Two Models of Competition in Innovation

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Abstract

A limit-pricing model is used to show how royalty cutting can emerge as a competitive process over the conventional rushing model in innovation. Vertical integration is used as an enforcement mechanism in this model to discourage premature innovation. It can be shown that if certain output effects are ignored, the timing of innovation will be identical to the idealized society's optimum.

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Competition can take on many forms.[1] Probably the most noted in

economic textbooks being price cutting. In problems dealing with innova-

tion, however, there appears to be a departure from such conventional

emphasis in that competition is usually assumed to take the form of inven-

tors rushing to innovate (Barzel 1968, Kamien & Schwartz 1972, Kitti,

1973). Such bias can be potentially supported by some assertion about

transaction cost, but the literature has not been explicit on this. In

fact, much of it seems unaware of the alternative.

Recent literature reaffirms our speculation: the rushing result has

been studied under different game theoretical assumptions (Loury 1979,

Gilbert & Stiglitz 1979, and Dasgupta & Stiglitz 1980), but the analyses

uniformly assume the winning inventor would charge monopoly prices.

This paper attempts to model the alternative of inventors cutting

royalty rates before the act of inventing. The starting point of the

analysis is a zero transaction cost world where there are no economic

incentives for either organized research or vertical integration of research

with production facilities. Such an idealized situation is chosen for com-

parisons because including these organizational structures into the model

often blurs the main issue under consideration (cf. p. 18); also, the con-

ventional rushing argument is commonly understood to hold even without

vertical integration and thus the condition can be a legitimate base for

comparison.

In the context of a competitive nonintegrated market, our analysis shows that royalty cutting would emerge as a _competitive process_ over the conventional rushing model.[2] The timing of innovation in the royalty-cutting model will be identical to the idealized society's optimum if the outputs of manufacturers and their industry as a whole do not change significantly post innovation. In more general cases where output effects are considered, there are two offsetting factors: On the one hand, downward sloping industry demand typically implies a welfare triangle if uniform pricing policy is adopted, and that by itself would result in "too late" timing for innovation. On the other hand, the possibility of a manufacturer expanding his output by adopting cost reducing innovation ahead of his competitors will prompt inventors to speed up their research. The two offsetting factors may or may not cancel each other, and the timing of innovation may exceed or fall short of the idealized optimum. However, the important point to note is: this divergence from the society's optimum is _not_ caused by competition in the R&D market. Thus, free entry into the R&D market will not necessarily give rise to premature innovation.

Section I uses the recent model by Dasgupta & Stiglitz to show the benchmark case,which will be called a rigid-royalty model. The result here holds regardless of vertical integration. The implications of non-identical inventors will be emphasized to facilitate our subsequent arguments; some results in Dasgupta & Stiglitz will also be clarified in the process. Section II modifies the model by Dasgupta and Stiglitz in the context of a nonintegrated competitive market to illustrate royalty cutting as a profit-maximizing strategy of competing inventors. Vertical integration as an enforcement mechanism in the royalty cutting contract is discussed. Section III examines how royalty cutting would affect the timing of innovation.

I. A Rigid-Royalty Model

Assume that inventors see an expected value of innovation, G (we will discuss the factors affecting G in the next section). The discovery date of the innovation is T(x), which is nonstochastic and which can be sped up by inventors incurring expenditure x: i.e., $T' < 0$, $T'' > 0$. Conventional analyses suggest premature innovation in the sense that wealth maximization implies a date of innovation satisfying[3]

