expectations, and Cournot behavior to be that increasing the extent of rivalry unambiguously reduces an individual firm's incentive to invest in R & D.

It does *not* follow from Proposition I that a more competitive market structure means a later expected introduction date for the innovation. To see this, define the random variable $\tau(n) \equiv \min_{1\leq i\leq n} \{\tau(x_i^*)\}$, the random date on which the innovation first becomes available to society. Notice that in equilibrium we have (suppressing dependency on r and V)

(11) $$E\tau(n) = \{nh[x^*(n)]\}^{-1}.$$

The following proposition shows that given a reasonable stability condition, increasing the number of competitors in an industry reduces the expected time that society has to wait for the innovation, despite the fact that each competitor invests less in R & D.

PROPOSITION II. Suppose that with the industry in equilibrium, a marginal increase in R & D investment by any single firm causes the investment of each other firm to fall by a smaller amount. Then increasing the number of firms always reduces the expected industry introduction date.

Proof. Industry expected introduction date declines with the number of firms if and only if $d/dn\ (nh(x^*(n))) > 0$. Now

$$\frac{d}{dn}(nh(x^*(n))) = h(x^*(n)) + nh'(x^*(n))\frac{\partial x^*}{\partial n}$$

$$= h(x^*(n))\left[1 + \frac{nh'(x^*(n))\partial\hat{x}/\partial a}{1-(n-1)h'(x^*(n))\partial\hat{x}/\partial a}\right]$$

from the proof of Proposition I. Thus,

$$\frac{d}{dn}(nh(x^*(n))) \gtreqless 0 \quad \text{as} \quad -h'(x^*)\frac{\partial\hat{x}}{\partial a} \lesseqgtr 1.$$

Suppose that the industry is in equilibrium and some firm raises investment one unit. Then each other firm sees an increase in a of $h'(x^*)$, and hence reduces investment by the amount, $-h'(x^*)\partial\hat{x}/\partial a$. Q.E.D.

III. COMPETITIVE ENTRY AND LONG-RUN EQUILIBRIUM

The foregoing discussion has examined optimal firm investment in R & D with the market structure (n) given. In the absence of barriers to entry, we may expect additional firms to enter the innovation race as long as expected profits are strictly positive.[6] Using (7) and (8), we may write the equilibrium expected profits of a representative firm as

$$\Pi(a,x;r,V) = \frac{h(x^*)}{h'(x^*)}\left[\frac{(a+r+h(x^*))}{(a+r)}\right] - x^*, \tag{12}$$

where equilibrium requires that $a = (n-1)\ h(x^*)$. Now if h is a concave function, then $h(x)/x \geq h'(x)$, and expected profits are always positive. This gives the following result:

6. Note that the reference is to ex ante expected profits which, prior to innovation, are the same for all firms and constant over time. Ex post only one firm will earn positive profits; all of the others will have incurred losses.

PROPOSITION III. If the technology for innovation exhibits diminishing returns to scale throughout, in a sense that $h'' < 0$, then expected profits are driven to zero only in the limit as the number of firms approaches infinity.

Thus, atomistic competition would be the natural outcome with continuously diminishing returns and zero entry costs. In this limiting case, each firm would invest an infinitesmal amount. Given our stability conditions, however, aggregate innovative activity would be greater than that forthcoming in equilibrium with any finite number of firms.

More interesting is the case with an initial range of increasing returns. Here there are two exhaustive possibilities. Either entry continues until equilibrium expected profits have been driven to zero with a finite (though perhaps non-integral) number of firms in the industry, or expected profits approach zero asymptotically as the number of firms goes to infinity. In either case continued entry causes a monotonic decrease in equilibrium expected profits. Moreover, the zero expected profit equilibrium will involve firms operating with "excess capacity" in the sense that they will not exploit all of the scale economies in the innovation technology. These results are summarized in the following proposition.

PROPOSITION IV. The equilibrium expected profits of a representative firm decrease as additional firms enter the industry. With initial increasing return, entry eventually drives expected profits to zero, possibly with a finite number of firms in the industry. Long-run industry equilibrium when there is an initial range of increasing returns and zero expected profits always involves "excess capacity" in the R & D technology.

