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Product Innovation in a Cournot Economy: Competition on Innovation and Competition on Imitation

by

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ABSTRACT

A product is developed and introduced into the market as an output of research efforts. At first it is a monopolistically supplied new product, then newer products appear and it becomes an old product to which imitation may or may not occur, and finally it exits from the market. We formulate this product lifecycle using a variation of generation-overlapping model, to separate competition on imitation from competition on innovation. It is found that the firm spends more on product innovation when imitation is not allowed (irrespective of whether entry is free or not into the innovation sector), and when fewer firms are engaged in innovation (if the number of innovators is fixed). Also, it is conjectured that market mechanism produces too little product innovation and too little variety of products relative to the social optimum.

1. INTRODUCTION

This paper investigates firm decision-making on product innovation, namely, research and development toward new products, and market equilibria under diverse market conditions, assuming a Cournot economy in which every firm takes as given not only prices but also research and development expenditures of its rivals.

As is well known, when Schumpeter (1942) discussed innovation, he regarded the development of new products as one of the most important means of innovation. In fact, in real firms, developing new products is a very important corporate strategy. For instance, when 941 firms were asked to state the objectives of R & D in an investigation by the Economic Planning Agency of Japan (1981, p.220), 69.3 percent of them raised developing new products and/or entering into new industrial fields, which is almost three times the percentage (24.1 percent) given to the development of new processes and/or saving energy and resources.[1]

Despite this importance of product innovation, little effort has been given to theoretically analyze the firm decisions on product innovation and their implications. True, there are several studies on innovation such as the works by Dasgupta and Stiglitz (1980a, 1980b); however, these all considered process innovation, namely, research efforts to reduce production costs. We also have studies on product differentiation such as Spence (1976) and Koenker and Perry (1981); however, these studies used static models in which the cost of developing new differentiated products is not taken into account except as a fixed cost in production. It is needed therefore to model firm research efforts toward new products in order to inquire into the relation between research and development or product variety on the one hand and industrial structure or social welfare on the other.

When a firm succeeds in developing a new product, it establishes itself as a monopolist in the supply of the product, thus earning monopoly profits. However, as time passes and particularly as the patent expires, other firms start imitating to produce the same product and enter into the market. The monopolist position of the original innovator then erodes and his monopoly profits diminishes or vanishes. This suggests that competition occurs in two aspects -- competition on innovation, namely, developing new products, and competion on imitation, namely,supplying the same product as that already introduced by someone else. Likewise, entry occurs in two aspects -- entry into the innovation sector, and entry into the market of an established product. We analyze the problem under this situation by means of the following model.

Suppose that a firm makes research today (period 0) expending R. This research may or may not succeed, but suppose that the extent of the success is measured by the number of resulting new products. Since this number is uncertain at the time of the research, denote its expected value by m, which may be integer or not and may exceed one or not. It is reasonable to assume that m is increasing in R when R exceeds the minimum level R_f that is a fixed-cost portion of the research cost, such as the cost of building and maintaining a laboratory of a minimum scale. It is also reasonable to assume diminishing returns with research; hence, $m = m(R)$ with $m'(R) > 0$ and $m''(R) < 0$ for $R > R_f$ and $m(R) = 0$ for $R \leq R_f$.

Suppose that the new product is introduced into the market at the beginning of the next period (period 1). During this period, only the innovator can produce the product due to, say, the patent protection; thus, he is a monopolist. At the end of the period, however, the patent expires and in the following period (period 2) entry occurs unless other barriers are effective such as those due to brand names or resource availability, and as a result the innovator loses his monopoly profits. In period 3 and the following periods, all the products are assumed to find no demand.

When product life cycle is formulated in this fashion, if entry barrier exists to the market of an old product is one question, and if someone else may enter the innovation sector starting efforts for product innovation when existing innovators earn positive profits net of research costs is another. Thus four cases are separated; monopoly-monopoly with entry barriers, monopoly-competition with entry barriers, monopoly-monopoly with free entry, and monopoly-competition with free entry, where "monopoly" before the hyphen indicates that every innovator is a monopolist in the market for a new product, "monopoly" or "competition" following the hyphen indicates if in the market for an old product monopoly by the innovator persists or entry occurs and perfect competition prevails with zero profit, respectively, and "with entry barriers" or "with free entry" indicates whether or not entry into the innovation sector is impossible even when innovation is profitable.

In this paper, we will compare the levels of research efforts under these four alternative situations, and compare them with the social optimum.

2. MODEL

In each period, there are two types of products -- new products which were introduced into the markets at the beginning of the period as a result of research in the previous period, and old products which were introduced at the beginning of the previous period as a result of research two periods ago. The quantity and price of i-th new product are denoted by x_i and p_i, respectively, whereas those of i-th old product are y_i and q_i. Thus, y_i in this period is the quantity of the product the quantity of which in the last period was x_i.

The utility function of the representative consumer we assume to be

$$U = \sum_i a_1 x_i^b + \sum_i a_1 a_2 y_i^b \qquad (1)$$

where a_1, a_2, and b are all positive constants, b is assumed less than one, and a_2 is assumed not greater than one. If the consumer prefers both an old product and a new product to the same extent, then $a_2 = 1$. However, realistically, a consumer may enjoy novelty getting a larger satisfaction out of a new product than an old one. If so, $a_2 < 1$. The summation in (1) goes over all the products in the market; hence, it in fact is a double summation such that one summation is over the products produced by each firm and the over is over firms. Also, because the first summation in (1) is with respect to the products introduced into the markets in this period whereas the second summation is with respect to the products introduced in the last period, the upper limit of the summation differs between them unless the number of new products is invariant over successive periods.