$$-r \; T'(x) \; Ge^{-r \; T(x)} = 1 \; ; \qquad (1)$$

but under competition, the market will introduce the innovation earlier at

$$Ge^{-r \; T(x)} = x \qquad (2)$$

The implicit assumptions behind the argument are that inventors are all identical, and that the active firm works on the reaction function of potential entrants.[4] With nonidentical inventors, each perceiving different gains or costs, the situation may be quite different: suppose a superior inventor has $T_s(x_s)$ and an inferior inventor has $T_i(x_i)$ rushing functions respectively, $T_s(x_s) < T_i(x_i)$ for all $x_s = x_i$. If such rushing ability differential can be conveyed to both parties, e.g. via some dynamic strategies as mentioned in Dasgupta and Stiglitz, the inferior inventor would recognize that rushing is futile, and the superior inventor does not have to rush. However, if the rushing ability differential is not known, and if dynamic strategies are impractical, the superior inventor must precommit resources, x_s^L, to dissuade the inferior inventor from rushing. This is a limit-pricing problem; i.e., the superior inventor chooses x_s^L subject to a zero profit
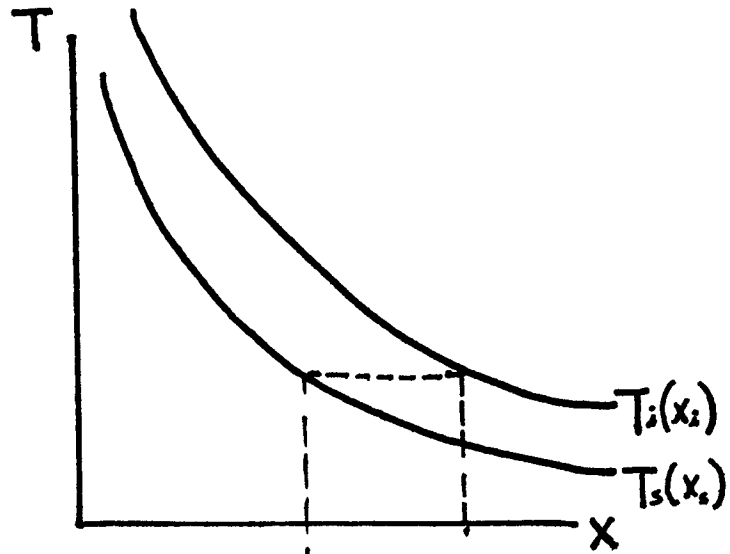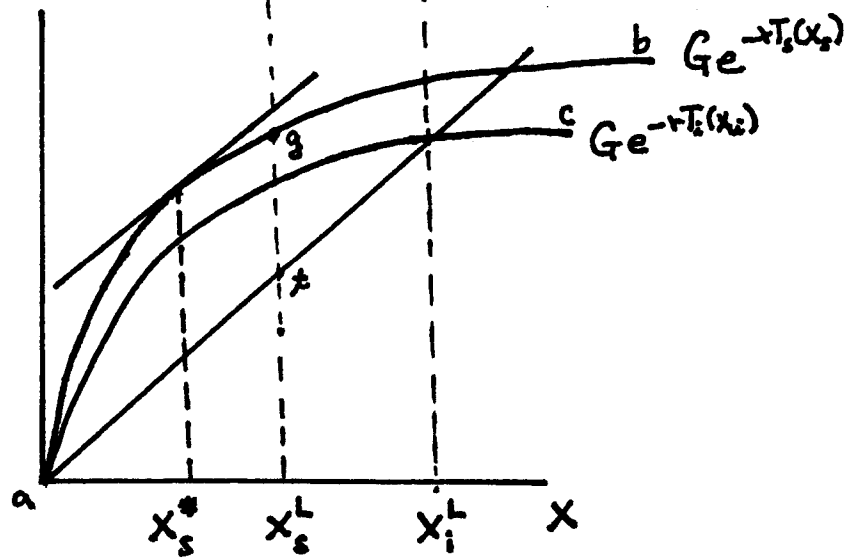
Figure I (a)

Figure I (b)

condition of the inferior inventor. Formally, the superior inventor

$$\underset{x_s^L}{\text{Max}} \quad (Ge^{-r\,T_s(x_s^L)} - x_s^L) + \lambda(T_s(x_s^L) - T_i(x_i^L)) \qquad (3)$$

x_i^L is the economically fastest effort the inventor can invent. It is derived from

$$Ge^{-r\,T_i(x_i^L)} = x_i^L \qquad (4a)$$

$$T_i(x_i^L) = \frac{\ln(x_i^L/G)}{r} \qquad (4b)$$

Figure 1 illustrates the solution to (3) subject to (4). Figure 1(a) gives the shapes of $T_s(x_s)$ and $T_i(x_i)$, which are treated as exogenous. Figure 1(b) gives the total gain and cost of rushing to innovate. Curves ab and ac are the gain curves faced by the two inventors respectively. The 45° line is the total cost curve of either one of the inventors. The intersection of this line and curve ac in 1(b) gives the zero profit condition of the inferior inventor. Based on this, the economically fastest time for the inferior inventor to invent can be traced to $T_i(x_i^L)$ in Figure 1(a). To win the race, the superior inventor must obtain the patent before this time, i.e., choose $T_s \leq T_i(x_i^L)$ in 1(a). This corresponds to the minimum expenditure of x_s^L in 1(b). It is obvious that so long as $T_i(x_i) > T_s(x_s)$, $x_s^L < x_i^L$.

The solution of equation (1), x_s^* , can also be shown in Figure 1(b). It corresponds to the point where the slope of curve ab equals the slope of the 45° line. As the way the curves are drawn, the superior inventor will rush to innovate since $x_s^* < x_s^L$, but his profit will still be positive; gt in Figure 1(b).[5] This solution, however, is not general. By changing the shapes of the curves in the diagram, one can easily construct situations where $x_s^* > x_s^L$.[6]

In that case, the superior inventor will not rush because his unconstrained maximizing effort is already fast enough to win the race.

While the superior inventor may or may not rush, his winning probability is always certain as long as his gain (cost) curve is higher (lower) than that of the other inventor.[7] On the other hand, if inventors were identical -- i.e., all face the same gain and cost curves -- the winning probability of an inventor will be less than 1. The difference between the gains (or costs) of inventors (as represented by curves ab and ac in Figure 1) can be caused by many factors. In the preceding analysis, we have discussed only the rushing ability, $T(x)$. But it is clear that there can be a variety of other factors that may also cause a difference. For example, Dasgupta and Stiglitz discussed a difference in G as perceived both by the incumbent monopoly and by a potential entrant.[8] They also discussed implications caused by differences in the patent lives.

Other factors such as borrowing rate, the degree of uncertainty affecting G and $T(x)$, etc., can similarly be simple extensions of the basic argument. However, the important thing we wish to note is: all these _exogenous_ factors, even if they are marginally different among inventors, would raise the winning probability of one inventor to certainty if T is nonstochastic. In the next section, we will utilize this result to analyze the effects of discrepancies in perceived gains as caused by _endogenous_ adjustments among competing inventors.

II. A Royalty-Cutting Model

In a world of zero transaction cost, the production and dissemination of ideas can be conveniently thought of as separable economic activities performed by two separate groups of specialists: (i) the inventors, who have the comparative advantages in inventing ideas, and (ii) the manufacturers, who specialize in the production and marketing of the final products. The consumers in this basic framework only consume goods and services produced by the manufacturers, they have no preferences or ability to appreciate innovative ideas per se. In this section, we will discuss how the manufacturers, who take the role of middlemen, would affect inventors' rushing behavior.

