Discussion Paper No. 750

COMPETITION, RELATIVISM, AND MARKET CHOICE

by

Debra J. Aron*

and

Edward P. Lazear**

October 1987

---

*J.L. Kellogg Graduate School of Management, Northwestern University, 2001 Sheridan Road, Evanston, Illinois 60208.

**Graduate School of Business, University of Chicago, Chicago, Illinois and the Hoover Institution, Stanford, California.

[3-2]

I. Introduction

Economists' notion of competition is almost the opposite of that held by businessmen. With large numbers of firms, market prices combined with cost data generally provide enough information for firms to optimize, irrespective of their rivals' decisions. Thus, firms rely on absolute prices and costs, and for the most part, relative comparisons are irrelevant. The impersonal nature of competitive markets allows a firm to be introspective.

The standard way to characterize competition is least convincing in new markets, where product market choice is the essence of the problem. Consider, for example, two firms that compete in an existing market, say, main frame computers. One firm is trying to decide whether to enter a new currently nonexistent market, say, personal computers. The decision to enter depends on expectations about what the firm's rival will do. Theories of oligopoly in general, and game theoretic structures in particular, make relative comparisons crucial. Calculations about how one firm does relative to its rival are as important as calculations that align marginal cost with absolute levels of marginal revenue. This paper focuses directly on relative comparisons to derive a theory of product choice. We obtain testable empirical implications about the kind of markets that firms choose to enter. The most important are:

1. Firms that are behind in some sense are more likely to lead in an alternative market. The successful firms in an old market are less likely to be the innovator of a new product line, but may follow into the new line.

2. Given that one firm has broken into a new market, it is most likely that other firms will follow when demand in a market is highly correlated across firms.

3. Dominant firms are more likely to follow into a new market if their lead in the old market is smaller.

4. Increasing the number of firms does not alter the qualitative nature of the discussion, but does make it more likely that the dominant firm will follow into a new market.

The notion that relative comparisons are important is not new. The original Hotelling (1929) model of product quality choice recognizes that the position of one's rival is important in determining optimum location in quality space. This model has been adapted to the problem of market or brand selection by Schmalensee (1978) and others. More recently, Williamson (1968) and Salop and Sheffrin (1983) have pointed out that implicit in the competitive model is that rivals' costs affect a firm's profits because price is set by the cost of the marginal producer. In another vein, compensation structures have been modeled as relative comparisons, much like a sports event, where the winner receives one prize and the loser receives another. (See Lazear and Rosen, 1981; Nalebuff and Stiglitz, 1983; Green and Stokey, 1983; and Carmichael, 1983.) Finally, the literature on patent races (Reinganum, 1982a and b; Dasgupta and Stiglitz, 1980; Loury, 1979; Bhattacharia, Dasgupta and Mookherjee, 1984; and Judd, 1985b) describes a game in which relative comparisons are crucial.[1]

There is a large patent race literature to which this analysis is related. Some of those papers are significantly more sophisticated and general than the model set out here with regard to the range of strategies available to the players (e.g., see Judd(1985b)), however, they do not analyze the strategic problem in a market context. Our work is, in many ways, closer to that of Lazear and Rosen(1981) than to the patent race papers, even though the topic of Lazear and Rosen (labor markets) is further removed. The reason is that in the labor market model, the prizes evolve as part of the market's competitive process and are not given exogenously. This is more than a mere wrinkle, because it guarantees efficiency. (Lazear and Rosen show that tournaments achieve first-best for risk-neutral workers.) In patent races, efficiency is achieved only when the exogenous prize is set correctly. Below, we demonstrate that efficiency is likely with respect to product choice even if output is sold monopolistically.

The game-theoretic literature in industrial organization is also relevant. It models explicitly the behavior of one firm as it takes into account the behavior of its rivals. But this literature has only begun to investigate product choice in a competitive environment. Our work differs from existing literature in a number of respects. Game theoretic models often focus on prices and quantities as the important strategic variables; here, we propose that firms compete through their choice of products, product attributes and technologies. We treat these explicitly as strategic tools with which firms can affect not only their absolute position in the industry but their relative position as well, by influencing the decisions of their rivals.

This work illustrates the importance of relative performance in industrial competition. The model endeavors to explain real world phenomena. For example, a few years ago IBM became the leader in the personal computer market with the IBM PC. Apple had led until that point. Rather than attempting to regain its share in that market, Apple introduced a smaller, cheaper model: the Macintosh. IBM countered with the PC Jr., which was a colossal flop. IBM's PC Jr. was clearly behind the Apple technology, but IBM entered that market anyway. Must this be explained as a mistake? It can be argued that it was optimal ex ante for IBM to counter, even though it knew that its probability of doing well in the small PC market was low. IBM may have entered this market because it wanted to cover itself in the rare chance that the small PC market displaced the larger PCs. Because the success that Apple enjoys in one market is correlated with the success of IBM in that same market, and because small PCs and large PCs are substitutes, IBM followed Apple's lead.

A second example is the selection of television shows by the major networks. A few seasons ago, each network decided to produce at least one anthology-type series. Anthologies had not been produced on television for many years, so the market is currently unknown. The anecdotal evidence is that the networks keep a very close eye on one another and are quite concerned if a rival tries a new concept; it indeed appears that the anthology shows were a direct response to one network devoting considerable resources to its anthology series. This kind of defensive innovation in television programming was not peculiar to that year--as anyone who admits to watching television will testify.

A final example is the observation that Time and Newsweek chose cover stories that are often identical. This is, of course, to be expected in weeks of a major news story, but it is probably not coincidence that cover stories ranging from AIDS to Bruce Springsteen appear in the same week.