The utility function, obviously, is separable among goods, and symmetric among new products and among old products (but not between a new product and an old product unless $a_2 = 1$). This symmetry implies that between any pair of new products, between any pair of old products, or between any pair of an old product and a new product, the distance (subjectively evaluated by the consumers) in terms of product characteristics is the same. Hence, such a case is excluded that one new product is a closer substitute to a particular old product than other new products.

The consumers maximize (1) subject to the constraint that

$$\sum_i p_i x_i + \sum_i q_i y_i = Y \qquad (2)$$

where Y is the income or, if we are dealing not with entire economy but with a part of them (say, the machinery industry only), Y may be interpreted as the total expenditure planned to the relevant industry provided that it is determined independently of the prices, p_i and q_i. The constrained utility maximization yields the following conditions:

$$\begin{aligned} x_i &= Ap_i^{-\theta} \\ y_i &= aAq_i^{-\theta} \end{aligned} \qquad (3)$$

where $\theta = 1/(1 - b) > 1$, $A = (\lambda/a_1 b)^{1/(b-1)}$ with λ denoting the Lagrange multiplier, and $a = a_2^{1/(1-b)} \leq 1$ which shows the ratio of the demand to an old product to the demand to a new product at a common price. Since λ depends on Y and prices, so does A. How it is determined will be analyzed later.

On production side, we assume a constant unit cost to be denoted by u. This is assumed constant across different generations of goods; thus, the innovation is a <u>pure</u> product innovation without any element of a cost-reducing product innovation.

Now consider a firm succeeded in innovation and started selling the new product as a monopolist. His gross profit (gross because research cost is not deducted yet) π_x from the product equals $(p - u)x$ suppressing subscript i for p and x. Because he is a monopolist, he determines x and p so that π_x is maximized given the demand function (3). In this maximization, we assume that the firm ignores the dependence of A on its output and pricing decisions. In short, this means that income effect is not taken into account in the pricing decisions. Such effect will be present if the amount spent on the good in question consists a substantial portion of the consumer's budget and hence its price increase significantly decreases his real income, or if the firm thinks it likely that the price change causes changes in other products' prices. That we deny the latter possibility is in line with the Cournot assumption on conjectural variation. It is noted, however, that the Cournot assumption here is extended to apply to other products supplied by the same firm in addition to the products supplied by other firms. That is, even though the firm may supply multi products, in pricing decisions it considers each product separately. It is noted that later, in the firm's decision-making on R & D expenditures, we will assume that the firm takes into account the effect that innovating and introducing another product into the market reduces the demand for other products of the firm because consumers have to cut their expenditures to the other products in order to buy the new product. This may appear inconsistent with the negligence of the income effect in pricing decisions. Logically it probably is. Nevertheless, we consider this rather realistic because increasing the price of a product marginally is likely to reduce consumers' real income only slightly whereas introducing a new product may well cause consumers to significantly alter the allocation of their budgets among diverse products. This is all the more true when, as is very often the case, the firm adopts a multidivisional structure relegating the pricing and output decisions of each good to the relevant division but maintaining the decision on R & D withing the general office (the top executive and the staffs). For each division tends to think of only the product it is dealing with whereas the general office considers matters from the viewpoint of the entire organization.

The maximization then yields

$$p = \theta u/(\theta - 1) \tag{4}$$

and

$$x = A[\theta u/(\theta - 1)]^{-\theta} \tag{5}$$

The gross profit from the product evaluated at the optimal solution is

$$\pi_x = A\theta^{-\theta}u^{-(\theta-1)}(\theta - 1)^{\theta-1} \tag{6}$$

For an old product, depending on whether the market structure is monopoly-monopoly (MM) or monopoly-competition (MC) the market price and output vary. Consider MM first. Then the monopolist's gross profit from the product equals $(q - u)y$ and this is maximized subject to (3), yielding

$$q = \theta u/(\theta - 1) \tag{7}$$

$$y = aA[\theta u/(\theta - 1)]^{-\theta} \tag{8}$$

Thus, the price is the same but the output is less by the proportion of a compared to those of a new product. The gross profit evaluated at this optimal solution is

$$\pi_y = aA\theta^{-\theta}u^{-(\theta-1)}(\theta - 1)^{\theta-1} \tag{9}$$

In MC where the market for an old product is perfectly competitive, the gross profit should be zero. Thus

$$q = u \tag{10}$$

with the output

$$y = aAu^{-\theta} \tag{11}$$

We are now ready to proceed to the analysis of the optimal research efforts.

3. MONOPOLY-COMPETITION (MC) WITH ENTRY BARRIERS

Consider a firm, j, planning research under monopoly-competition (MC). When he expends R^j in this period (period 0), he expects to have new products by the number of $m(R^j)$ in the next period (period 1). Therefore, his expected total gross profits in period 1 are $m(R^j)\pi_x$ where π_x is defined by (6). In period 2, due to the assumption of MC, the firm earns no profit from the products he is to innovate. Hence the expected present value of net profits (net in that research cost is deducted), $V_c(R^j)$, is as follows when β is the discount factor (subscript c indicates MC):

$$\begin{aligned} V_c(R^j) &= m(R^j)\beta\pi_x - R^j \\ &= m(R^j)\beta A_1 \theta^{-\theta} u^{-(\theta-1)}(\theta - 1)^{\theta-1} - R^j \end{aligned} \tag{12}$$

where A_1 denotes the value of A at period 1. Assuming an expected-value-maximization behavior, the optimal level of R^j is determined so as to maximize (12). Before carrying out this maximization, however, we need to evaluate A_1.