Let's first examine the composition of the value of the innovation, G, used in the last section. Consider a manufacturer who has marginal cost, MC_o, and average cost, AC_o, in producing Q. An inventor can incur research expenditure, C, to lower the cost curves to $MC_s(C)$ and $AC_s(C)$, $MC_s' < 0$, $AC_s' < 0$. For simplicity, assume (1) the minimum average cost output, q, remains the same before and after the innovation, and (2) the elasticity of demand of the product is such that an inventor, in the absence of competition, will charge each manufacturer the full saving in production cost. This implies a per unit royalty rate, $\pi_0(c)$.

$$\pi_0(c) = \min AC_o - \min AC_s(C) \tag{5}$$

If there are m identical manufacturers and the inventor perceived all of them to be his potential customers, the net gain to him will be[9]

$$G = mq \, \pi_0(c^*) - c^* \tag{6}$$

where c^* is the return maximizing level of R & D expenditure and $\pi_0(c^*)$ is the royalty corresponding to that level of investment.

The G in (6) is the net gain used in constructing curves ab and ac in Figure 1. Its specification in (6) suggests the role manufacturers can play in influencing inventors' rushing behavior. Consider an inventor's offer of a lower royalty rate to a manufacturer in exchange for the latter's commitment to buy from him exclusively. If the brand-name of the inventor is well established, the manufacturer suffers a small chance of committing to an unproductive inventor and hence would be foolish to reject the offer. The net gain facing this royalty-cutting inventor is thus

$$G_t = \pi_t(c^*, s) + (m-1)q \pi_0(c^*) - c^* \qquad (7)$$

$\pi_t(c^*, s)$ is the lower royalty rate the inventor is giving to a committed manufacturer. It is a function of the anticipated usefulness of the innovation, c^*, and the manufacturer's search cost, s.[10]

G_t is obviously lower than G in (6). However, the gain as perceived by an inventor who holds rigid royalty will be even lower, since he loses a customer for sure. Letting $\tilde{G}_t$ be his perceived gain,

$$\tilde{G}_t = (m-1) q \pi_0(c^*) - c^* \qquad (8)$$

Thus, even though we start from a situation with two identical inventors, a lowering of royalty rate before inventing by one would lead to a discrepancy between the gain perceived by the royalty-cutting inventor and that perceived by the inventor who holds firm. This marginal discrepancy, using the result from the last section, may be sufficient to dissuade the inventor who holds firm from rushing if T is nonstochastic. And if T is stochastic, there is always a finite number of manufacturers that the royalty-cutting inventor can sign up so as to create a significant discrepancy between the two gain curves. The upshot of this is that the royalty-cutting inventor does not have to sign

up the whole industry in order to dissuade his competitor from rushing. Thus any hold-up effort by an individual manufacturer (in terms of bargaining for a below cost royalty) will be ineffective.

The incentive to cut the royalty rate is not so much to drive out competing inventors per se. The royalty-cutting inventor directly benefits himself with a rent (equivalent to gt in Figure 1) as a result of the discrepancy between the two gain curves. The economics behind this is that while the inventor gets a lower total royalty, he saves an even larger rushing cost by dissuading his competitors from rushing. Thus, royalty cutting is consistent with the inventor's maximizing behavior.

Two related issues immediately arise: (1) How to enforce the exclusive purchase commitment of the manufacturers?, and (2) Will a manufacturer's request for exclusive license from the inventor destabilize the royalty-cutting argument?

A commitment to purchase an inventor's research results can be enforced in a variety of ways: the oft-reported "stubborn" strategy among high technological firms of listening only to "in-house" ideas,[11] the development of specific accessories suitable only for a particular machine model, etc.[12] are a few potential candidates for such enforcement mechanisms. But perhaps the most popular method, and one we think potentially testable, is vertical integration (i.e. unified ownership of production and research). This arrangement is often treated as an institutional constraint in innovation models, but the observation should really be explained rather than assumed. In the context discussed here, one can indeed think of a research organization employing production facilities as a form of exclusive purchase commitment to discourage premature innovation.[13]

The point needs some elaboration: A unique feature of the limit-pricing model described above is that integration (or prior commitment of manufacturers) need not involve the whole industry; in other words, the output market does not have to be monopolized in order to make the pricing scheme effective. This has strong welfare implications in light of an alternative argument that vertical integration of R & D with output market is a means to extend monopoly leverages. The extension of monopoly argument <u>does</u> require the firm to occupy a substantial share of the output market,[14] but our argument here <u>does not</u>. What our argument does imply is that the output level of the integrated firm should perhaps be larger than its "minimum efficient size."

The answer to the first question also bears on the second question about the stability of the royalty-cutting model. If believable commitments have been made by some manufacturers to other inventors, the incentive for a manufacturer-inventor pair to arrange for exclusive license for the purpose of monopolization will be less.[15] If x% of marketing and production facilities are committed to a rival inventor (or a different research approach), exclusive license between a single manufacturer and a single inventor would lose its attractiveness since ex-ante they can capture (1-x)% of the market at most. Furthermore, from the point of view of a given manufacturer-inventor pair, the x they anticipate can be shown to be close to 100%. To avoid distraction, however, I will summarize the reasons here, leaving the details in the appendix: Manufacturers do not in general sit around and let an inventor (or a manufacturer-inventor pair) to monopolize. They would have zero or negative profit (in terms of loss in quasi-rent) if such a strategy was adopted. On the other hand, searching and committing to a low-

royalty (but able) inventor generates hope of positive profit. Thus, competing manufacturers' commitment in exchange for low royalty is in general a rational strategy that should be anticipated by any manufacturer-inventor pair who wish to monopolize via exclusive license.