II. The Framework

The principle insight we wish to explore here is that a firm may take actions in the interest of furthering its relative position in an industry. A somewhat whimsical but real example from the world of yacht racing illustrates the point.

In 1983 the United States lost the America's Cup competition for the first time in the event's history. Experts commented that the United States lost the cup in part because the skipper violated a fundamental rule of yacht racing. The typical situation was as follows. The U. S. yacht would find itself with a substantial lead over the 2nd place Australian team. With both boats sailing the same course of direction, the Australian team would almost surely lose if it remained on the same course. Thus, the best strategy for the second place boat was to tack. To tack is to veer off at an angle from the current course of direction, and take a saw-toothed path to the finish. One does this in the hopes of benefitting from an unexpected shift in the wind that would make the longer, indirect course the faster one. The rule of racing is that the leader should follow the strategy of his opponent in selecting sailing direction. Even though the initial path may have a shorter expected finish time, the probability of winning is maximized by switching if the second-place opponent switches, because the leader maintains his relative advantage over the challenger. If the wind shifts favorably for the challenger, the leader benefits as well. If it does not, the leader is still likely to maintain his lead. The key is that randomness in wind associated with choosing the new path is correlated across competitors.

A race is an example of a competition in which only one's relative position, and not one's absolute position, matters. In that case, each player's strategy is to take actions that maximize the probability of beating the other players, or maintaining one's relative advantage, independent of any direct efficiency considerations. What underlies this example is that the initial, straight path has low variance relative to the tacking strategy, and that in either path the speed of the two boats is highly correlated. Variance and covariance are the crucial variables determining the players' strategies because of the purely ordinal nature of a race. In particular, a team is indifferent to losing by a lot or a little; similarly, winning by a lot is equivalent to winning by a little. The former ensures the optimality of the second place team taking the high variance strategy and the latter insures the optimality of the first place team imitating the opponent's strategy.

Economic markets are not pure races. The return to a firm competing with another is dependent not only on its rank but also on its level of costs, the quality of its product, and so forth. Even in the extreme case of patent races, which are often modeled as pure races, the payoff is not strictly rank-determined. First, the winner's profits are endogenously determined by his costs and product decisions. Second, the payoff to the loser is not independent of the winner's return, to the extent that some imitation of the winner is feasible.

Thus, the strategy of a firm competing in a market is determined in part by features characteristic of a race, and by efficiency considerations as well. This makes the firm's optimization problem somewhat more complicated than that in a pure race, but the crucial variables in a race, variance and covariance, are still important. One goal of this study is to disentangle the race-oriented from the efficiency-oriented incentives in an oligopolistic market.

III. The Model

Consider two firms, A and B. Each produces its version of some product X. The costs of production are the same for both firms, but the products are not identical from the perspective of the consumers. Indeed, even if firm B charged price equal to marginal cost for its product, all consumers would prefer A's version over a large range of prices exceeding marginal cost (this will be specified more clearly presently). Thus, we consider a market in which one firm has gained advantage in a product market by virtue of marketing a product that is superior in the consumers' eyes.

The attributes of a firm's product are idiosyncratic and cannot be imitated by rival firms. Each firm has a unique set of attributes and the expected value of each firm's product may be the same, but ex post, after consumers reveal their preferences, one product is found to be superior.

A firm can, at any time, choose to enter into production of a different product Y, which is a substitute for X to some degree. By entering another product the firm must divert resources from production of X. We consider the limiting case in which the firm must exit X entirely in order to produce Y.[2]

Demand for Y in unknown ex ante. It is a new product, and could "hit"or "miss." One characterization implies that if Y hits it will, over some range of prices exceeding marginal cost, supplant demand for X entirely; if it misses and X is still on the market, no one will purchase Y. However, if X is unavailable, there will be some demand for Y even when it misses. Both A and B could produce a version of Y, and, again, these would not be identical. Since consumers see the two versions as imperfect substitutes, either, both, or neither version could be a hit. To the extent that Y_A and Y_B are similar products, however, the probability that Y_A hits will be correlated with the probability that Y_B hits. But correlation is unlikely to be perfect. Since A has proven to produce a superior product in the X market, one might suspect that A would have a higher probability of success in Y than does B. The idiosyncratic feature of firm A generating the success of X_A is likely to carry over into the Y market.

In this scenario, firms make decisions about which market they choose to operate in. Their decisions will, of course, depend on the payoffs in each market, which are endogenously determined by the consumers' preferences, the firms' costs, and the strategic interaction between the firms given their market choice. Assume that firms behave as Bertrand oligopolists, and parameterize consumers' preferences as follows:

$$(1) \qquad U = f[[(\alpha X_A + X_B) + (\gamma Y_A + \beta Y_B)], m]$$

where α is known, $\alpha > 1$, γ and β are unknown, and m is a vector of other goods. In this utility function X_A, X_B, Y_A, and Y_B are perfect substitutes in proportions determined by the parameters α, β, and γ. This is as implication that captures the essence of the general case in which the products are substitutes to some degree, but not necessarily perfect substitutes.[3]

We specify the distribution of γ and β as follows:

$$\gamma = \{\gamma_L, \gamma_H\}, \quad \beta = \{\beta_L, \beta_H\},$$

where L denotes low and H denotes high. For simplicity, assume that

$$\text{Prob}\ (\gamma_H) = \text{Prob}(\beta_H) = p,$$

where β, γ may be correlated. The story of the last few paragraphs can be told using the following assumptions:

A1: $\gamma_H > \beta_H,\ \gamma_L > \beta_L > 0.$

A2: $\gamma_L < \alpha,\ \beta_H > \alpha.$

A3: $\alpha > 1$

A4: $MC_X^A = MC_Y^A = MC_X^B = MC_Y^B = 1.$

A1 means that if both firms' version of Y were hits or both were misses then consumers would prefer Y_A to Y_B at equal prices. This corresponds to the earlier argument that if A is successful in dominating B in the X market, the same firm is more likely to dominate in the Y market as well.