At period 1, the total number of new products is $\Sigma_j m(R^j)$ where the summation goes over all the firms, and the total expenditures to new products are $\Sigma_j m(R^j)px$. During the same period, the number of old products depends on research efforts during period (-1) because these are the products introduced at the beginning of period 0. Obviously, research efforts at period (-1), namely, at the past period, are now historically given. Denoting these by $\bar{R}^j$, the total number of old products, $\Sigma_j m(\bar{R}^j) \equiv \Sigma_j \bar{m}^j$, is also given. Then the total expenditures on old products are $\Sigma_j \bar{m}^j qy$. Substituting (4), (5), (10) and (11) into (2), we have

$$\Sigma_j m(R^j) A_1 \theta^{1-\theta} u^{1-\theta} \theta^{\theta-1} + \Sigma_j \bar{m}^j a A_1 u^{1-\theta} = Y_1 \tag{13}$$

with the subscript 1 to A and Y denoting their values in period 1. Solving for A_1, we have

$$A_1 = u^{\theta-1}Y_1/[\theta^{1-\theta}(\theta - 1)^{\theta-1}\Sigma_j m(R^j) + a\Sigma_j \bar{m}^j] \qquad (14)$$

Substituting this into (12), we have

$$\begin{aligned} V_c(R^j) &= \frac{m(R^j)\beta\theta^{-\theta}(\theta - 1)^{\theta-1}Y_1}{\theta^{1-\theta}(\theta - 1)^{\theta-1}\Sigma_j m(R^j) + a\Sigma_j \bar{m}^j} - R^j \\ &= \frac{m(R^j)\beta\hat{\theta}Y_1}{(\hat{\theta}\Sigma_j m(R^j) + a\Sigma_j \bar{m}^j)\theta} - R^j \qquad (15) \end{aligned}$$

where $\hat{\theta} = [(\theta - 1)/\theta]^{\theta-1} < 1$.

To obtain the optimal level of R^j, we differentiate (15) with respect to R^j and set it equal to zero. In this differentiation we assume that $\partial R^k/\partial R^j = 0$ for all $k \neq j$. That is, we assume that an innovator expects his choice of reseach expenditures not affecting his rivals'. This of course is the Cournot behavioral assumption extended to research decisions (see Ruff 1969 for a similar treatment applied to process innovation). We then have (the second-order condition is satisfied because of the negativity of $m''(R^j)$)

$$\frac{m'(R^j)\beta Y_1\hat{\theta}}{(\hat{\theta}\Sigma_j m(R^j) + a\Sigma_j \bar{m}^j)\theta} \left\{ 1 - \frac{\hat{\theta}m(R^j)}{\hat{\theta}\Sigma_j m(R^j) + a\Sigma_j \bar{m}^j} \right\} = 1 \qquad (16)$$

Since $\Sigma_j \bar{m}^j$ is a given datum and β, θ, a, and Y_1 are common across firms, (16) immediately implies that R^j is common across innovators. Therefore the superscript j may be suppressed. Also, the number of innovating firms n is constant over periods due to entry barriers; hence, $\Sigma_j m(R^j) = nm(R)$ and $\Sigma_j \bar{m}^j = n\bar{m}$. In the long-run equilibrium with constant Y as well as constant β, θ and a, which we will call the stationary equilibrium, R is also constant; hence, $\bar{m} = m(R)$ and we have

$$\frac{m'(R)\beta Y\hat{\theta}}{nm(R)\theta(\hat{\theta} + a)} \left\{ 1 - \frac{\hat{\theta}}{n(\hat{\theta} + a)} \right\} = 1 \qquad (17)$$

It is straightforward to prove that $\partial R/\partial\beta > 0$, $\partial R/\partial Y > 0$, $\partial R/\partial n < 0$, and $\partial R/\partial a < 0$ provided $n \geq 2$, by differentiating (17). That is, the stationary level of research efforts per innovator is larger the larger the discount factor (the smaller the discount rate), the larger the size of the economy or the market, the fewer the number of innovators, and the less preferred an old product is relative to a new product (the larger the utility is gained from novelty). These results all appear reasonable. For instance, as people tend to prefer new products more over old products, firms should have a stronger incentive to introduce new products. As the number of innovators is larger, the market for each innovator is smaller resulting in less incentive for innovation. The effect of demand elasticity θ on R is ambiguous.

4. MONOPOLY-MONOPOLY (MM) WITH ENTRY BARRIERS

When no imitation is allowed to take place, an innovator keeps his monopolistic position up to period 2. Thus, he earns monopoly profits not only during period 1 but also during period 2. His gross profit from a new product at period 1 is given by (6) and his gross profit for the same product at period 2, now an old product, is given by (9). Hence, the expected present value of net profits, $V_m(R^j)$, under monopoly-monopoly (MM) is as follows:

$$V_m(R^j) = m(R^j)[\beta A_1\theta^{-\theta}u^{1-\theta}(\theta - 1)^{\theta-1} + \beta^2 aA_2\theta^{-\theta}u^{1-\theta}(\theta - 1)^{\theta-1}] - R^j \quad (18)$$

where A_2 denotes the value of A at period 2.

Consider period 1. The number of new products is $\Sigma_j m(R^j)$ and the number of old products is $\Sigma_j \bar{m}^j$, just as in the previous section. However, each of the old products is now supplied monopolistically with the price and quantity given by (7) and (8), respectively. Substituting (4), (5), (7) and (8) into (2) and solving the equation for A_1, we have

$$A_1 = \theta^{\theta-1}u^{\theta-1}(\theta - 1)^{1-\theta}Y_1/[\Sigma_j m(R^j) + a\Sigma_j \bar{m}^j] \quad (19)$$

In period 2, the number of old products is $\Sigma_j m(R^j)$. The number of new products is $\Sigma_j m(R_1{}^j)$ where $R_1{}^j$ denotes the expenditures to be made on research during period 1. Similarly to (19), therefore,

$$A_2 = \theta^{\theta-1}u^{\theta-1}(\theta - 1)^{1-\theta}Y_2/[\Sigma_j m(R_1{}^j) + a\Sigma_j m(R^j)] \quad (20)$$