Finally, explicit cooperation among all manufacturers is prohibitively costly by assumption; and even if possible, the monopoly rent arising from joint action will not lead to rushing of R&D. The reason is simple: A collusive output market now becomes a monopsonist in the R&D market. Indeed, it will be difficult to convince someone that manufacturers smart enough to monopolize will not be smart enough to pay inventors their supply prices (resource costs of innovation). Thus, the timing of innovation will be optimal in this situation also.

III. We examine the market equilibrium in the royalty-cutting model in this section. In general, inventors compete in terms of rushing (higher x), offering more useful innovation (higher c), and reducing royalty rate (lower π_t). A conventional way to tackle this problem would be to set up some sort of duopoly model (two inventors). With certain Nash assumptions, one can have something resemble the familiar Cournot duopoly result. Then, by extending the model to n inventors, one perhaps arrives at some interior solutions at full competitive equilibrium.

This approach, however, ignores the reaction of the manufacturers, which, we have just shown, can influence the behaviors of the inventors without cooperation from all manufacturers. The preference of the buyers of innovation must be respected: a competitive manufacturer always looks for inventors who can provide him with the most useful innovation introduced at the right time with the lowest royalty rate. The equilibrium values of x, c and π_t in a conventional duopoly model may not be ideal for a manufacturer, and thus, the latter may bribe one of the inventors out of such an equilibrium. The inventor, on the other hand, has strong incentive to accept the bribe if the manufacturer will commit to his research result, because doing so generates positive rent for himself and helps him to win the race to invent.

To examine the equilibrium in this problem, I first assume that c and x have already been chosen to be c* and x*, and concentrate only on adjustment in π_t. It is clear that even under this restricted condition, there can be two potential adjustment methods leading to two equilibria. First, one might expect identical inventors would all cut their royalty rates in signing up their own manufacturers,

thus sharing the market. With two inventors, the equilibrium royalty rate π_t^A under this adjustment mode can be described by

$$(\tfrac{m}{2}q\pi_t^A(c^*,\ s) - c^*)e^{-rT(x^*)} = x^* \qquad (9a)$$

or,

$$\pi_t^A(c^*,\ s) = \frac{2(x^*e^{-rT(x^*)} + c^*)}{mq} \qquad (9b)$$

Alternatively, with zero search cost,[16] one might expect the original royalty-cutting inventor to "limit-price" in that the royalty reduction offered by him is low enough that other inventors will not find it profitable to match the royalty reduction. The equilibrium royalty rate π_t^B under this adjustment mode can be described by

$$(mq\ \pi_t^B(c^*,\ s) - c^*)e^{-rT(x^*)} = x^* \qquad (10a)$$

or,

$$\pi_t^B(c^*,\ s) = \frac{(x^*e^{rT(x^*)} + c^*)}{mq} \qquad (10b)$$

Although inventors have zero profit in either (9) or (10), manufacturers would certainly prefer (10) to (9). A manufacturer in (9) must take the risk of signing up with an inventor who might not win (half of them are in this category ex post facto), and the royalty rate π_t^A is higher. By contrast, a manufacturer in (10) knows the winner and the royalty rate π_t^B is lower.[17] Thus, an inventor cutting the royalty rate before the act of inventing should result in a single inventor.

With x simultaneously adjusting, the equilibrium conditions will be more complicated. For each adjustment mode there can be multiple equilibria. Take the adjustment mode where inventors share the market the competing inventors can rush by any amount provided a high enough royalty will cover the rushing cost. Thus, equation (9) becomes a locus of equilibria describing the trade-off between rushing cost and royalty rate.

Figure Two
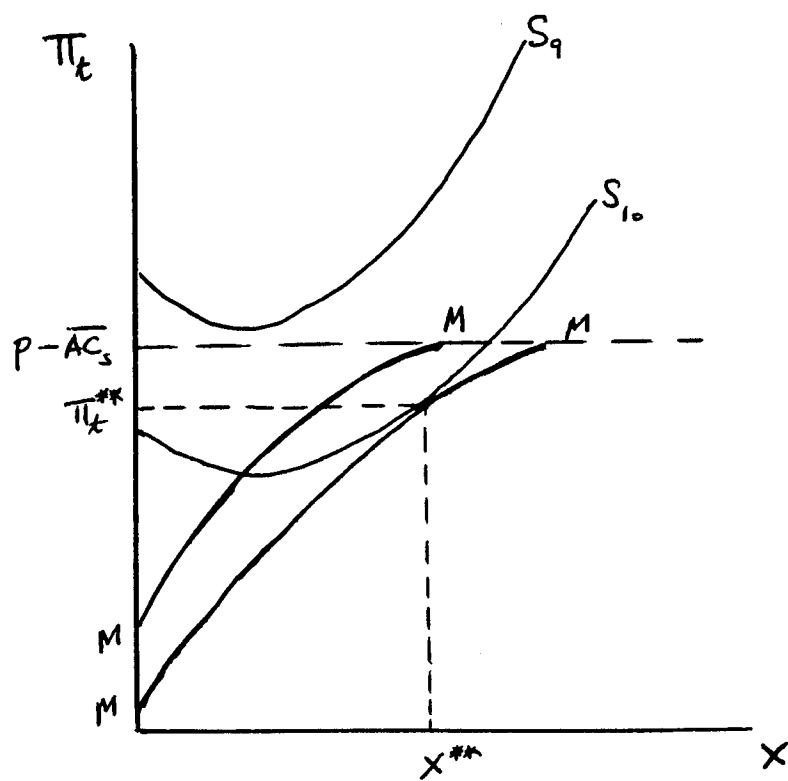
Similarly, the alternative adjustment mode has inventors bidding on combinations of π_t^B and x, (i.e. quoting a royalty rate and implicitly promising a delivery time). Again, because of the zero profit condition, there is a locus of equilibria corresponding to (10).