Of course, it is possible for one version of Y to be a "hit" and the other a "miss." In any case, the price either firm can charge will depend on how closely the product of the rival is viewed as a substitute. A major simplification is the assumption that whenever the product of firm is preferred to that of firm j, the maximum price i could charge and retain the demand when j is charging marginal cost exceeds the monopoly price. For example, if both firms chose to produce Y and both Y_A and Y_B were "hits" (i.e., $\gamma = \gamma_H$, $\beta = \beta_H$), then γ would exceed β sufficiently that A could charge the monopoly price and not lose customers to B, even when B charges marginal cost.[4] This assumption is made to focus on the relative aspects of the problem. Without it, the price that A can charge depends on Y's draw and makes the firm's decision depend on absolute as well as relative issues. By assuming that the monopoly price is below the Bertrand constraining price, we need not worry about the amount by which A or B wins. This helps to simplify the model substantially, and facilitates the comparative statics. It diminishes the model's generality, but does not change the flavor of the results. In addition, this assumption is not necessary to get our results. Any market can exhibit the kind of behavior we describe, and certain attributes of markets will accentuate their relative nature. For example, in markets in which networking is important (such as computers), markets in which brand loyalty is observed, for reputational or any other reason, or markets in which the dominant firm can act as a Stackelberg leader, there is a discontinuous advantage to being the market leader.

A2 is needed so that it may pay for the firm that is behind to switch to Y; specifically, $\beta_H > \alpha$ means that if A stays in X and B switches to Y and Y hits, then B wins. It also implies that the firm in the lead does not automatically switch to production of Y; specifically, $\alpha > \gamma_L$ means that if Y misses, A would have been better off continuing to produce X.

A3 assures that consumers prefer X_A to X_B, and A4 is merely a convenience. Since we want to focus on uncertain product demand, we assume that costs of production are independent of product choice and nature and normalize marginal cost to 1.

We can now define the conditional payoffs to each of the firms in each potential outcome. The following matrix defines the flow payoffs to A and B as a function of their strategies/outcomes. A's payoff is in the upper left corner of each box:

B

A	X	Y_H	Y_L
X	W_X ; 0	0 ; V_Y	W_X ; 0
Y_H	W_H ; 0	W_H ; 0	W_H ; 0
Y_L	DW_L ; $(1-D)V_X$	0 ; V_Y	W_L ; 0

Table 1

D is a dummy. If $\gamma_L > 1$, then D = 1 so that A wins in (Y_L,X), where we define (k.j) to mean firm A produces K and firm B produces j. If $\gamma_L < 1$, then D = 0 so that B wins in (Y_L,X). D = 1 means that Y may be a dominant strategy even for A. If $\gamma_L > \alpha$, then A would move to Y and so would B. This corresponds to a new product's being vastly superior to the old, even under the worst scenario. If $\gamma_L < 1$, then A may prefer X if this could be achieved as an equilibrium. But B may force him to choose Y. This is the more interesting case that is analyzed in detail below.

Recall that $\text{Prob}(\gamma = \gamma_h) = \text{Prob}(\beta = \beta_H) = p$. Let $q \equiv (1 - p)$, and $\text{Prob}(\gamma = \gamma_h,\ \beta = \beta_L) = \text{Prob}(\gamma = \gamma_L,\ \beta = \beta_H) = z$. Then, the ex ante expected payoffs in any period can be written as follows: Let $\pi_i(a,b)$ denote the expected payoff to firm i when A produces in market a and B in market b (and before it is known whether any firm's Y is a hit or a miss):

$$\pi_A(X,X) = W_X$$

$$\pi_A(X,Y) = qW_X$$

$$\pi_A(Y,Y) = pW_H + (q - z)W_L$$

$$\pi_A(Y,X) = pW_H + qW_LD$$

$$\pi_B(X,X) = 0$$

$$\pi_B(X,Y) = pV_Y$$

$$\pi_B(Y,Y) = zV_Y$$

$$\pi_B(Y,X) = qV_X(1 - D)$$

We can put these payoffs in matrix form, as follows:

B

A	X	Y
X	W_X ; 0	qW_X ; pV_Y
Y	$pW_H + qW_LD$; $qV_x(1 - D)$	$pW_H + (q - z)W_L$; zV_Y

Table 2

where the upper left corner of each cell gives the return to A.

The structure of the market is as follows. Firms compete over some time period with infinite horizon. They play in continuous time, which is to be thought of as the limit of an alternating moves, discrete time game, as the time intervals go to zero. In the discrete time game either player is allowed to move first. The expected future payoff at time 0 to each firm is the integral of the discounted flow payoffs, conditional on the choice of market by each firm, given a discount factor δ. Each firm is initially producing X, with return to A of W_X, and return to B of 0. At any time, either firm can decide that it will exit from the X market and enter the Y market. Once a firm chooses to enter Y, however, it is committed to Y for the indefinite future; that is, it cannot later return to product X. This corresponds to the reality that in order to enter a new product line, firms must invest a considerable amount of time developing the new product, and it thereafter takes time to learn if the product is or is not a success. Once a firm learns that its product is a miss it can, in the real world, abandon it and return attention to its substitute products. However, the intervening process requires a sufficient amount of time that the discounted present value to the firm, at the time of making the decision to enter the new product, of an eventual return to the original product is assumed to be zero. (We briefly consider below the role that exit would play if it was explicitly included in the model; the qualitative implications of the model are virtually unchanged.)