Proof. Suppressing dependence on r and V, we have from (7) that $\Pi = \Pi(a,x)$. In equilibrium, $a = (n-1)h(x^*)$, and (10) gives x^* as a function of n. Thus,

$$\left.\frac{d\Pi}{dn}\right|_{eq} = \frac{\partial \Pi}{\partial a}\left[(n-1)h'(x^*)\frac{\partial x^*}{\partial n} + h(x^*)\right] + \frac{\partial \Pi}{\partial x}\frac{\partial x^*}{\partial n}.$$

It is obvious from (7) that $\partial\Pi/\partial a < 0$, while (8) is the requirement that $\partial\Pi/\partial x = 0$. Hence,

$$\frac{d\Pi}{dn} \gtreqless 0$$

as

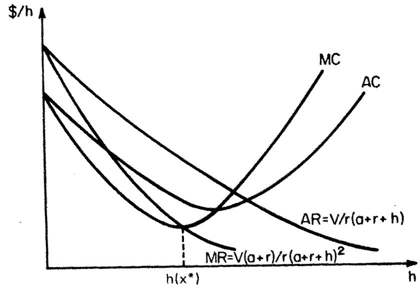

FIGURE III

$$\frac{-(n-1)h'(x^*)\partial\hat{x}/\partial a}{-(n-1)h'(x^*)\partial\hat{x}/\partial a + 1} \gtreqless 1.$$

Thus, equilibrium profits decrease in n. Now suppose that profits are positive for all finite n. Then (10) implies that $\lim_{n\to\infty} x^*(n) = 0$. Moreover, from (12) and the fact that $\lim_{x\to 0} h(x)/x = h'(0)$, it follows that

$$\lim_{n\to\infty} \Pi((n-1)h(x^*(n)),\ x^*(n)) = 0.$$

On the other hand, if there exists $n_0 < \infty$ for which equilibrium expected profits are zero, then (12) implies that

$$\frac{h(x^*(n_0))}{x^*(n_0)}\ \frac{(n_0h(x^*(n_0)) + r)}{((n_0-1)h(x^*(n_0)) + r) = h'(x^*(n_0))}.$$

Clearly $h(x^*(n_0))/x^*(n_0) < h'(x^*(n_0))$. Thus, $x^*(n_0) < \tilde{x}$, and there is excess capacity.

Q.E.D.

The results of Proposition IV may be illustrated graphically as a special case of Chamberlin's monopolistic competition equilibrium.[7] Recall the cost function $C(h)$ introduced above. Now with initial increasing returns, the average cost function $C(h)/h$ will be U-shaped. Moreover, average and marginal revenues may be expressed as functions of h for the representative firm with a, r, and V given. These relationships are noted in Figure III. Expected profits are maximized where $MR = MC$. Now the argument to prove $d\Pi/dn\,|_{eq} < 0$ may be employed to show that $d/dn\ [(n-1)h(x^*(n))] > 0$, without recourse to the stability assumption. Thus, entry raises a for the representative firm in equilibrium, causing the marginal and average revenue curves

7. See Chamberlin [1960].

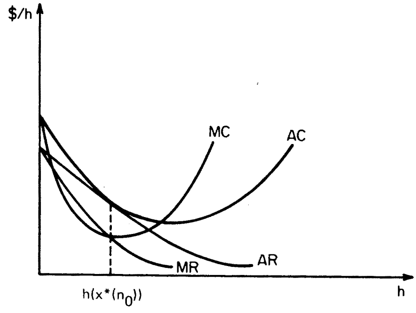

FIGURE IV

of Figure III to decline. This Chamberlinian process continues until the average cost curve is just tangent to the average revenue curve at a level of h (and hence x) where marginal revenue equals marginal costs (Figure IV). Since average revenue is everywhere downward sloping, marginal revenue lies below it everywhere. Consequently, when profits are maximized and simultaneously equal to zero, it must be that $MC < AC$. Hence there will be excess capacity.

