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CONSUMPTION EXPERIENCE AND SALES PROMOTION EXPENDITURE

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ABSTRACT

An economic theory of habit formation through consumption learning is developed to explain order differences in relative sales promotion expenditures among brands. The theory applies to consumer brands in equilibrium markets, where consumer information from sources other than advertising, sales promotion, and previous consumption experience is negligible.

Three propositions are derived from the theory: brands with more consumption experience (1) spend proportionately less on sales promotion as well as (2) on advertising and promotion combined, and (3) place proportionately more emphasis on advertising relative to sales promotion. These propositions are formulated as hypotheses and tested against empirical data from the PIMS project. It is found that the data are generally consistent with the propositions. In order to examine the robustness of the results, the hypotheses are subjected to three different empirical tests, each with different assumptions. The findings are shown to be reasonably robust with respect to these changes in assumptions.

INTRODUCTION

Among the variables in a firm's communications or promotional mix, advertising has received by far the most research interest. Even though the assumption that advertising, sales promotion, and other communications variables operate independently is highly unrealistic, most studies have focused on advertising in isolation. There is a vast literature on advertising expenditure, ranging from the classical theoretical works of Dorfman and Steiner (1954); Rasmussen (1972); Nerlove and Arrow (1962); and Schmalensee (1972), and more recently by Deal (1979) and Teng and Thompson (1983) to large scale empirical projects by Comanor and Wilson (1974); Rundfelt, (1973); and Lambin (1976) including numerous marketing studies (see the review of Assmus, Farley, and Lehmann, 1984). In contrast, very little attention has been given to sales promotion expenditure, the magnitude of which substantially exceeds that of advertising in the aggregate (Frankel, 1980; Weiss et al., 1981; Yovoich, 1983).

The conflicting empirical results in the literature regarding advertising raise the question of how appropriate it is to study communications variables as independent of one another. For example, studies of the relationship between advertising/sales and market share have found both positive and negative associations (Comanor and Wilson, 1974; Long, 1980; Lilien, 1979; Bass, Cattin and Wittink, 1978; Buzzell and Farris, 1977; Farris and Buzzell, 1979). A variety of explanations have been proposed in light of these inconsistencies (Porter, 1980; Brown, 1978; Peles, 1971; Farris and Albion, 1981; Ferguson, 1974; Comanor and Wilson, 1974, 1979; Simon, 1970; Albion and Farris, 1981; Schmalensee, 1972; Arndt, 1982; Long, 1980).

Compared to the literature on advertising, the literature on sales promotion expenditure is fairly meager. Similarly, however, it contains inconsistent findings. At a fundamental level, there is a lack of agreement about what sales promotions accomplish and how they should be viewed (Strang, 1976; Lilien and Kotler, 1983). In reviewing empirical findings on sales promotion, Bearden, Teel, and Williams (1981) note that promotions seem to be most effective for unfamiliar brands, and that promotions can generate immediate effects in terms of sales. According to Wind (1982), it is often assumed that the primary effect of promotions is to change the timing of sales. Empirically, however, it has been difficult to confirm the existence of this effect (Shoemaker, 1979).

Even though much more has been written about advertising, a number of modeling approaches to sales promotion has appeared in the marketing literature (Kuehn and Rohloff, 1967; Rao and Lilien, 1972; Aaker, 1973; Little, 1975; Blattberg, Buesing, Peacock, and Sen, 1978; and Blattberg, Eppen, and Lieberman, 1981). Some of these models have theoretical support; others have not (for a discussion and summary, see Lilien and Kotler, 1983).