Substituting (19) and (20) into (18), we have

$$V_m(R^j) = \frac{m(R^j)\beta}{\theta}\left\{\frac{Y_1}{\Sigma_j m(R^j) + a\Sigma_j \bar{m}^j} + \frac{\beta a Y_2}{\Sigma_j m(R_1{}^j) + a\Sigma_j m(R^j)}\right\} - R^j \quad (21)$$

$V_m(R^j)$ therefore depends not only on current research expenditures of all the firms, $R^1, \ldots, R^n$, and on historically given research expenditures which determine $\bar{m}^1, \ldots, \bar{m}^n$, but also on the expected research expenditures of all the firms in the next period, $R_1{}^1, \ldots, R_1{}^n$. To analyze the decision of the innovator thus requires to assume that he not only knows the levels of current research efforts of other firms but also correctly estimates the levels of research efforts to be undertaken in the next period by other firms. This admittedly is a heroic assumption. In the analysis of the stationary equilibrium to which most of our analyses will be confined, however, this assumption perhaps is acceptable because then the level of R

stays constant over periods for any innovator and each innovator only needs to know the current research levels of other firms and expects them to persist in the future.

We also need to extend the behavioral assumption of the Cournot type to imply that the innovator, j, expects that his rival's research efforts in the following period, R_1^k, are not affected by his choice of current research efforts R^j, for all $k \neq j$. Even, then, however, it will not be logical to assume that $\partial R_1^j/\partial R^j = 0$, namely, that his choice of future research efforts is independent of the choice of his current research efforts. To determine $\partial R_1^j/\partial R^j$ requires an analysis of the entire time path of R^j by means of dynamic programming. Such an analysis is complicated and here we only assume that $\partial R_1^j/\partial R^j$, which we will hereafter denote by δ, is not greater than one. This assumption we consider is safe enough for the following reasons. When R^j is increased, this increases the number of old products supplied during period 2 implying that the market for new products is smaller. This will reduce the incentive for research in period 1 to introduce new products in period 2. Hence δ is likely negative.

At the other extreme, we may suppose that the innovator only considers a steady state such that his level of research efforts is kept constant. That is, when he considers changing R^j, he always plans to change R_1^j by the same amount. If such rules of thumb is adopted, then δ equals one. Still another possibility is that the innovator considers the impact of R^j on his future decisions negligibly small, which is most likely when there are numbers of innovators. In this case δ is approximately zero. All these possibilities are acceptable under our assumption that $\delta \leq 1$.

Let us now obtain the optimal level of R^j by maximizing $V_m(R^j)$ with respect to R^j. By differentiation, we find that the following condition must be satisfied:

$$\frac{m'(R^j)\beta}{\theta} \left\{ \frac{Y_1}{\Sigma_j m(R^j) + a\Sigma_j \bar{m}^j} + \frac{\beta a Y_2}{\Sigma_j m(R_1{}^j) + a\Sigma_j m(R^j)} \right.$$

$$\left. - m(R^j) \left[\frac{Y_1}{(\Sigma_j m(R^j) + a\Sigma_j \bar{m}^j)^2} + \frac{\beta a Y_2(\delta + a)}{(\Sigma_j m(R_1{}^j) + a\Sigma_j m(R^j))^2} \right] \right\} = 1 \qquad (22)$$

As in the previous section, there is no reason that R^j and $R_1{}^j$ should differ among firms; hence, $R^j = R$ and $R_1{}^j = R_1$ for all j. The number of firms n is constant for all periods due to the entry barriers to the innovation sector. In a stationary equilibrium (22) reduces to

$$\frac{m'(R)\beta Y}{nm(R)\theta(1 + a)} \left\{ 1 + \beta a - \frac{1 + \beta a(\delta + a)}{(1 + a)n} \right\} = 1 \qquad (23)$$

By means of comparative analyses (ignoring the variability of δ), it is straightforward to prove that $\partial R/\partial \beta > 0$, $\partial R/\partial Y > 0$, $\partial R/\partial n < 0$, and $\partial R/\partial \theta < 0$ provided $\delta \leq 1$ and $n \geq 2$, but the sign of $\partial R/\partial a$ is ambiguous. That is, each firm makes larger research efforts the larger the discount factor (the smaller the discount rate), the larger the market, the fewer the number of rivals, and the less elastic the demand. These results again appear intuitively agreeable.

5. COMPARISON: MM VERSUS MC UNDER ENTRY BARRIERS

We now compare (17) and (23) to investigate which of MM and MC yields larger research efforts in the stationary equilibrium when n is fixed. To ease this comparison the condition for MC, (17), is rewritten as

$$\frac{m'(R_c)\beta Y}{m(R_c)\theta n} \frac{\hat{\theta}}{\hat{\theta} + a} \left\{ 1 - \frac{\hat{\theta}}{(\hat{\theta} + a)n} \right\} = 1 \qquad (24)$$

and the condition for MM, (23), is rewritten as

$$\frac{m'(R_m)\beta Y}{m(R_m)\theta n}\frac{1}{1+a}\left\{1-\frac{1}{(1+a)n}\right\}=1-\frac{m'(R_m)\beta^2 Y}{m(R_m)\theta n}\frac{a}{1+a}\left\{1-\frac{\delta+a}{(1+a)n}\right\} \tag{25}$$

where subscripts c and m are attached to R to indicate the level of R under MC and MM, respectively.