Once a firm decides to move to the Y market, it takes some time to effect the change; the new product must be developed, personnel must be trained, contracts written with new suppliers and terminated with old ones, plants must be restructured. This is publicly observed behavior. The decision to commit to Y is an announcement, but production does not begin until after some delay T. If firm i decides at time t to enter Y, firm j could follow immediately or wait until firm i produces. By waiting, j discovers whether firm i's product is a hit or a miss before committing to Y.[5] The cost of waiting is that if it subsequently decides to produce Y, j must then wait for time period T until it is ready to actually begin production of Y.

At any moment in time, each firm will choose its action based on whether or not its opponent has moved, and if so, what, if anything, has been learned. Once a firm's opponent has committed himself to product Y, a firm faces a simple, nonstrategic optimization problem. He can choose to commit to product Y immediately, or he can choose to wait. We impose subgame perfect behavior on the firms, so no firm can commit ex ante to do something that would be suboptimal ex post.

The gain to waiting is that if the opponent's product is a failure, firm j can choose not to enter Y. On the other hand, if i waits and Y_j is a success, then j suffers a loss for the entire period required for j to develop its version of Y. Thus, depending on how long is required to develop a new product, a firm may choose to follow its opponent into a new market without waiting to see if the product is successfully produced ex ante. For example, if $\alpha > E(\max(\gamma,\beta))$, that is, the expected social value Y is low relative to X, it is possible that in equilibrium Y is produced and X is not. We are particularly interested in the equilibrium in which the firm that is losing in market X enters market Y and the leader in the X market follows the rival into Y.

Lemma 1: There will always be an equilibrium in the limit of the discrete time game in which B commits to Y immediately with probability one.

Proof: We consider 2 mutually exclusive and jointly exhaustive cases.

Case 1:

L1. $\pi_A(Y,Y) > \pi_A(X,Y)$ (A follows into Y if B leads.)

and,

L2. $\pi_B(Y,Y) > \pi_B(Y,X)$ (B follows A into Y if A leads.)

and,

L3. $\pi_A(Y,X) \geq \pi_A(X,Y)$ (If one player is in Y, A prefers that it is he.)

This is the case in which both firms would at least weakly prefer to move first. The equilibrium is supported by the following subgame perfect strategies: In period one and every odd period B commits to Y with probability one conditional on reaching that period without either firm having yet committed to Y; in every even period firm A commits to Y with probability one conditional on reaching that period without either firm having yet committed to Y.

Consider first B's strategy. If B waits A will switch, and B will follow by L2. (This is automatic if D=1.) If B switches in period 1, A will follow by L1. Thus, the long run outcome is the same regardless of who moves first. In the intervening period in which one firm has moved and the other remains, the payoff depends on who has moved first. By L2 and the fact that $\pi_B(X,Y)$ always exceeds $\pi_B(Y,Y)$, B would strictly prefer to move first. Thus, his strategy is optimal given A's.

Now consider A. If A moves first his long run payoff is (the discounted present value of) $\pi_A(Y,Y)$ by L2. If A waits for B to lead A gets $\pi_A(Y,Y)$ by L1. Thus A is at best indifferent, with respect to his long run payoff, to leading or following if and only if L1 and L2 hold; that is, in that case his long run payoff is the same whether he leads or waits for B to lead. His payoff in the one intervening period when one firm has switched and the other has not depends on whether he leads or waits. Firm A at least weakly prefers to lead if and only if L3 holds. Under these conditions A's optimal strategy given B's strategy is to commit to Y in every even period with probability 1.

Case 2: Any one or more of conditions L1-L3 is violated.

The equilibrium is supported by the following subgame perfect strategies: In period one and every odd period B commits to Y with probability one conditional on reaching that period without either firm having yet committed to Y; in every even period firm A commits to Y with probability zero conditional on reaching that period without either firm having yet committed to Y. Given A's strategy, B's strategy is clearly optimal since B's payoff is zero if he remains in X and strictly positive if he moves to Y, regardless of A's subsequent response. Firm A's strategy is optimal and subgame perfect since if any of conditions L1-L3 is violated, firm A strictly prefers that B lead into Y: if L1 is violated, then A prefers (X,Y) to (Y,Y) which can be attained by allowing B to lead and refusing to follow.

If L2 is violated, then B prefers Y,X to Y,Y, which means a lead by A into Y would not be followed by B. But if L1 holds then A prefers (Y,Y) to (X,Y), which can be attained by doing nothing until B leads into Y. It is rational for B to lead into Y if A is committed to remain in X until B leads into Y. If L2 and L1 are violated, then each prefers to remain in X with the other in Y. But if A does nothing, B is forced to move to Y, knowing that A remains in X because $\pi_B(X,Y) > \pi_B(X,X)$. So again A prefers to remain in Y.

If L3 is violated, then A prefers that in the intervening period, before both are in Y, that B be in Y before A. Thus, A allows B to lead again by refusing to move until A has. Any one period cost that A incurs by waiting for B to move in period two becomes insignificant as the time periods go to zero.

<u>Lemma 2</u>: Let

(2) $\pi_B(Y,Y) < \pi_B(Y,X)$,

and

(3) $\pi_A(X,X) > \pi_A(Y,X)$.

