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In a differential game model, it is shown that growth, learning on the producer side, or learning on the consumer side can make profit-maximizing oligopolists maximize growth early in the product life cycle.

# I. INTRODUCTION

The Boston Consulting Group (BCG) has had an enormous influence on business practice. Haspeslagh [1981] reports that the majority of the Fortune 500 use BCG's portfolio planning techniques.

The reasoning behind the BCG approach to new product pricing (from pp. 163-164 in Henderson [1979]) goes approximately as follows. Assume the following premises to be true:

1. Costs follow experience curve reductions.
2. Market shares exhibit time-declining price sensitivity.
3. Growth rates for individual products are positive.

Given premise 1, a history of big market shares will lead to relatively low costs; and (by premises 2 and 3) this can be exploited by an all-out effort early in the life cycle, when the market is small and shares are easy to get.

A growing body of marketing literature (Dolan and Jenland [1981] is the latest example) has examined the logic of the above argument in the case of a monopolist. No work, however, has been done on pricing strategies in non-monopolistic markets. (In the economics literature, Shepherd [1962 and Spence [1979] look at conditions for equivalence of growth and profit maximization and investment patterns in new markets, respectively.)

The purpose of this paper is to examine the validity of the BCG reasoning in an oligopolistic market.

# 2. THE MODEL

I shall look at an oligopolgy with n firms, $\{1,2,\ldots,n\} \equiv N$. To participate in the industry, each firm, $i \in N$, has to pay a fixed cost at a rate $F_{it}$, which declines in response to both an experience curve effect and a public technical progress factor. So the dynamics for $F_{it}$ are

(1) $\dot{F}_{it} = h(t)MS_{it}y(p_{it}) - k(t),\ F_{i0} = F_0 > 0,$

where h(t) and k(t) are positive and declining, $MS_{it}$ is the share of customers in the market who currently buy from firm i, and $y(p_{it})$ is the rate at which each of these buys. The demand $y(p_{it})$ is positive, declining, and concave in the price charged, $p_{it}$.

In order to model the influence of the capital market, and perhaps also that of regulatory agencies, I will require each firm to have a nonnegative contribution at all times; thus,

(2) $p_{it} - c \geq 0,$

where c is the industry's common and constant variable production cost.

To model brand loyalty learning, it is assumed that market shares flow with declining speed as a function of price differences in the market, in the way described by

(3) $\dot{MS}_{it} = f(t)MS_{it} \sum_{j\neq i}^{n} g_{ij}p_{jt} - p_{it}\ ,\ 0 \leq MS_{i0} = 1 - \sum_{j\neq i}^{n} MS_{j0} \leq 1,$

where f(t) is positive and declining and, for all $i\varepsilon N$, $\sum_{j\neq i}^{n} g_{ij} = 1$. Although the many g-parameters allow some flexibility in (3), it suffers from the problem that it fails to ascertain that $\sum_{i=1}^{n} \dot{MS}_{it} = 0$, unless all prices are identical. A trivial solution to this problem is, of course, to change the interpretation of MS into relative market share. The underlying issue, however, is that (3) lacks a microbasis, and that it is hardly possible to give it one. In other words, I do not think it is possible to specify models of individual agents which aggregate to (3). It will turn out that the Nash equilibrium path has the property that all prices are identical, so we can, somewhat artificially, retain the interpretation of MS as market shares.

Getting finally to the third BCG premise, I will assume the total number of customers in the market, $TM_t$, to be growing.

All firms are striving to maximize profits through the use of pricing strategies $\hat{p}_i$, which are to be chosen as piecewise continuous functions of $(t, MS_{1t}, MS_{2t}, \ldots, MS_{nt}, F_{1t}, F_{2t}, \ldots, F_{nt})$. So the object of the game is to

$$(4) \qquad \underset{\hat{p}_i}{MAX} \int_0^T [TM_t MS_{it} y(p_{it})(p_{it} - c) - F_{it}]\, dt,$$

subject to (1), (2), and (3).