In comparing these equations, we first note that the second term in the RHS of (25) is positive provided $n \geq 1$, and consequently the RHS is less than one. Second, because $\hat{\theta} < 1$, $[\hat{\theta}/(\hat{\theta} + a)][1 - \hat{\theta}/(\hat{\theta} + a)n] <$ $[1/(1 + a)][1 - 1/(1 + a)n]$ if $n \geq 2$. These two observations imply that if $n \geq 2$, $m'(R_c)/m(R_c) > m'(R_m)/m(R_m)$ by (24) and (25). Because $m'' < 0$, this immediately implies that $R_c < R_m$ given the same condition. Therefore,

> <u>Proposition 1</u>: If the number of innovating firms is fixed and there are at least two such firms, then each firm makes more research efforts under MM than MC in a stationary equilibrium.

This results because the innovator can capture a greater level of profits under MM for two reasons. First, because the supply of an old product is less under MM (compare (8) to (11)), demand tends to be larger for new products under MM. This effect is shown by the fact that $\hat{\theta}$ is less than one in (24). Second, the innovator can earn monopoly profits in period 2 from old products under MM but not under MC. This effect is shown by the second term in the RHS of (25). Thus the profits from product innovation are larger under MM stimulating research efforts.

This is true even taking into account a sort of income effect that introducing a new product reduces the market for other products hurting the profits from the products the innovator has already introduced, which is larger under MM than MC. This negative effect is shown in the equations by the fact that the negative term in the brace is larger in absolute value in the LHS of (25) than (24). Our proposition in effect shows that this disincentive under MM is not large enough to overturn the stronger incentive under MM discussed above.

6. FREE ENTRY INTO THE INNOVATION SECTOR

Suppose now that entry is free into the innovation sector; that is, everyone can undertake research to develop new products. Because such entry will take place as long as the present value of research, $V_c(R_c)$ or $V_m(R_m)$, is expected to be positive, the value must be zero at any long-run equilibrium with free entry. That is, the number of firms n is determined so that the value equals zero.[2]

Under MC, $V_c(R_c)$ must be zero. By (15), therefore, in a stationary equilibrium with free entry such that n is constant and $R^j = R$ for all j and for all periods, it must be that

$$n_c R_c = \frac{\hat{\theta}\beta Y}{(\hat{\theta} + a)\theta} \tag{26}$$

where n_c denotes the number of innovating firms in a stationary equilibrium under MC with free entry.

Under MM, $V_m(R_m)$ must be zero. Hence, by (21),

$$n_m R_m = \frac{\beta(1 + \beta a)Y}{(1 + a)\theta} \tag{27}$$

where n_m is the stationary equilibrium level of n under MM with free entry.

Comparing (26) and (27) and noting that $\hat{\theta} < 1$ and $\beta a > 0$, we immediately find that $n_m R_m > n_c R_c$. Since $n_m R_m$ (or $n_c R_c$) is the sum of research expenditures of all the firms in the economy under MM (or MC), we obtain the following proposition:

> Proposition 2: In a stationary equilibrium with free entry into the innovation sector, total research expenditures are larger under MM than under MC.

Since comparative analyses are straightforward from (26) and (27), the result is presented without proof: Under both MM and MC, total research expenditures (nR) is larger the larger the discount factor (the smaller the discount rate), the larger the size of the economy Y, and the smaller a, that is, the more consumers prefer new products to old products. Also, a smaller demand elasticity results in a larger total research efforts under MM but an ambiguous effect under MC. These appear reasonable to the author.

We now want to compare n_c and n_m, and R_c and R_m in the stationary equilibrium with free entry. For this purpose, we eliminate n_c from (17), the value-maximization condition, and (26), the zero-profit condition, to get

$$\frac{R_c m'(R_c)}{m(R_c)} \left\{ 1 - \frac{\theta R_c}{\beta Y} \right\} = 1 \tag{28}$$

Similarly, we eliminate n_m from (23) and (27) to get

$$\frac{R_m m'(R_m)}{m(R_m)} \left\{ 1 - \frac{1 + \beta a(\delta + a)}{(1 + \beta a)^2} \frac{\theta R_m}{\beta Y} \right\} = 1 \tag{29}$$

Obviously, (29) differs from (28) only by the term, $[1 + \beta a(\delta + a)]/(1 + \beta a)^2$. But since $0 < a \leq 1$, $0 < \beta < 1$, and $\delta \leq 1$, this is less than one. The term outside of the brace in each of these equations is the elasticity of m with respect to R. Denote it by $\varepsilon(R_c)$ or $\varepsilon(R_m)$. Then we find that the LHS of (28) or (29) is decreasing in R_c or R_m if (but not only if) ε is constant or decreasing in R_c or R_m. These two facts together imply that $R_m > R_c$ if ε is constant or decreasing in R. Thus the following condition is obtained:[3]

> <u>Proposition 3</u>: If the elasticity of research output (the expected number of new products) with respect to research input (research expenditures) is constant or decreasing in research input, then in a stationary equilibrium with free entry, research expenditures per firm are larger under MM than under MC.

Proposition 2 showed that $n_m R_m > n_c R_c$ and Proposition 3 showed that under the condition on elasticity, $R_m > R_c$. Therefore, which of n_m and n_c is larger is ambiguous. In fact, from (26) and (28),

$$n_c = \frac{\hat{\theta}}{\hat{\theta} + a} \frac{\varepsilon(R_c)}{\varepsilon(R_c) - 1} \tag{30}$$

and from (27) and (29)

$$n_m = \frac{1 + \beta a(\delta + a)}{(1 + \beta a)(1 + a)} \frac{\varepsilon(R_m)}{\varepsilon(R_m) - 1} \tag{31}$$

When the condition in Proposition 3 is satisfied, $\varepsilon(R_c) \geq \varepsilon(R_m)$. Thus, $n_m > n_c$ if $[1 + \beta a(\delta + a)]/(1 + \beta a)(1 + a) > \hat{\theta}/(\hat{\theta} + a)$. The latter condition is satisfied if $\delta + a > 1$, because $\hat{\theta} < 1$. As discussed in section 3, however, δ may be negative and $a \leq 1$; hence, the condition is not likely satisfied. Therefore, it does not appear that the relative ranking between MM and MC in terms of the number of innovators can be unambiguously determined.