IV. Welfare Analysis of Industry Equilibria

Let us now consider the efficiency properties of short-run and long-run market equilibrium. There are essentially three factors that work against efficient resource allocation here. First is the classical argument for failure in the market for inventions—that private investors cannot appropriate for themselves the entire social benefit of the innovations they finance.[8] In our model this could be expressed by assuming that the net social benefit flow (V_s) is not equal to the private flow of quasi rents (V). The inappropriability argument suggests that $V_s > V$, though (as observed in note 8) there are instances when it is plausible that $V_s < V$. This divergence between private and social return may work in either direction, depending, for example, on whether or not close substitutes already exist for an innovated product. Since this issue in general cannot be resolved, I as-

8. This argument is advanced many places, for example, in Arrow [1962]. As Hirshleifer [1971] has pointed out, private returns to investment in the production of information can *exceed* social returns. This is also true for product innovations. (For evidence see Mansfield *et al.* [1977].) They can generate less net social than private surplus because of reduced demand on markets adversely affected by the introduction of a new product. On this see Spence [1976].

sume that $V_s = V$ and focus on two other reasons for market failure.[9]

The first of these arises in the short run because of what might be termed "duplication of effort." Each firm chooses an investment level to maximize $\pi(a,x)$, taking a as given. In a symmetric Nash equilibrium, $a = (n-1)h(x)$. From the assumption of symmetry, each firm has probability $1/n$ of being the innovator. Since the private and social net benefit flows coincide, the expected present value of social benefits at an equilibrium is equal to $n\pi((n-1)h(x^*(n)), x^*(n))$. This is so because (given that innovation has occurred) private and social gains coincide, but while each firm faces probability $1/n$ of being first, society is indifferent as to which firms win the race. It is clear then that in (short-run) equilibrium firms tend to overinvest in R & D because they do not take account of the parallel nature of their activities. Let $x^{**}(n)$ denote the socially efficient firm investment level when market structure is fixed at n.

PROPOSITION V. Given a fixed market structure (n), in industry equilibrium each firm invests more in R & D then is socially optimal.

Proof. Given n, social welfare is maximized when

$$0 = \frac{\partial \pi}{\partial x}((n-1)h(x),x) + (n-1)h'(x)\frac{\partial \pi}{\partial a}((n-1)h(x),x),$$

but industry equilibrium is characterized by

$$\frac{\partial \pi}{\partial x}((n-1)h(x),x) = 0.$$

Since $\partial\pi/\partial\alpha < 0$ and $\partial^2\pi/\partial x^2 \leqq 0$ (by second-order condition) it follows that $x^*(n) > x^{**}(n)$.

Q.E.D.

The other source of inefficiency manifests itself in long-run industry equilibrium. Industry structure and firm investment are determined by n and x, respectively. A socially optimal long-run industry allocation is a pair denoted (n^*,x^{**}), which maximizes $n\,\pi((n-1)h(x),x)$. Long-run industry equilibrium, however, occurs at an industry structure n_0 that satisfies $\pi((n_0-1)h(x^*(n_0)), x^*(n_0)) = 0$. If $n_0 < \infty$, this implies zero net social benefit in long-run equilibri-

9. The resolution of this issue depends on the facts peculiar to each case in question. The assumption $V_s = V$ would hold (for example), if the innovation were a new product which had no effect on the demand curves for existing products, and if the innovator were a perfectly discriminating monopolist.

um. It is apparent that such an industry allocation could not be socially optimal.

PROPOSITION VI. If $\bar{x} > 0$ (see equation (3)), then competitive entry induces too many firms to join the innovation race.

Proof. As above, denote by (n^*,x^{**}) the solution of

$$\max_{(n,x)} n\pi((n-1)h(x),x).$$

First-order conditions for this problem are

$$\frac{h(x^{**})}{x^{**}} = \frac{(n^*h(x^{**})+r)^2}{V} = h'(x^{**}).$$

It is clear then that $x^{**} = \tilde{x}$. We show now that $n^* < n_0$. By Proposition IV $x^*(n_0) < \tilde{x}$, and Proposition V implies that $x^*(n^*) > \tilde{x}$. Moreover, Proposition I asserts that $\partial x^*/\partial n < 0$. Therefore, $n^* < n_0$.

Q.E.D.

