Market structure and Innovation

This presentation is based on the paper “Market structure and Innovation” authored by Glenn C. Loury, published in “The Quarterly Journal of Economics”, Vol. 93, No.3 (Aug 1979)

I. Introduction

The possibility of acquiring monopoly power and associated quasi rents is necessary to provide entrepreneurs an incentive to pursue innovative activity.

Both theoretical and empirical studies have suggested the existence of a degree of concentration intermediate between pure monopoly and perfect competition that is best in terms of R&D performance.

The present paper drawing on the work of Scherer and Kamien and Schwartz (1972, 1976), formulates a model in which each firm invests in R&D under both technological and market uncertainty.
Given the industry’s market structure, equilibrium occurs when each firm’s investment decision maximizes its expected discounted profits, subject to the other firm’s R&D investment strategies being given.

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.
II The model

Assumptions:

1. n identical firms compete for the constant flow of rewards \( V \) that will become available only to the first firm that introduces an innovation.

2. infinite patent protection so that belated innovators get no net rewards.

Firm \( i \) makes an investment in R&D with a present value of cost \( x_i \). And \( \tau(x_i) \) represents the uncertain date at which the R&D project will be successfully completed.

Assume the following technological relationship:

\[
pr[\tau(x_i) \leq t] = 1 - e^{-h(x_i)t}
\]  

That is, \( \tau(x_i) \) is exponentially distributed with an expected time of introduction given by
\[ E \tau(x) = \frac{1}{h(x)} \]  \hspace{1cm} (2)

Thus, \( h(x) \) is the instantaneous probability that the innovation will be successfully completed (or ready for the market) at any subsequent moment.

We take \( h(.) \) to be twice continuously differentiable, strictly increasing, satisfying

\[ h(0) = 0 = \lim_{x \to \infty} h'(x) \]  \hspace{1cm} (3)

and \( h''(x) \geq 0 \) as \( x \geq \bar{x} \)

\[ \tilde{x} > \bar{x} > 0 \]
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 \( \hat{x} \) denote the point where \( h(x)/x \) is greatest.

1. Define \( \hat{\tau}_i \) as the random variable representing the ith firm’s market uncertainty regarding the time at which any rival will introduce the innovation. \( \hat{\tau}_i \) is related to the behavior of other firms by

\[
\hat{\tau}_i = \min_{1 \leq j \neq i < n} \{\tau(x_j)\} \quad (4)
\]

2. Assume the random variables \( \tau(x_i), i=1,2,\ldots,n \) are independent

\[
pr[\hat{\tau}_i \leq t] = 1 - \exp(-t \sum_{i \neq j} h(x_j)) = 1 - e^{-a_it} \quad (5)
\]

where \( a_i \equiv \sum_{i \neq j} h(x_j) \) and \( a_i \) is taken as constant by the ith firm.

3. At any time \( t \geq 0 \) the ith firm earns a revenue flow \( V \) in the event that \( \tau(x_i) \leq \min(\hat{\tau}_i, t) \).
Integrating the joint density of \( (\tau(x_i), \hat{\tau}_i) \) over the relevant region, we have

\[
pr[\tau(x_i) \leq \min(\hat{\tau}_i, t)]
\]

\[
e^{-a_i t} (1-e^{-h(x_i)t}) + a_i \int_0^t (1-e^{-h(x_i)s}) e^{-a_i s} ds
\]

\[
= \frac{h(x_i)}{a_i + h(x_i)} (1 - \exp(-t[a_i + h(x_i)]))
\]

The \( i \)th firm chooses \( x_i \), given \( a_i, r \) (discount rate) and \( V \) to maximize expected discounted profits, it must solve the following problem:

\[
Max \{ \frac{Vh(x)}{r(a_i + r + h(x))} - x \} \equiv Max \prod (a_i, x_i; V, r)
\]

F.O.C:

\[
\frac{h'(\hat{x})(a + r)}{[a + r + h(\hat{x})]^2} - \frac{r}{V} = 0
\]

S.O.C:

\[
h''(\hat{x}).[a + r + h(\hat{x})] - 2h'(\hat{x})^2 \leq 0
\]