7. THE SOCIALLY OPTIMAL RATE OF PRODUCT INNOVATION

We would now like to consider the socially optimal rate fo research efforts toward product innovation and compare it with the rate under market mechanism.

In this paper we assume that the social objective is to maximize the discounted present value of utility stream where the level of utility at each period is determined by the utility function (1). The discount factor to be used in this objective is assumed β. This is for simplifying purposes only and if the reader finds it uncomfortable, he may use, say, $\hat{\beta}$, in the following analysis. Whether the rate that the society uses to discount future utilities is greater than, equal to, or less than the rate that the innovating firms use to discount their future profits is a difficult question as discussed in the literature on optimal economic growth, which we will avoid here.

The objective function is thus

$$\sum_{t=0}^{\infty} [n(t-1)m(R(t-1))a_1 x(t)^b + n(t-2)m(R(t-2))a_1 a_2 y(t)^b]\beta^t \tag{32}$$

where, as before, $n(t)$ is the number of research unit (innovator) and $R(t)$, the amount of research expenditures per research unit so that $n(t-1)m(R(t-1))$ is the total expected number of new products introduced to the economy at the beginning of period t.

As the representative individual is subject to the budget constraint, the economy as a whole is subject to the constraint that the resources to be used -- in production and research -- cannot exceed the available amount Y; hence, for all t,[4]

$$n(t-1)m(R(t-1))ux(t) + n(t-2)m(R(t-2))uy(t) + R(t) = Y(t) \tag{33}$$

The social optimum requires that $x(t)$, $y(t)$, $R(t)$ and $n(t)$ are determined so that (32) is maximized subject to (33). Maximizing with respect to $x(t)$ and $y(t)$ yields

$$x(t) = Bu^{-\theta} \quad \text{and} \quad y(t) = aBu^{-\theta} \tag{34}$$

which are both constant over time, where $B = (\mu/a_1 b)^{1/(b-1)}$ when the Lagrange multipliers given to the constraints (33) are $\mu\beta^t$ for all t, $\theta = 1/(1-b)$, and $a = a_2^{1/(1-b)}$. Comparing (34) to (3), we immediately find that these conditions for the social optimum are satisfied when the output markets are competitive so that $p = q = u$, if the Lagrange multipliers are the same. This agrees with the standard proposition in welfare economics.

Maximization with respect to $R(t)$ yields

$$\begin{aligned} &n(t)m'(R(t))[a_1 x(t+1)^b \beta^{t+1} + a_1 a_2 y(t+2)^b \beta^{t+2}] - \mu\beta^{t+1} n(t)m'(R(t))ux(t+1) \\ &- \mu\beta^{t+2} n(t)m'(R(t))uy(t+2) - \mu\beta^t n(t) = 0 \end{aligned} \tag{35}$$

Using (34) and dividing both sides by $\mu\beta^t n(t) > 0$, we get

$$m'(R(t))Bu^{1-\theta}(1 + \beta a)\beta/(\theta - 1) = 1$$

Combining this equation with (33) and (34) assuming constant Y, we have for all t

$$\frac{R_s m'(R_s)}{m(R_s)} \frac{(1 + \beta a)\beta}{(\theta - 1)(1 + a)} \left\{ \frac{Y}{n_s R_s} - 1 \right\} = 1 \tag{36}$$

indicating by subscript s the socially optimal level.

The number of research units may or may not be a policy variable. If it is, then maximization must be made with respect to n_s, which, combined with (35), yields

$$n_s = \frac{R_s m'(R_s)}{m(R_s)} \tag{37}$$

that is, the number of research units should equal the elasticity $\varepsilon(R_s)$ of m with respect to R_s.

On the other hand, we may suppose that research is monopolized in a government-financed laboratory; then, $n_s = 1$. Or we may compare the socially optimal level of research per innovator with the value-maximizing level with the number of innovators or research units fixed. At any case, (36) must hold.

Unfortunately, analyzing this social optimality condition in comparison to that under market mechanism (either MM or MC, and either with free entry or with entry barriers) does not yield conclusive results in most instances. For this reason, in place of algebraic analyses, we will attempt to conjecture the general tendency by means of numerical examples. In these examples, we assume the following production function in research:

$$m = k_0(R - R_f)^k \tag{38}$$

where k_0 and k are positive constants with $k < 1$, and R_f is the fixed-cost portion of research cost. Note that this function assumes a constant elasticity of m with respect to $R - R_f$, which is k, but a decreasing elasticity with respect to R satisfying the assumption in Proposition 3, for $\varepsilon = kR/(R - R_f)$.

All the relevant conditions were rewritten in terms of R_ℓ/Y, denoted by r_ℓ (ℓ = c, m, and s), which indicates the share of research expenditures (per research unit) in the national income or, if we are dealing with a particular industry only, in the total expenditures in the industry. We also denote R_f/Y by f. Then, given the values of the demand elasticity θ, the discount factor β, the ratio a of the demand to an old product to the demand to a new product at a common price, the elasticity k of m with respect to $R - R_f$, the ratio f of the minimum research expenditures to the market size, and the extent δ that the research efforts in the next period of an innovating firm is affected by its own research efforts this period in the case of MM, we can calculate the socially optimal research share r_s, the socially optimal number of research units n_s, research share r_c and the number of innovators n_c in the stationary equilibrium with free entry under MC, and research share r_m and the number of innovators n_m in the stationary equilibrium with free entry under MM. The results are given in Table 1.