Then the unique equilibrium outcome is that B will commit to Y immediately with probability 1.[6]

<u>Proof</u>: First consider whether A would ever lead. If A commits to lead at any time t, then B can follow immediately and get $(1/\delta)\pi_B(Y,Y)e^{-\delta(t+T)}$ or not follow and get $(1/\delta)\pi_B(Y,X)e^{-\delta(t+T)}$. (It will never be in B's interest to wait and then follow after observing A's outcome.) Since $\pi_B(Y,X) > \pi_B(Y,Y)$, a lead by A guarantees $(1/\delta)\pi_A(Y,X)e^{-\delta(t+T)}$. If A waits, then B can lead or wait. If B waits it is optimal for A to wait as well by (3). B leads because $\pi_B(Y,Y)$ and $\pi_B(X,Y)$ are both greater than $\pi_B(X,X)$. Now, A knows that if A waits, B will lead so A is faced with a choice of leading and receiving $(1/\delta)\pi_A(Y,X)e^{-\delta(t+T)}$ or waiting and receiving A's choice of $(1/\delta)\pi_A(X,Y)e^{-\delta(t+T)}$ or $(1/\delta)\pi_A(Y,Y)e^{-\delta(t+T)}$ (or a combination of these in which A waits to observe B's outcome, then follows if B is successful). Condition (2) implies that D=0, and if D=0 $\pi_A(Y,Y) > \pi_A(X,Y)$; A will wait for B to lead and B will lead. The equilibrium is supported by the following strategies: In period one and every odd period B commits to Y with probability one conditional on reaching that period without either firm having yet committed to Y; in every even period firm A commits to Y with

probability zero conditional on reaching that period without either firm having yet committed to Y.

Lemma 3: If, additionally,

(4) $$\pi_A(Y,Y) > \pi_A(X,Y)$$

and T is sufficiently large, then A follows immediately into Y.

Proof: If A waits until it is observed whether Y_B is a success, A's expected return is

(5) $$\int_0^T W_X e^{-\delta t} dt + \int_T^{2T} qW_X e^{-\delta t} dt + \int_{2T}^{\infty} (qW_X + (p - z)W_H) e^{-\delta t} dt$$

If A commits immediately, his expected return is

(6) $$\int_0^T W_X e^{-\delta t} dt + \int_T^{\infty} (pW_H + (q - z)W_L) e^{-\delta t} dt$$

Firm A will commit immediately if and only if (6) > (5), which implies

(7) $$-qW_X - (p - z)W_H e^{-\delta T} + pW_H + (q - z)W_L > 0$$

which is guaranteed for any δ for large enough T by (4).

The strategies are identical at each time t conditional on no firm having committed before t; thus, the strategies are subgame perfect.

The argument above is sufficient to show that the unique equilibrium outcome is supported by pure strategies by both players. Further, we can show that players will never optimally adopt mixed strategies. Define $T(\delta)$to be the minimum waiting time under which the Nash equilibrium outcome, under assumptions of Lemmas 2 and 3 is the follow equilibrium. Then:

Lemma 4: Under the assumptions of Lemmas 2 and 3, given discount factor δ and waiting time $T > T(\delta)$, there exist no subgame perfect mixed strategies Nash equilibria.

Proof: The argument follows from the previously observed fact that once one firm has committed to Y, the other has a dominant strategy. Neither firm could adopt a mixed strategy after the other has committed; this would not be subgame perfect.

What underlies B's move to Y is that firm B has "lost" in the X market. It is in his interest to take a risky strategy. If B moves first he knows that A will follow if $\pi_A(Y,Y) > \pi_A(X,Y)$ due to the correlation in their probabilities of winning, but if they both compete in the Y market B still has some positive probability of winning. Thus, to the extent that markets imitate races, firms will tend to compete in the high variance market, even if it is the less desirable one socially. Further, the weaker firm in the current market "draws in" the leader to the new market. The weaker firm enters the new market first, and the leader follows immediately. We will refer to this as the "follow" equilibrium.

Under a variety of circumstances, the product choice of the two firms is socially efficient. Even though output is determined monopolistically,

]in all utility functions that we have investigated A follows into Y if and only if it is socially optimal. The conditions necessary for $\pi_A(Y,Y) > \pi_A(X,Y)$ are sufficient for expected utility of (Y,Y) to exceed that of (X,Y). Expected utility is calculated such that the consumer is assumed to control production so that he maximizes utility subject to production constraints. Thus,

$$E(U(Y,Y)) = pU^{\rho=\gamma_H} + zU^{\rho=\beta_H} + (1 - p - z)U^{\rho=\gamma_L}$$

and

$$E(U(X,Y)) = (1 - p)U^{\rho=\alpha} + pU^{\rho=\beta_H}$$

where $U^{\rho=i}$ is the maximum utility attainable when the highest coefficient available from the two technologies is i. Even though there is some redundancy when two firms are in Y, there is some social benefit because there is some chance that only one firm will hit. Also, when A hits in Y, consumers gain more than when B hits because $\gamma_H > \beta_H$. Unfortunately, we have not been able to show that efficiency holds in general, nor have we been able to find an example where A follows into Y inefficiently. The welfare analysis, therefore, awaits further inspiration.

We now describe the market characteristics that make the follow equilibrium more likely.

Theorem 1: The set of parameters over which the market leader follows the maverick (immediately) into the new product line (i.e., the follow equilibrium) increases in the covariance between the probability of each new product being a hit, given variance.

Proof: The covariance in the outcomes of Y_A and Y_B is given by

$$pq - z,$$

which is decreasing in z. The variance is pq; thus, we must show that conditions (2), (3) and (7) are more likely to hold as z decreases.

First, note that only the entries in the (Y,Y) cell of Table 2 are functions of z. Further, $\pi_A(Y,Y)$ is decreasing in z, and therefore increasing in correlation; $\pi_B(Y,Y)$ is increasing in z and therefore decreasing in correlation. Thus, (1.2) and (1.3) are clearly more likely to hold as z decreases.