The two equilibrium loci implied by (9) and (10) can be plotted on Figure II as S_9 and S_{10} respectively. From (9b) and (10b), it is obvious that S_9 is always higher than S_{10} for any given value of x. The y-intercepts of the two curves reflect the royalty rates if there is no rushing, which should barely cover the expected cost of the innovation, c*. The slopes of the two curves can be derived by taking the first and second derivatives of (9b) and (10b) with respect to x.[18]

To choose the final equilibrium, we include the preference of the manufacturer in the picture. A manufacturer prefers a high winning probability, a low royalty rate, and a fast timing of innovation, but for a given level of "profit," there are trade-offs between these variables. The trade-offs between the winning probability and the other two variables obviously depend on the risk preference of the manufacturer. This issue, though important in a more general context, will be set aside to highlight the competitive process emphasized here. Concentrating on the trade-off between the royalty rate and the timing of innovation (rushing effort), we know that a manufacturer will balance his marginal revenue from lowering the royalty rate with the marginal revenue from adopting the innovation a little earlier.

Formally assume that a manufacturer is a price taker in the product market where the price, p_0, equals the pre-innovation marginal cost, MC_0. The manufacturer hopes that the product price remains at this level while he searches for the lower cost method (AC_s) at a lower royalty rate of π_t. His profit function R is thus

$$R = (p - \overline{AC_s} - \pi_t)\ \overline{q}e^{-rT(x)} \qquad (11a)$$

where $\bar{q}$ is the output that maximizes the manufacturer's profit and $\overline{AC}_s$ its

corresponding value of average cost. Assume away such adjustment in output for the

time being, $\overline{AC}_s \approx \min AC_s$ and $\bar{q} \approx q$. Equation (11a) can thus be rewritten as

$$\pi_t = (p - \overline{AC}_s) - \frac{R\, e^{rT(x)}}{q} \tag{11b}$$

Simple differentiation will show that (11b) is increasing with respect to

x at a diminishing rate.[19] Furthermore, since (11a) makes sense only when

$p - \overline{AC}_s - \pi_t > 0$, (11b) is bounded above by $\pi_t = p - \overline{AC}_s$. These considerations

suggest a series of "iso-profit" curves which take the shape of MM in Figure II.

To maximize profit, a manufacturer would hope to reach a lower MM curve; but

subject to the cost of rushing in (9) and (10), he chooses only the tangency

point between the S_{10} curve and the MM curve. The competitive contract that

emerges from such equilibrium thus stipulates a royalty rate π_t^{**} and a delivery

time $T(x^{**})$.[20]

It is also interesting to compare the contracted delivery time, $T(x^{**})$,

with the idealized socially efficient time, $T(x_s)$, the monopolist rushing time,

$T(x_m)$, and the competitive rushing time, $T(x_e)$. The ranking between $T(x_s)$,

$T(x_m)$, and $T(x_e)$ has been analyzed in Dasgupta and Stiglitz (p. 7), who

showed that $x_m < x_s < x_e$. Here, we wish to show that $x^{**} \simeq x_m$. That is,

the contracted delivery time is close to a monopolist rushing time. Fur-

thermore, a slight extension of Dasgupta and Stiglitz' model would imply

that if output effect on the industry demand is zero (i.e., perfectly in-

elastic demand), $x_m = x_s$. Thus, ignoring the output effects, the timing of

innovation in the royalty-cutting model will be close to the idealized

socially efficient time also.

Recall that the R&D monopolist problem is

$$\underset{x_m}{\text{Max}} \quad G \, e^{-rT(x)} - x \qquad (12a)$$

Based on (6), this can be rewritten as

$$\underset{x_m}{\text{Max}} \quad (\pi_0(c^*) \, mq - c^*) \, e^{-rT(x)} - x \qquad (12b)$$

The royalty-cutting inventors compete for the patronage of manufacturers who would maximize the objective function in (11a) subject to the rushing constraint of (10).

i.e.

$$\underset{x^{**}}{\text{Max}} \quad [p \cdot q - \overline{AC}_s \cdot q - \pi_t^B \cdot q] \, e^{-rT(x)}$$

$$= [p \cdot q - \overline{AC}_s \cdot q - \frac{(xe^{rT(x)} + c^*)}{m}] e^{-rT(x)} \qquad (13a)$$

If $p - \overline{AC}_s \approx \text{Min } AC_0 - \text{Min } AC_s(c^*) = \pi_0(c^*)$, i.e. (manufacturer's output effect is ignored),

(13à) becomes

$$\underset{x^{**}}{\text{Max}} \quad [\pi_0(c^*) \, q - \frac{(xe^{rT(x)} + c^*)}{m}] e^{-rT(x)}$$

$$= \frac{1}{m} [(\pi_0(c^*) \, mq - c^*) e^{-rT(x)} - x] \qquad (13b)$$

(13b) differs from (12b) by a multiplicative constant $\frac{1}{m}$. Thus, the solutions of (12b) and (13b) should be identical.

$$Q.E.D.$$

It is clear that the argument above implicitly ignores manufacturer's outputs as well as industry's output post-innovation. This can be a legitimate simplifying assumption if one is interested only in competition in the R & D market. Assuming output effects away is equivalent to a partial equilibrium analysis which would not affect the gist of our argument that inventors are using manufacturers to discourage premature innovation. However, it will affect the general conclusion with respect to the idealized timing of innovation.