(8) defines \( \hat{x} = \hat{x}(a, r, V) \) implicitly
A symmetric Nash equilibrium implies each firm pursue the
same investment strategy. For each firm, we have that
\( a = (n-1)h(x^*) \). From (8), we have:
\[
\begin{align*}
  x^* &= \tilde{x}((n-1)h(x^*), r, V) \\
  (10)
\end{align*}
\]
Equation (10) implicitly defines the equilibrium level of firm
R&D investment \( x^* = x^*(n, r, V) \)
Now, we examine the impact of greater rivalry on a firm’s
innovative activity by studying the dependency of \( x^* \) on
\( n \).

**Proposition I:**
As the number of firms in the industry increases, the
equilibrium level of firm investment declines.

**Proof:**
Regarding \( n \) as a continuous variable, totally differentiate
(10) to find (\( n \geq 2 \)) that
\[
\frac{\partial x^*}{\partial n} = \frac{\partial \tilde{x} / \partial ah(x^*)}{1-(n-1)h'(x^*)\partial \tilde{x} / \partial a} < 0
\]
Thus, we have found that increasing the extent of rivalry
reduces an individual firm’s incentive to invest 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 (the date on which the innovation first becomes available to society).

Proof:
Define a 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. In equilibrium, we have

\[
E \tau(n) = \frac{1}{nh[x^*(n)]}
\]

Industry expected introduction date declines with the number of firms if and only if

\[
\frac{d}{dn} (nh[x^*(n)]) > 0
\]

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

\[
= h[x^*(n)][1 + \frac{nh'[x^*(n)] \frac{\partial x^*}{\partial a}}{1 - (n-1)h'[x^*(n)] \frac{\partial x^*}{\partial a}}]
\]
From the proof of Proposition I, thus \( \frac{d}{dn} (nh[x^*(n)]) \geq 0 \) as 

\[-h'(x^*) \frac{\partial \hat{x}}{\partial a} \leq 1 \]

This 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.

III. Welfare analysis of industry equilibrium.

Now consider the efficiency properties of short-run and long-run equilibrium

1. In the short run, “duplication effort” will cause inefficiency. Each firm chooses an investment level to maximize \( \pi(a,x) \), taking \( a \) as given. In a symmetric Nash equilibrium, \( a = (n-1)h(x) \). The expected present value of social benefits at an equilibrium is equal to \( n\pi((n-1)h(x^*),x^*(n)) \). Each firm faces probability \( \frac{1}{n} \).
of being first, but society is indifferent as to which firms win the race. Then in short-run equilibrium firms tend to overinvest in R&D because they do not take account of the parallel nature of their activities.

Proposition III:
Given a fixed market structure \((n)\), in industry equilibrium each firm invests more in R&D than is socially optimal.

Proof:
Let \(x^{**}(n)\) denote the socially efficient firm investment level when market structure is fixed at \(n\). Given \(n\), social welfare is maximized when

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

but industry equilibrium is characterized by

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

Since \(\partial \pi / \partial a < 0\) and \(\partial^2 \pi / \partial x^2 \leq 0\). It follows that \(x^*(n) > x^{**}(n)\)
2. In long-run industry equilibrium, there is also a source of inefficiency.

**Proposition IV:**

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

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. In this instance, no scale economies are being exploited, and "mergers" of parallel R&D efforts would obviously improve performance.

These inefficiencies may be corrected through the judicious choice of a patent life and an entry tax-subsidy.

**Proposition V:**

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.
IV conclusion

. This is an equilibrium model of investment in R&D under rivalry. In this model, firms are assumed to maximize their expected profits under conditions of technological and market uncertainty.

. More competition reduces individual firm’s 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. In equilibrium, more firms will enter the innovation race than socially optimal. Competing firms also invest more in R&D than socially optimal because they do not take account of the parallel nature of their efforts.
Some shortcomings of this model:

- Imitation may reduce private investment incentives. In this case, competitive firms may not overinvest. But this model didn’t take this effect into account.

- This model assume 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.