The meaning of Proposition VI is clear. When entry is unimpeded, if the technology possesses economies of scale initially, and if innovating firms struggle for the entire social payoff, *there will be too much competition.*[10] Intuitively this may be seen as follows. Economies of scale are always fully exploited in a socially optimal allocation. This implies a finite number of firms, each operating at the efficient scale, earning positive expected profits. Now the social payoff is obtained when any one of these firms is successful, and each firm has an equal chance of success. Thus, the social net gain is proportional to the private net gain. Yet positive private returns attract entry. When all of the private profits have been competed away and the number of firms is finite, then the net social gain has vanished as well. When the number of firms is infinite in the zero profit equilibrium, net social gain could be positive, but could hardly be maximal. In this instance no scale economies are being exploited, and "mergers" of parallel R & D efforts would obviously improve performance.

Finally, let us consider how these various inefficiencies may be corrected through the judicious choice of a patent life and an entry tax-subsidy. Suppose that instead of indefinite patent protection as assumed above, the government provides an innovator with exclusive rights for a finite length of time T. Assume further that, upon expiration of the patent, the quasi-rent flow V will be competed away

10. This result appears to be a special case of that given in Weitzman [1974], section 6.

completely. Then, as may be readily seen, this state of affairs is equivalent to each competitor facing a *perpetual* income flow of $V(1 - e^{-rT})$ in the event of innovation. Thus, a limited life patent in this model has the effect of altering the perceived flow of benefits such that (when market structure is n and a patent of length T is in use) equilibrium firm investment is given by $x^*(n,r,V(1 - e^{-rT}))$. By Proposition V we conclude that, for each n, there exists a patent life $\hat{T}(n)$ such that $x^*(n,r,V(1 - e^{-r\hat{T}(n)})) = x^{**}(n)$. Choice of patent life $\hat{T}(n)$ by the public authority will induce rivalrous firms to invest optimally, given the fixed market structure.

This still does not guarantee that competitive entry will result in the socially optimal market structure n^*, since firm expected profits need not be zero when $n = n^*$ and $T = \hat{T}(n^*)$. On the other hand, by levying a lump sum entry tax (subsidy) equivalent to the level of firm expected profits (losses) when market structure is n^* and patent life is $\hat{T}(n^*)$, long-run industry equilibrium will be socially optimal. Thus, we have established the following:

PROPOSITION VII. There exists a finite patent life and an entry tax (possibly negative) in the presence of which the long-run industry equilibrium is socially optimal.

V. CONCLUSION

An equilibrium model of investment in R & D under rivalry has been constructed. In this model firms are assumed to maximize their expected profits under conditions of technological and market uncertainty. Their perceived market risks are not social risks, however, and this leads to a basic failure of the competitive mechanism. It is seen that more competition (rivalry) reduces individual firm investment incentives in equilibrium, yet leads (under certain reasonable conditions) to an increased probability that the innovation will be introduced by any future date.

More competition is not necessarily socially desirable. With continuously diminishing returns to R & D investment, atomistic competition is the market structure giving optimal innovative activity. This structure is approached under competitive conditions with costless entry. In the more realistic case of initial scale economies, the optimal market structure involves a finite number of firms. Yet, if entry is again costless and occurs until no firm expects positive profit in equilibrium, more firms will enter the innovation race than is socially optimal. In any market structure, competing firms invest more in R & D than would be optimal because they do not take account of the parallel nature of their efforts. The nature of the market failure is quite similar to what occurs in common pool resource problems. Social welfare can be maximized by appropriately limiting entry and firm investments with licensing fees and finite patent life.

The model is highly simplified; several qualifications are in order. Imitation may lower the flow of rewards to the innovating firm subsequent to the introduction of the innovation. Imitation does not affect the socially optimal allocation, but it does reduce private investment incentives. Thus, in this case, competitive firms may not overinvest. Similarly, with the possibility of imitation, the zero expected profit equilibrium market structure would seem to involve fewer firms. Thus, the result that entry barriers can improve welfare may also fail. A final, important shortcoming of this model is that competing firms lose nothing but their R & D investment when a rival beats them to the innovation. In reality the market shares of competing firms are constantly changing as new innovations attract competitors' customers.[11] Again, these gains and losses of market shares involve private, but not social, payoffs. Their inclusion will affect results on the relationship between equilibrium and optimal allocations. Given these qualifications, the agenda for future work should be clear.

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11. For a model that considers some of the positive implications of this observation, see Futia [1977].

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