This paper is an attempt to contribute towards the understanding of sales promotion from a theoretical as well as empirical perspective. As in the work of Blattberg et al. (1978, 1981) we draw upon Becker's (1965, 1981) notion of the household as a production unit. Blattberg et al. applied the economic theory of the household or consumer as a production unit (that optimally allocates its resources by trading off holding costs, transaction costs, and promotional discounts) and propose a promotional model based on inventory control. While viewing the problem from the same theoretical perspective of "consumption as production" we adopt a different perspective with respect to sales promotion. If one considers household consumption as a form of production, it

seems reasonable, following Stigler and Becker (1977), to assume that production learning in the form of experience effects (e.g., experience curves) also operates at the consumption level. Applying the idea of production experience to consumption behavior will lead us to a theory of consumer habit formation. We argue that sales promotion can play a dual role in that it can be involved in both "habit-formation" as well as in "habit-destruction." Assuming that our arguments about the individual consumer translate to the aggregate brand level, we show that, compared to brands faced with little consumption experience, brands with more consumption experience will:

(1) spend proportionately less on promotion,

(2) spend proportionately less on combined advertising and promotion, and

(3) place proportionately more emphasis on advertising relative to promotion

in consumer markets at equilibrium where consumer information is dominated by advertising, sales promotion, and past consumption experience. Other potential information sources are assumed to have negligible effects.

Despite the empirical difficulties (to be discussed later) in identifying a relevant sample (markets in equilibrium where consumer information sources other than those specified by our theory are inconsequential), operationalizing "consumption experience," and matching brand level analysis to business level analysis, it is concluded that data from the PIMS project are generally consistent with the propositions of the theory.

THEORY

The observation that unit cost declines as cumulative sales volume increases is often attributed to underlying factors of learning and experience on the part of the firm. Popularized by the Boston Consulting Group (1972),

the experience curve is thought to affect not only labor costs but total value-added costs, including advertising and promotion, thereby giving large market share firms important cost advantages. However, there is no reason to assume that learning is limited to the supply side. There may well be significant effects of learning on the demand side as well. For example, is there a relationship between consumption learning and relative marketing cost? Surprisingly enough, even though marketing scholars traditionally focus their analysis on the demand side, the relationship between cost behavior and learning has essentially been analyzed with respect to the supply side. And, even though learning is a central concept in the consumer behavior literature (Howard, 1977; Bettman, 1979) and brand choice learning models (Kuehn, 1962; Lawrence, 1975; Wierenga, 1974; Lilien, 1979; Leeflang and Boonstra, 1982; Haines, 1969), fairly little is known about the relationship between consumer learning and the behavior of marketing costs.

The idea of consumption learning is not new in economic theory (Demsetz, 1962; Comanor and Wilson, 1974, 1979; Katona, 1951; Lynk, 1981; Schmalensee, 1972, 1982). Recently, Spence (1981) presented a model based on production learning and showed how it can be adapted to at least one type of demand dependence on accumulated volume. Similarly, Stigler and Becker (1977) discussed the accumulation of experience from consumption and its effects on consumer choice. Schmalensee (1982) developed a model in which the advantages that pioneering brands have in consumer experience are highlighted. What these writers suggest is basically that consumer experience in the aggregate favors choice of established brands with high cumulative sales.

Following Becker (1965) and later Lancaster (1971), we view consumption as the production of experiences from products. As a consumer increases his or her experience with a product, user skills are developed and habits are formed.

The process of developing user skills applies to almost any type of purchase. Consider, for example, a consumer who is about to choose a cereal brand for breakfast. For the sake of illustration, suppose that this consumer is visiting the U.S. for the first time and comes from a country where one always eats local fruits for breakfast. Suppose also that the consumer is ignorant of what cereal brands, types, prices, etc., are available in the U.S. supermarket. Under most circumstances, it would not be optimal to engage in an extensive information search. Decision making obviously carries some cost because of the effort involved in gathering and processing information. Nevertheless, assume that the consumer somehow reaches a decision and buys a cereal brand about which he or she, of course, knows very little.

Once the purchase has been made, problems of consumption arise. How should the cereal be devoured? With milk? With sugar? Perhaps with fruit? If so, what kind of fruit? And also, how much of each of the above? By viewing consumption this way, we realize that the product bought (i.e., the cereal) is an input into a process that produces a meal. In our example, it is also clear that the consumer knows very little about the production process. Thus, the meal that is actually produced is to a large extent a result of trial and error. Depending on the degree of success (e.g., how the meal tasted), the combination of inputs may be altered in various ways the second time the meal is produced. Further improvements can be made as the consumer gains in experience.