Firm A will strictly prefer to commit immediately after B rather than waiting if and only if (1.6) holds. For A's return to following B immediately to be strictly increasing in z, we require (1.6) to be strictly decreasing in z. This will be true if and only if

$$-W_L + W_H e^{-\delta T} < 0,$$

which implies that

$$T > (1/\delta)\ell n(W_L/W_H),$$

which is always true since the right side of this expression is negative.

Q.E.D.

Theorem 2: Define the size of A's lead in market X by W_x (since (X,X) results in W_x to A and zero to B). Then given that B leads, A is more likely to follow into Y as A's lead in X decreases.

Proof: A follows into Y if condition (7) holds. The left side of (7) is decreasing in W_x so (7) is more likely to hold as W_x decreases.

The logic of Theorem 1 makes the following result obvious.

Theorem 3: Given conditions (2) and (3), the range of parameter values over which A follows B's lead immediately into Y increases with the start-up delay, T.[3,4]

Proof: Examination of condition (7) reveals that the left hand side is increasing in T.

We have assumed that a firm cannot exit once it has committed to market Y. As, for example, Judd (1985a) has pointed out, the opportunity to exit can, for some models, change the nature of the equilibrium strategies of firms. This is not the case here. Clearly, if a firm has the option of exiting and returning to X after entering Y, the cost of shifting from X to Y has fallen. Suppose, once a firm decides to exit Y and reenter X, some delay E must be incurred before the exit can actually take place. Again, the firm must prepare to produce X by reconfiguring its capital, retraining personnel, etc.

With some messy algebra one can show that as long as E is close to T lemma 2 holds for all δ above some critical value, and lemma 3 holds for all δ. Further, Theorems 1 and 2 will hold for all δ. Of course, as E gets large the expected payoffs approach the no-exit payoffs of the model analyzed in the paper. The main impact of permitting exit is to weaken the threat of firm A to remain in X if B remains in X; but to increase the return to following B into Y once B has committed to Y.[7]

IV. The Model with More Than Two Firms

The results obtained above hold in the case of exactly two firms. It is not obvious how robust these results would be in the presence of more than one fringe competitor. However, the existence of a third competitor can actually make the follow equilibrium more likely.

Consider a market with a lead firm and two fringe firms. Initially firm A has the advantage in X, as in the case with two firms. There are many assumptions one could make about which firm wins in which situation, but for our purposes we need not make assumptions about who wins in each case. We simply assume that the third firm plays a role like the second firm; if either B or C hits in Y and A misses in Y then the firms that has hit wins. (If both hit and A misses they get some payoff that we need not specify, as long as A loses.) If A hits in Y, A wins regardless of the positions of B and C. Adjusting our previous notation, where now $\pi_i(a,b,c)$ is the expected flow payoff to firm i when firm A is producing a, B is producing b and C is producing c, the payoffs to firm A in the presence of two fringe competitors are:

$$\pi_A(X,X,X) = \pi_A(X,X) = W_X$$

$$\pi_A(X,Y,X) = \pi_A(X,X,Y) = \pi_A(X,Y) = qW_X$$

$\pi_A(Y,X,X) = \pi_A(Y,X) = pW_H$

$\pi_A(Y,Y,X) = \pi_A(Y,X,Y) = \pi_A(Y,X) = pW_H$

$\pi_A(Y,Y,Y) = pW_H + pr(L,L,L)W_L$

To understand the equilibrium in the presence of a third firm let us return to the yacht race analogy. Suppose the lead boat has not one but two boats behind it. The boats that are behind are probably going to lose if they do not change their strategy, so at least one of them will tack. Suppose boat B tacks. What will A do? His strategy now depends on the relative threats of the two boats. If C is so far behind as to be a weak threat relative to B, we would expect A to tack to cover B, and the final configuration would have C in the initial path and B and A on a tack. However, suppose C poses a sufficient threat that A's best strategy is not to tack in order to cover C. In this case C loses for sure by remaining on the initial path behind A. Thus, the best strategy for C will be to tack also. Now, with B and C on a tack, we would expect A to cover and the outcome will be that all boats are on the tack. It is interesting to note that, based on this simple analogy, it appears that the stronger is C as a competitor for A, the <u>more</u> likely it is that <u>all</u> of the boats end up tacking. This is perhaps contrary to one's initial intuition.

Let us now consider explicitly the conditions that make this equilibrium more likely. We will need the following result:

<u>Lemma 5</u>: Let $r_1,,,r_n$ be exchangeable binomial random variables[8]. Let $P_n(L)$ be the probability that all n random variables take the value L. Then $P_n(L)$ is decreasing and convex in n.

Proof: By a theorem of de Fenetti (Feller, section 7.4), to every infinite sequence of exchangeable random variables r_n assuming only the values 0 and 1 there corresponds a probability distribution F concentrated on [0,1] such that

$$P_n \equiv P(r_1=0,\ldots,r_n=0) = \int_0^1 (1-\theta)^n F\{d\theta\}.$$

Since the integrand is clearly bounded for all n, then by the Lebesgue Dominated Convergence Theorem (Rao, p. 136) the derivative of the integral with respect to n is the integral of the derivative. Thus,

$$dP_n/dn = \int_0^1 \ln(1-\theta)\ (1-\theta)^n F\{d\theta\} \le 0,$$
$$d^2P_n/dn^2 = \int_0^1 [\ln(1-\theta)]^2\ (1-\theta)^n F\{d\theta\} \ge 0.$$

The inequalities will be strict unless F has positive density only at 0 and 1. (This would be the case if the random variables were perfectly correlated.)