The general problem of analyzing the interaction of competition in the output market (or any other output effects) and competition in the R & D market (or the timing of innovation) is a difficult problem which has not been analyzed until very recently (Stiglitz, 1981; Gilbert and Newberry, 1979). These studies implicitly assume a dominant firm in the _output_ market and are not directly applicable to our problem at hand.[21] However, the underlying economics could be similar in that the analyses behind the studies also involve inter-actions between the output and the R & D market. Such interactions would affect _both_ the timing of innovation in the conventional rigid royalty model as well as the royalty-cutting model. Comparison of the timing of innovation in this context is indeed important, but it can also be misleading: Consider the assumptions about manufacturers in these models -- i.e. dominant firm vs. atomistic manufacturer who behaves like a Cournot oligopolist in his adoption of technology. For well-known reasons, these assumptions are not free from controversy,[22] and their welfare implications are quite different. Thus, any welfare implications derived from a general model that includes the output effects may very well be the result of a particular oligopolistic behavior assumption in the output market rather than the direct result of the force of competition in the R & D market. If one is interested in only the latter issue, considerations of various output effects would blur the issue.[23]

With these caveats, we turn to a "relatively" general case where the outputs of the manufacturers and the industry as a whole increase post-innovation. Figure Three illustrates the deciding factors that will influence the timing of innovation. The diagram duplicates Figure 1 in Dasgupta & Stiglitz (p. 6) with the horizontal sum of existing manufacturers' post-innovation marginal costs (SS) added into the picture also. Area ABCDEFG is the social gain of the innovation. The idealized society's optimal timing of innovation, $T(x_s)$, will result if one maximizes the discounted expected gain of this amount with respect to time. The R&D monopolist's timing of innovation, $T(x_m)$, is latter than this because he sees only an expected gain of ABC EFG. Thus, some nonzero product-demand elasticity would suggest that $T(x_m) > T(x_s)$, and on this effect alone, $T(x**) > T(x_s)$. We call this the industry output effect, which implies that the timing of innovation is too late relative to the idealized society's optimum. Next, consider the output effects of the manufacturers. A price-taker would expand output beyond his minimum efficient size once the low-cost method is obtained. His willingness to precommit to a low-cost technology is thus the sum of cost saving on the pre-innovation output and the additional profit due to output expansion. The latter component, aggregating over all manufacturers, amounts to area ECS in the diagram, which will speed up the timing of innovation. Thus, as long as short-run elasticity of supply is positive, $T(x**) < T(m)$, and ignoring post-innovation industry output, $T(x**) < T(x_s)$. We call this the manufacturer's output effect which implies that the timing of innovation is too fast relative to the idealized society's optimum. Combining the industry's and the manufacturer's output effects, $T(x**) \lessgtr T(x_s)$ depending on the relative magnitudes of areas ECS and ECD, which in turn depends on the relative magnitudes of demand and short-run supply elasticities.