In these examples, we set $\beta = 0.25$ and $\delta = 0$. The latter means that when an innovator makes a decision on the current level of research he ignores its repercussion to the level of his own research in the next period. We make this assumption mainly for lack of any other plausible value, but it was confirmed that changing δ does not change the results much. Note that δ is relevant only under MM; hence, the calculated values of r_s, n_s, r_c, and n_c are independent of δ. The value, 0.25, of β corresponds approximately to an annual discount rate of 15 percent if one period is 10 years long, 10 percent if 15 years long, 7 percent if 20 years long, and 5 percent if 30 years long. For other parameters, we tried several values as shown in Table 1.

The table shows that if $\beta = 0.25$, $\delta = 0$, $k = 0.9$, $f = 0.01$ (1 percent), $a = 1$, and $\theta = 1.2$, then the socially optimal research share (per research unit) is 1.01 percent while the socially optimal number of research unit is 97.8, and so forth. We immediately find from the table that for any combination of the values of the paremeters r_s is small and very close to f whereas n_s is very large. This is due to the diminishing marginal returns against research input. That is, the society is better to have numerous research units each barely exceeding the minimum size f.

This appears rather unrealistic and unconvincing. We thus proceeded to find the socially optimal level of research when the number of research units is fixed for some reason. Numerical examples for such second-best solution are given in the last three columns of Table 1, each column showing r_s when n is fixed at one (the case of government monopoly in research), n_c (the stationary equilibrium level of n under MC with free entry), or n_m (the stationary equilibrium level of n under MM with free entry). From these emerge some interesting facts. First, r_s given $n = n_c$ always exceeds r_c, and r_s given $n = n_m$ always exceeds r_m. That is, we may conjecture that at a stationary equilibrium under free entry, each innovating firm tends to make research efforts at a level less than is socially optimal, and that this result holds whether the economy is MC or MM.

Second, with n fixed r_s tends to be larger as θ is smaller, as f is larger, and as k is larger. Also when $n = 1$, a smaller a implies a larger r_s. These are not surprising because a smaller θ implies that marginal utility declines faster as the quantity of a good increases; hence, increasing the variety of products becomes more effective in increasing utility than increasing the quantity of each good given the catalogue of products. A smaller a of course implies that people prefer to have many new products. A large k implies that the marginal product of research does not decrease rapidly and a large f implies that the minimum scale of research must be large; hence, it is no wonder that the optimal research size is larger.

Third, we find that total research expenditures under MC and MM, $r_c n_c$ and $r_m n_m$, respectively, are smaller than those socially optimal, $r_s n_s$, in every case including the case in which the government monopolizes research, except for a very few instances.

Combining these observations from our numerical examples, we may conjecture as follows irrespective of whether we compare total research expenditures, nR (= nrY), between the social optimum and market equilibria or we compare research expenditures per research unit or innovating firm, R (= rY), at the same number of research units:

> Conjecture: Market mechanism (whether MC or MM) tends to produce smaller research efforts toward product innovation than is socially desirable.

Needless to say, since we are only using numerical examples, we may not deny other possibilities. Ackowledging this limitation, we still find the result interesting. In particular, the conjecture above implies that we may have too few new products and too little variety of products under market mechanism. This is not in agreement with what many people tend to think and not with what we teach in microeconomics using the Chamberian monopolistic competition model. On the other hand, it is consistent with the findings in other recent studies such as Spence (1976) and Koenker and Perry (1981), even though these authors employed a static model ignoring the dynamic (intertemporal) aspect of the consequence of product innovation such as product lifecycle and generation-overlapping (of products) as discussed here, and failing to separate competion on imitation from competition on innovation.

8. SUMMARY

We have employed a discrete model in which research efforts result in a certain number of new products, which depends on the research expenditures, at the beginning of the following period. These products have the life span of two periods; that is, in the first period after the innovation they are sold as new products and in the second period, as old products, but in the third and following periods they are not demanded at all. In the first period, each of the innovators is a monopolist in the market for his new product. In the second period, there are two possibilities -- the case called monopoly-monopoly (MM) in which no imitation and entry can take place to the now old product, and the case called monopoly-competition (MC) in which imitation and entry takes place to the effect that profits out of the product vanish. Thus, MM and MC differ in whether competition takes place in imitation.

Competition may also occur in another aspect, namely, innovation. That is, when innovators earn positive profits others may start research efforts to capture the profits. Therefore, entry may be free forcing the innovator's profits to vanish, or there may be barriers to entry allowing the innovators to earn positive profits in the long-run. This is competition on innovation. Thus, depending on MM versus MC, and on free entry versus entry barriers into the innovation sector, we separated four cases. We have analyzed the optimization behaviors of firms and the equilibrium conditions under these alternative cases. We then compared them to the social optimum.

Among the major findings were that (i) with entry barriers, an innovator makes more research efforts in MM than MC if there are an identical number of innovators, (ii) with entry barriers, research expenditures per innovator is a decreasing function of the number of innovators in both MM and MC, (iii) under free entry, both total research expenditures and per-innovator research expenditures are larger in MM than MC, and (iv) from the result of numerical examples, it is conjectured that in both MM and MC innovators tend to make research efforts at a suboptimal level.

The last result depends heavily on the assumed utility function of a representative consumer in which the marginal utility due to an increase in the quantity of a good given the variety of goods is diminishing whereas the marginal utility due to an increase in the variety of goods given the quantity of each good is constant. Thus, when the quantity of each good reaches some level, expanding the catalogue of products becomes more effective in increasing utility level than increasing quantities given the catalogue. This is in contrast to the standard Chamberlin model of monopolistic competition where consumers are supposed indifferent to the variety of products. Consequently, our model expected too little variety of products whereas the Chamberlin model expects too much variety compared to the social optimum.