We can now prove the following result:

Lemma 6: If A switches when he has 1 competitor in Y (and none in X) he switches when he has n competitors in Y (and none in X).

Proof: For A to follow n competitors into Y it is necessary that

(8) $\pi_A(X,Y_1,\ldots,Y_n) < \pi_A(Y,Y_1,\ldots,Y_n)$

(where the subscripts allow us to keep track of the number of competitors to A).

This implies that

$$P_n(L)W_X < pW_H + P_{n+1}(L)W_L.$$

If A follows with one competitor (4) must hold:

$$P_1(L)W_X < pW_H + P_2(L)W_L$$

But (4) implies (8) by lemma 5 and the maintained assumption that $W_X > W_L$.

<u>Theorem 5</u>: Assume

(9) $$\pi_B(Y,X,\cdot) > \pi_B(Y,Y,\cdot)$$
$$\pi_C(Y,\cdot,X) > \pi_C(Y,\cdot,Y)$$

as well as (3) and (4), T large.[9] If, additionally,

(10) $$pW_H < qW_X$$

the equilibrium will be that B and C lead into Y and A follows. The equilibrium outcome is unique up to the interchangeability of B and C.

<u>Proof:</u> As long as the payoffs to B and C are non-negative in any configuration other than (X,X,X) there will be an equilibrium in which B (resp. C) leads into Y. (The supporting strategies may well be mixed, depending on the particular payoffs for each firm in each outcome.) Given (9), A will never lead for the same reason as in lemma 2. Suppose B leads. Will C follow? The optimal strategy of C depends on A's optimal strategy. By (9) A knows that if A follows C will remain in X. Thus, A follows if and only if

$$\pi_A(Y,Y,X) > \pi_A(X,Y,X),$$

which implies that (10) does not hold.

Thus, A's unique optimal strategy is to remain in X with probability one as long as C remains in X. Given this strategy C's optimal strategy is to follow B into Y, and by lemma 6 and (4), A then follows B and C into Y.

In cases where the follow equilibrium does not hold with two firms it may nevertheless hold with three. This is possible since the incentive for A to follow into Y increases with the number of competitors in Y, by lemma 5. Thus, if (9) and (3) hold but (4) is violated, A will not follow B into Y, yet the addition of C could allow (8) to be satisfied and all 3 firms would produce Y in equilibrium. The existence of the third firm makes the follow equilibrium more likely, in that having two competitors in Y makes Y relatively more attractive to A than if there were only one.

The equilibrium outcome with n competitors can be inferred from the above results. Consider n fringe firms, all of whom earn zero profits in X with probability one. Under conditions analogous to those of Theorem 5 there will be no equilibrium in which A leads into Y. Some number of firms $s \leq n$ will find it in their interest to switch to Y (supported perhaps by mixed strategies). Firms will continue to switch until enough firms are in Y that it is in the interest of A to follow into Y. Once A has switched into Y other fringe firms may continue to switch, depending on the structure of payoffs in X. Nevertheless, we can say that A will be drawn into Y but A will not be the first entrant into Y, under the same conditions as in the case of two firms. Thus, Theorems 1 and 2 continue to hold in this sense for n firms.

V. Conclusions

Product choice, like yacht racing, is an activity where relative comparisons are crucial. In a yacht race, winning by an inch is as good as winning by a mile. Product markets are similar. As a result, a firm may follow a rival into a less desirable market because it increases the probability of winning and does not substantially decrease the profit associated with a win.

The focus on relative comparisons implies that firms that are behind are most likely to lead into a new product. Leading firms are more likely to follow into the new market when their lead in the old market was small and when the fortune of one firm is highly correlated with the fortune of the other in the new market. Like a shift in the wind that affects both yachts similarly, consumer tastes affect all firms in the market with some commonality. The more highly correlated the demand for one firm's product with the demand for the other firm's product, the more likely the leader in the old market is likely to maintain his advantage if he switches to the new market. Second place firms lead into new markets a because likely losers have more to gain by high risk strategies. Outcomes in previously nonexistent markets are likely to exhibit higher variance.

Notes

[1]Bulow, Geanakoplos, and Klemperer (1985) examine the interaction between duopolists who compete in two markets. They are looking at a situation where both firms are committed to producing both products. The choice of market in which to produce cannot be analyzed in that context.

[2]I.e., there is an extreme diseconomy of scope.

[3]As contrasted with Bulow, Geanakoplos and Klemperer (1985), the goods are substitutes on the demand side, rather than in production.

[4]Formally, this can be shown by the following matrix:

B's Strategy/Outcome

A's Strategy/Outcome	X	Y_H	Y_L
X	A wins: Need $P^A < \alpha$	B wins: Need $P^A < \gamma_H/\alpha$	A wins: Need $P^A < \alpha/\beta_L$
y_H	A wins: Need $P^B < 1/\gamma_H$	A wins: Need $P^A < \gamma_H/\beta_H$	A wins: Need $P^A/\gamma_H/\beta_L$
y_L	If B wins: Need $P^B < 1/\gamma_L$	B wins: Need $P^B < \beta_H/\gamma_L$	A wins: Need $1< P^A < \gamma_L/\beta_L$
	If A wins: Need $P^A < 1/\beta_L$		

Denote P^i_j as the monopoly price when firm i wins with outcome/strategy j. Then given A1 to A4, the table can be summarized by the following assumptions:

A5: $P^A_X < \alpha$

A6: $P^{A}_{y_H} < \gamma_H/\beta_H$

A7: $1 < P^{A}_{Y_L} < \gamma_L/\beta_L$

A8: $P^{B}_{X} < 1/\gamma_L$ if $\gamma_L < 1$

A8: $P^{A}_{Y_L} < \gamma_L$ if $\gamma_L > 1$

A9: $P^{B}_{Y_H} < \beta_H/\alpha$

We have verified by example that demand functions derived from utility functions of the form (1.1) exist that simultaneously satisfy these assumptions and the conditions of Lemmas 2 and 3.