Figure III
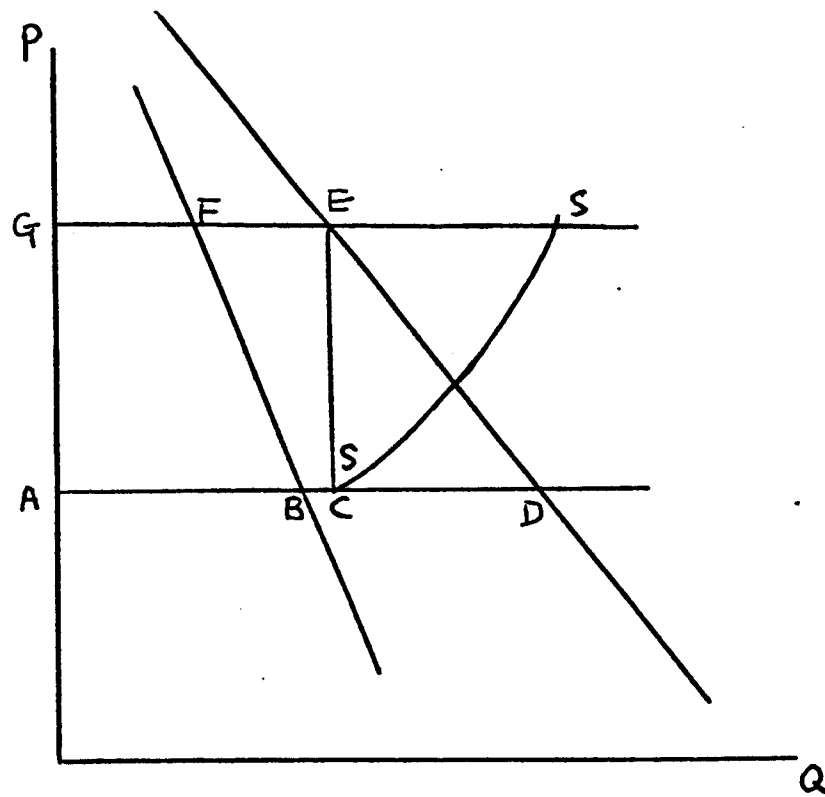
Conclusion and Remarks

This paper compares two models of competition in innovation. The
first is a rigid-royalty model where inventors rush to innovate if
certain game theoretical assumptions are made. A limit-pricing model
demonstrates that there will be a clear winner if inventors perceive different
gains or costs. The second model is a royalty cutting model where the buyers
of the innovation (manufacturers) and the inventors have similar expected
value about the future innovation. Inventors in this model compete in terms
of cutting the royalty rate before the act of inventing. The limit-pricing model
used in the first model can be modified to demonstrate how a competitive
process would turn ex-ante identical inventors into a situation where gains
or costs perceived by the inventors are different (and thus, a winner is
clearly determined). It has been shown that a royalty-cutting inventor will
gain a winning edge over the inventors who hold a rigid royalty rate.
Furthermore, the royalty-cutting inventor does not have to sign up all the
manufacturers in order to dissuade his competitors from inventing. Thus,
individual manufacturers cannot hold up a royalty-cutting inventor.
Vertical integration is argued as an enforcement mechanism in the royalty
cutting model. The equilibrium in such a model delivers an optimal timing of
innovation if certain output effects are ignored. With the ouput effects,
the timing of innovation may be sooner or later depending on the trade-off
between a manufacturer's output effect and an industry's output effect. However,
any divergence between this timing and the idealized society's timing is caused
by such output effects and not by competition in the R & D market.

Competition by cutting royalty is a Pareto improvement over competition
by rushing. However, to argue that the royalty-cutting model will always be

chosen in the real world is to commit as serious a mistake as the other extreme of blindly asserting rushing in the real world. Like all economic analyses, the magnitude of the gain from royalty cutting must be compared with its cost. It is thus crucial to examine the nature of transaction costs in these competitive contracts and to see how they vary in different situations.

It is unfortunate that in spite of the vast amount of theoretical works on rushing, no one has yet provided a clear case of premature innovation that is due to competition. Casual empiricism is noted among private conversation, but it is seldom clear that a particular rushing observation is the direct result of competition in the R & D market. Other factors such as the stochastic element in $T(x)$, the protection of property right on intermediary research, and the various output effects described in this paper may very well be the true underlying motives. Empirical research weighing the relative importance of the two models therefore should be formulated along two directions: (1) a quantitative test on the extent of premature innovation to predict how the timing may vary across different industries. (2) To the extent that premature innovation does occur, ascertainment of whether it is caused by competition in the R & D market. Empirical proxies for these theoretical factors potentially exist; competent econometric analysis is needed to provide us with a clearer picture.

FOOTNOTES

[1]Alchian & Allen, Chapter 1.

[2]The idea of competitive process is explained in McNulty (1968), Kirzner (1973), and recently Demsetz (1981).

[3]The T in equation (1) will only be socially optimal if G equals the social value of the innovation.

[4]Dasgupta & Stiglitz (1980), and Gilbert & Stiglitz (1979), have questioned the robustness of the rushing result under different game theoretical assumptions. Their analyses suggest that even in this rigid-royalty perfect certainty model, rushing would result only under some specific Stackelberg interaction or the playing of mixed strategies. With uncertainty in winning the patent, the rushing result must be modified further, see Loury (1979) and Dasgupta & Stiglitz (1980).

[5]Dasgupta & Stiglitz have apparently overlooked that there can be profit in this situation, see their paper, fn. 12.

[6]Dasgupta & Stiglitz have also considered these possibilities, p. 14.

[7]This assumes $T(x)$ is nonstochastic. If $T(x)$ is stochastic, the winning probability of the superior inventor will be higher while that of the inferior inventor will be lower.

[8]There appears to be a contradiction between equation (7a), (17) and (19) in Dasgupta & Stiglitz' paper. In order to be logically consistent, V_m^d, in equation (19) must be negative. This implies that a necessary condition for pre-emption is that the incumbent monopolist must suffer loss in specific assets post entry.

[9]Interest rate and multi-periods are not germane to the argument in this paper. Both are suppressed.

[10]The significance of s is that it gives a lower bound on the magnitude of the royalty reduction for given level of c*; see the Appendix.

[11]Firms allegedly are reluctant to adopt changes and are more interested in developing existing products; see D. Hamberg, "Invention in the Industrial Research Laboratory," Journal of Political Economy, April 1963.

[12]The possibility was also suggested as a method of resolving another aspect of the contracting problem in innovation; see "Potential Competition and Contracting in Innovation," Journal of Law and Economics, October 1981.

[13]Although manufacturers entering the output market can mitigate the purpose of precommitment, we note that many innovations have the effect of increasing the minimum efficient size and thus the number of manufacturers decreases rather than increases post-innovation. Also, other explanations of vertical integration should be taken into consideration in empirical testing, see O.E. Williamson, Markets and Hierarchies. (New York: The Free Press, 1975) and Klein, Crawford and Alchian, "Vertical Integration, Appropriable Rents, and the Competitive Contracting Process," Journal of Law and Economics, October 1978).

[14]See also the discussions on p. 18.

[15]There are other reasons for obtaining exclusive license from inventors besides monopolization, e.g., market testing a new product, enforcement of nonpatenatable information, etc. These other transaction cost reasons do not affect the main argument in this paper and will be ignored here.

[16]The existence of search cost opens up another line of inquiry which will be crucial in explaining market structure in the real world. However, to limit the scope of the paper, this issue will not be considered here.