Given the conjecture of suboptimal research efforts under market mechanism, the first three results listed above imply that concentration (meaning fewer innovators) and barriers to imitation (meaning MM) may rather contribute than harm social welfare. Of course this contribution must be weighed against the welfare loss due to monopolistic pricing -- compare the monopolistic pricing given by equation (4) or (7) to the competitive pricing given by (10) which in section 7 was shown to be socially optimal. It must be also acknowledged that the presence of rivalry may induce an innovator to hasten the pace of innovation and increase the amount of research efforts for fear of the rival's success in innovating first, as discussed by Kamien and Schwartz (1978). Still we may at least say that criticizing concentration and entry barriers solely on the ground of monopolistic pricing and the resulting welfare loss overlooks the other side of the coin, namely, their contribution to supply a wider variety of products by making intense research efforts.

That this conclusion is very much in the spirit of Schumpeter, perhaps I need not remind the reader.

NOTES

1. Each firm was allowed to give multiple objectives. In addition to those quoted in the text, 58.6 percent of them raised "the applied research on existing products"; whether this implies improving products or improving production process is unclear.

2. To have an economic meaning, n must be an integer. Hence, strictly speaking, n will ne determined at the maximum integer that keeps the value nonnegative. In this analysis we avoid this complication and treat n as if it could be a non-integer.

3. Note that because research is assumed to involve a fixed cost R_f and hence m increases in R only for $R > R_f$, ε is more likely decreasing in R (satisfying the condition in the proposition) than the elasticity with respect to the variable portion of the research expenditures, namely, $(R - R_f)m'(R)/m(R)$. An example will be given in equation (38) in the next section.

4. An interpretation is that only labor is used in production and research with u the constant labor-output ratio and R the man-hours of researchers employed in a research unit, the wage rate is normalized to unity, and Y is the total amount of labor force.

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TABLE 1. NUMERICAL EXAMPLES

given parameters									r_s when n is fixed at		
f	a	θ	r_s	r_c	r_m	n_s	n_c	n_m	1	n_c	n_m
					-- when k = 0.9 --						
1	1	1.2	1.01	3.79	5.67	97.8	2.3	2.3	41.87	18.85	18.55
		2	1.01	3.10	4.81	92.6	1.3	1.6	13.21	10.04	8.45
		10	1.02	1.53	2.57	40.2	0.5	0.6	2.52	4.36	3.52
	.5	1.2	1.01	3.79	4.97	98.0	3.2	3.1	46.31	14.83	15.09
		2	1.01	3.10	4.15	93.7	2.0	2.3	15.29	8.01	7.24
		10	1.02	1.53	2.15	50.2	0.7	0.9	2.82	3.57	3.09
.1	1	1.2	0.10	0.75	0.89	997.8	11.4	14.6	41.34	3.69	2.89
		2	0.10	0.67	0.84	992.7	6.2	9.3	12.42	2.08	1.41
		10	0.10	0.41	0.60	941.4	1.7	2.6	1.64	0.99	0.69
	.5	1.2	0.10	0.75	0.85	998.0	16.1	18.3	45.82	2.90	2.55
		2	0.10	0.67	0.79	993.8	9.3	11.9	14.52	1.64	1.30
		10	0.10	0.41	0.53	951.1	2.7	3.6	1.94	0.78	0.62
.01	1	1.2	0.01	0.10	0.10	9997.6	189.3	131.9	41.29	0.47	0.31
		2	0.01	0.09	0.10	9992.7	44.5	79.8	12.34	0.29	0.16
		10	0.01	0.08	0.09	9941.5	8.9	17.2	1.55	0.18	0.10
	.5	1.2	0.01	0.10	0.10	9997.7	126.5	159.4	45.77	0.37	0.29
		2	0.01	0.09	0.10	9993.7	66.7	96.8	14.45	0.22	0.16
		10	0.01	0.08	0.09	9951.1	14.0	21.5	1.85	0.14	0.10
					-- when k = 0.5 --						
1	1	1.2	1.01	1.84	1.94	98.2	4.7	6.7	28.81	6.74	4.91
		2	1.01	1.75	1.91	93.1	2.4	4.1	8.17	3.98	2.70
		10	1.01	1.31	1.66	41.2	0.5	0.9	1.85	2.61	1.90
	.5	1.2	1.01	1.84	1.92	98.4	6.6	8.2	32.60	5.51	4.60
		2	1.01	1.75	1.87	94.1	3.6	5.0	9.49	3.32	2.62
		10	1.01	1.31	1.55	51.0	0.8	1.2	2.02	2.23	1.84
.1	1	1.2	0.10	0.20	0.20	998.2	43.3	65.3	28.16	0.72	0.50
		2	0.10	0.20	0.20	993.1	21.2	39.3	7.34	0.44	0.28
		10	0.10	0.19	0.20	941.9	3.8	8.0	0.96	0.33	0.21
	.5	1.2	0.10	0.20	0.20	998.4	61.3	78.5	31.98	0.59	0.47
		2	0.10	0.20	0.20	994.2	31.7	47.2	8.66	0.36	0.27
		10	0.10	0.19	0.19	951.5	5.9	9.7	1.13	0.27	0.21
.01	1	1.2	0.01	0.02	0.02	9997.7	428.9	651.2	28.10	0.07	0.05
		2	0.01	0.02	0.02	9993.0	208.7	390.8	7.26	0.04	0.03
		10	0.01	0.02	0.02	9941.9	35.2	78.3	0.87	0.03	0.02
	.5	1.2	0.01	0.02	0.02	9997.5	607.8	781.6	31.92	0.06	0.05
		2	0.01	0.02	0.02	9993.9	313.0	469.1	8.58	0.04	0.03
		10	0.01	0.02	0.02	9951.5	55.0	94.1	1.04	0.03	0.02

NOTES: f and r are given in percentages.
Given values are β = 0,25 and δ = 0.

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