The equilibrium concept to be considered here is that of a Nash equilibrium in pricing strategies, $\hat{p}_i$. At time 0, all firms present a strategy; and if none, after having seen the strategies of the others, wants to change its own, the presented strategies are in Nash equilibrium.

I can now exploit the fact that the game (1), (2), (3), (4) is in a so-called trilinear form, which means that a set of open-loop strategies $p_1^*(t), p_2^*(t), \ldots, p_n^*(t)$ qualifies as a Nash equilibrium in the broader class of feedback strategies allowed.[1] The dual dynamics can therefore be written in a particularly simple manner (since we avoid terms like $\frac{\delta p_j}{\delta MS_i}$); if $\mu_i^j$ governs $MS_j$ and $\gamma_i^j$ governs $F_j$, we get, for $i \epsilon N$:

$$(5) \qquad \dot{\mu}_{it}^{i} = -TM_t y(p_{it})(p_{it} - c) - \mu_{it}^{i} f(t)\Big(\sum_{j \neq i}^{n} g_{ij} p_{jt} - p_{it}\Big) + \gamma_{it}^{i} h(t) y(p_{it}), \quad \mu_{iT}^{i} = 0$$

$$(6) \qquad \dot{\mu}_{it}^{j} = -\mu_{it}^{j} f(t)\Big(\sum_{q \neq j}^{n} g_{jq} p_{qt} - p_{jt}\Big) + \gamma_{it}^{j}\, h(t) y(p_{jt}), \quad \mu_{it}^{j} = 0, \; j \neq i$$

(7) $\dot{\gamma}^i_{it} = 1, \ \gamma^i_{iT} = 0$

(8) $\dot{\gamma}^j_{it} = 0, \ \gamma^j_{iT} = 0, \ j \neq i.$

From (8), (7), and (6) we easily find, for $i \neq j$,

$$\gamma^j_{it} = 0, \ \gamma^i_{it} = t - T, \ \mu^j_{it} = 0.$$

The equation determining $p^*_i$ is, for $i \varepsilon n$:

(9) $TM_t[y(p_{it}) + \frac{\delta y}{\delta p}(p_{it}-c)] - \mu^i_{it} f(t) - (t-T)h(t)\frac{\delta y}{\delta p} = 0.$

Note that the system (5), (7), (9) is the same for all $i \varepsilon N$, so all firms will price identically. (5) and (9) now show $\mu^i_{it}$ to be positive and declining, such that application of the implicit function theorem to (9) shows $\dot{p}_{it} > 0$, with early $p_{it} < c$ if we start early enough. We thus refind the BCG result, that <u>the growth constraint binds early but never late</u>.

Several comments are now in order. First, inspection of (9) will show that <u>any one of the following three effects, each roughly corresponding to a BCG premise, will give a growing $p_{it}$</u>:

--the positivity of F,

--the decline of f(t),

--the growth of $TM_t$.

In light of this model, then, <u>BCG commits an overkill</u>, in the sense that their recommendation to maximize early growth and "harvest" late can be realized by application of fewer premises than those they state.

Second, the economic logic behind the pricing pattern is that the first effect above induces a premium on early learning of cost reductions, while the two latter effects cause the price sensitivity of sales to go down (while marginal costs are constant).

Third, I should caution that the solution is nowhere near unique; thus, other equilibria could have other properties.

## 3. CONCLUSION

Given the assumptions of the above model, any one of the following three effects is enough to induce firms to maximize growth early in the product life cycle:

--experience curve,

--increasing brand loyalty,

--market growth.

Even though the result has been found in the context of grossly unrealistic cost and demand functions, its strength seems compelling.

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FOOTNOTES

[1]The theorem in Clemhout and Wan [1974] is less general than their method of proof, and although the present model does not fit the theorem, one can insert it into their proof and verify the result. Alternatively, one can go directly to a verification theorem, e.g., Thrm. 3 in Stalford and Leitman [1973].

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