[17]With T or the value of innovation being stochastic, a manufacturer might not want to precommit to a single inventor. However, this type of risk exists also in the alternative adjustment mode. Since both adjustment modes require the manufacturer to precommit to an inventor, this type of risk has equal influence on the two adjustment modes and should not affect the choice between the two. The more interesting question of whether the manufacturer would precommit to an inventor at all is a risk preference issue that depends on a manufacturer's trade-off between a lower expected royalty and a higher risk of selecting the wrong inventor.

[18] The slope of (10b) is

$$\frac{e^{rT(x^*)}[1 + rx^*T'(x^*)]}{mq} \ ,$$

its curvature is

$$\frac{e^{rT(x^*)}[x^*(rT'(x^*))^2 + 2rT'(x^*) + rx^* \, T''(x^*)]}{mq} \ .$$

The signs of both expressions are ambiguous.

[19] The slope of (11b) is

$$\frac{d\pi_t}{dx} = -(p - \overline{AC}_s - \pi_t) \, rT'(x)$$

and its curvature is

$$\frac{d^2\pi_t}{dx^2} = -\frac{R \ re^{rT(x)}}{q} \ [T''(x) + r(T'(x))^2]$$

[20] The inventor's promise of a low royalty rate and a fast delivery time will not be consistent with his postcontractual maximizing behavior; i.e., once the inventor has gotten the manufacturers' precommitments, he has the incentive to shirk on the delivery of the promised expected innovation. However, this is a principle agent problem, which would not exist with zero transaction cost. In my working paper, I discussed a method of resolving this principle-agent problem.

[21] The ability of a dominant manufacturer to set state variables to influence price and quantity in the output market is a crucial pre-condition in these studies.

[22] See Stigler (1964).

[23] Indeed, Professor Stiglitz's suggestion of Pareto-Inferior competition is caused by a combination of competition in the R & D market (under a rigid royalty model) and the lack of competition in the output market. In fact, once the possibility of royalty cutting is acknowledged, the term Pareto-Inferior competition becomes highly misleading because the source of inefficiency then primarily arises from the lack of competition.

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Appendix: Competition among manufacturers

This appendix demonstrates a competing manufacturer's incentive
to exchange commitment for low royalty rate. Assume a manufacturer can be
"active" or "passive". The former refers to his activity of expending
resources in searching and negotiating a lower royalty rate with different
potential inventors before the act of invention. The latter refers to his
attitude of passively adopting whatever successful innovation there is in
the market. Note that in the passive situation, the successful innovation
may be controlled by an inventor or a manufacturer-inventor pair via ex-
clusive license (see, p. 9).

To derive the pay-off matrix to an individual manufacturer, consider
the cost-reduction innovation mentioned in the text. If all manufacturers
are passive, it is the conventional model which we have called the rigid
royalty model. Manufacturers in this situation have to pay a royalty of
π_0 (equation (1) in the text). If production costs of all manufacturers are
identical, competition in the output market dictates that the market price,
P_0, equals the minimum of average cost including the royalty, i.e.

$$P_0 = \pi_0 + AC_s \qquad \qquad (A1)$$

The profit to each manufacturer is obviously zero.

Now suppose that before the act of invention, a manufacturer can
negotiate and search among potential inventors in reducing the royalty
rate to $\pi_t(s)$, where s is the annuity equivalent of the cost of negotiation and
searching, $\pi_t'(s) < 0$. The manufacturer will

$$\text{Max}_{s} \quad \Pi = (P_o - \pi_t(s) - AC_s)q - s \tag{A2}$$

Although an interior solution of (2), s^*, ensures a positive gain from search, this gain can only persist if the product price, P_o, remains the same. This will not happen as all manufacturers search simultaneouly, because the product price in this case must fall to reflect the lower royalty rate and the search cost, i.e.

$$P_t = \pi_t(s^*) + AC_s + \frac{s^*}{q} \tag{A3}$$

Substituting P_t for P_o in (2) gives $\Pi = 0$, i.e., the gain from search is totally passed on to the consumer.

Apparently, if all manufacturers adopt uniform actions (either "active" or "passive"), none will have profit. However, it is the possibility of nonuniform actions that is interesting in a competitive economy. Table 1 describes such possibilities. The entries in the table refer to the pay-offs to an individual manufacturer conditional on the strategy chosen by the other manufacturers. As described above, $G_{EE} = G_{\overline{EE}} = 0$. The signs of the remaining two entries refer to nonuniform actions: $G_{E\overline{E}} > 0$ because (a) passive manufacturers have to pay their demand prices, thus keeping the product price up, and (b) an interior solution of searches implies that the reduction in royalty must be greater than the search cost. $G_{\overline{E}E} < 0$ because all other manufacturers have gotten a lower royalty, thus lowering the product price and leaving the individual manufacturer with a negative profit (or a decrease in salvage value of some fixed asset). Therefore, the gain of getting ahead of others and the fear of getting left behind turns active

into a dominant strategy, even though at full equilibrium, all would be

making a zero profit.

Table 1

		Other Manufacturers	
		(E) Active	($\bar{E}$) Passive
Individual Manufacturer	(E) Active	$G_{EE} = (P_t - AC_s - \pi_t(s^*))q$ $-s^*$	$G_{E\bar{E}} = (P_o - AC_s - \pi_t(s^*))q$ $-s^*$
	($\bar{E}$) Passive	$G_{\bar{E}E} = (P_t - AC_o)q$	$G_{\bar{E}\bar{E}} = (P_o - AC_s - \pi_o)q$