[5]The firm could also wait some intermediate amount of time before announcing its commitment to entering Y, but it will become clear that it will always be optimal to either commit immediately in response to the rival or to wait until he actually produces in order to learn whether the product is successful.

[6]Following Gelman and Salop (1983), if we allow firms to constrain and ration their output another equilibrium may be possible. In this equilibrium B will move to Y and if his product is a success he will constrain his output so that A can still make a profit by serving the excess demand left over from the Y market. Firm B can constrain his output in Y such that A's expected profit is lower in Y than in X. Depending on the values of the probability parameters this may be optimal for B. This strategy is subgame perfect, supported by the credible threat that if B deviates from his constraining strategy A will immediately enter Y. We are grateful to Michael Riordan for pointing out this possibility.

[7]When exit is permitted firm A might find it optimal to enter Y even in the absence of any competitor, just to find out if Y_A is a hit. We have

verified that the follow equilibrium may hold even when A would not enter Y in the absence of a competitor. In other words, A will follow B into Y to cover itself in the event that B hits in Y, but would not enter Y just to "test the waters" without a competitor.

[8]Following Feller (1971), the random variables $r_1, \ldots, r_n$ are <u>exchangeable</u> if the n! permutations $(r_{k1}, \ldots, r_{kn})$ have the same n-dimensional probability distribution. The variables of an infinite sequence $\{r_n\}$ are exchangeable if $r_1, \ldots, r_n$ are exchangeable for each n. Notice that in our framework the random variables determining the firms' payoffs are exchangeable; the asymmetry between the firms comes from the differences in payoffs conditional on a hit or a miss, not the probability of a hit or a miss.

[9]These are the analogous conditions to the conditions of lemmas 2 and 3, where (2) has been adjusted for three firms to become (9).

References

Amemiya, Takeshi, Advanced Econometrics, Harvard University Press, Cambridge, MA 1985.

Bhattacharya, Sudipto, Partha Dasgupta and Dilip Mookherjee, "Patents and Choice of Technique in Research and Development," March 1984, mimeo.

Carmichael, H. Lorne, "The Agent-Agents Problem: Payment by Relative Output," Journal of Labor Economics 1 (January 1983), 50-65.

Dasgupta, Partha and Joseph Stiglitz, "Uncertainty, Industrial Structure, and the Speed of Research and Development," Bell Journal of Economics 11 (1980), 1-28.

Dranove, David and Tommy C. Tan, "Reputation, Firm Size, and Risk Taking," mimeo, University of Chicago, July 1986.

Feller, William, An Introduction to Probability Theory, 2d ed., vol. 2, John Wiley & Sons, New York, 1971.

Fudenberg, Drew, Richard J. Gilbert, Joseph Stiglitz, and Jean Tirole, "Preemption, Leapfrogging, and Competition in Patent Races," European Economic Review 22 (1983), 3-31.

Gelman, Judith R. and Steven C. Salop, "Judo Economics: Capacity Limitation and Coupon Competition," Bell Journal of Economics 14 (Autumn 1983), 315-25.

Green, Jerry R. and Nancy L. Stokey, "A Comparison of Tournaments and Contracts," Journal of Political Economy 91 (June 1983), 349-64.

Hendricks, Ken and Charles Wilson, "Discrete Versus Continuous Time in Games of Timing," mimeo (November 1985).

Hotelling, Harold, "Stability in Competition," Economic Journal 39 (March 1929), 41-57.

Judd, Kenneth, "Closed Loop Equilibrium in a Multistage Innovation Race," Center for Mathematical Studies in Economics and Management Science, Northwestern University, Discussion Paper No. 647, February 1985.

Judd, Kenneth, "Credible Spatial Preemption," Rand Journal of Economics, Vol. 16, No. 2, Summer 1985, 153-166.

Lazear, Edward P. and Sherwin Rosen, "Rank-Order Tournaments as Optimum Labor Contracts," Journal of Political Economy 89 (1981), 841-64.

Lee, Tom and Louis L. Wilde, "Market Structure and Innovation: A Reformulation," Quarterly Journal of Economics (March 1980), 429-36.

Loury, Glenn C., "Market Structure and Innovation," Quarterly Journal of

Economics (August 1979), 395-410.

Maddala, G. S., Limited-Dependent and Qualitative Variables in Econometrics, Cambridge University Press, London, 1983.

Nalebuff, Barry J. and Joseph E. Stiglitz, "Prices and Incentives: Toward a General Theory of Compensation and Competition," Bell Journal of Economics 14 (Spring 1983), 21-43.

Rao, C. Radhakrishna, Linear Statistical Inference and Its Applications, 2d ed., John Wiley & Sons, New York, 1973.

Reinganum, J. F., "A Dynamic Game of R&D: Patent Protection and Competitive Behavior," Econometrica (1982a).

Reinganum, J. F., "Patent Races with a Sequence of Innovations" (1982b).

Salop, Steven C. and David T. Sheffrin, "Raising Rivals' Costs," American Economic Review 73, No. 2 (May 1983), 267-71.

Schmalensee, Richard, "Entry Deterrence in the Ready-To-Eat Breakfast Cereal Industry," Bell Journal of Economics 9 (Autumn 1978), 305-27.

Williamson, Oliver, "Wage Rates as a Barrier to Entry: The Pennington Case," Quarterly Journal of Economics 85 (February 1986), 85-116.