Consider now the next time the same consumer is about to purchase a brand of cereal. The process involved in the first purchase may be repeated or the consumer may rely on the experience gained in consuming the first brand. If some specific combination of cereal, milk, sugar, etc., did in fact produce a

satisfactory meal, the consumer has developed a certain user skill or production (consumption) experience. Clearly, if there is product differentiation such that user skills transfer imperfectly to other brands, the decision to purchase the same brand the second time may have advantages over a repeated trial-and-error/experience based process because of these acquired skills: in particular, the cost of information and its application to a somewhat different production process would be eliminated.

In viewing consumption as a form of production process, virtually all products become inputs into a process that also involves other products. A lawn mower may be an input into the production of a neatly trimmed lawn. Other inputs may be various forms of weed control, an edger, a rake, etc. It may take considerable user skill to combine and utilize these inputs effectively. Like the traditional concept of labor efficiency, as consumers repeat the particular consumption task, they become better at it and learn improvements. Unless the experience gained from using one product (brand) can easily be transferred to another product, consumer choice will be oriented toward simplification of choice heuristics (Bettman, 1979), routinized response behavior (Howard, 1977), and habitual purchase (Stigler and Becker, 1977) to use terms from behavioral as well as economic theory.

As first discussed by Katona (1951), habit formation may well be a rational response of a consumer with unchanged tastes. If the costs (of time, effort, etc.) of identifying and evaluating new potential habits are high, this can only be done occasionally and only few alternatives can receive serious consideration. The alternatives most likely to be considered are those which are easy to identify and about which information is available.

In performing a comparison between a given habit and a challenging alternative, an important factor is the age of the incumbent habit. The older

the habit is, the more established it has become and the more user skill has probably been accumulated. Since user skill increases the utility of the incumbent brand, it becomes increasingly difficult for a challenger to displace the established habit. Clearly, the successful challenger must first not only (1) become considered as an alternative to the current habit but then must also (2) emerge as the chosen brand in the comparison. For the challenger, advertising is generally a primary tool for the first task, whereas sales promotion might be used for both tasks (Lilien and Kotler, 1983; Aaker, 1973; Kuehn and Rohloff, 1967; Brown, 1974).

To make this a little more precise, let us view brand choice as a two-stage process. First, the consumer selects, from the set of available brands, one or more candidates to challenge the current habit. Second, the challengers are compared to the current habit on a cost-performance basis. In this two-step process, we adopt the Stigler and Becker (1977) view that advertising does not change consumer tastes; it may instead call a buyer's attention to a brand and thus make it a challenger. Sales promotion can produce the same effect, but may also "lower the cost" (e.g., through deals, cents-off etc.) in the cost-performance comparison. Only (previous) consumption experience, however, can affect the performance part in the comparison of habit and challenger. Thus, a challenger brand can arrive at the first stage via two routes: advertising and/or promotion. Regardless of how attention was produced, the second stage involves the weighting of challenger against incumbent brand on cost-performance.

Formalizing the Theory

We formalize the theory in the context of a differential game in which n firms set advertising and promotion expenditures as functions of time. In the

interest of expositional clarity, we make the traditional oligopoly assumption that there is competition with respect to advertising and promotion, but that price competition is negligible. These assumptions are almost always made in differential game models of advertising (Jorgensen, 1982). In particular, the idea of price collusion and marketing competition has a long history in economics dating back to Chamberlin (1933). It is, for example, the theory underlying the use of concentration ratios in models of firm performance (see, e.g., Shepherd, 1972 and Gale, 1972).

The implication of these assumptions is that our theory is most suitable for convenience goods industries. The typical industry in this category is mature and characterized by brands of low unit price and very little price competition. Instead, the major competitive tools are advertising and promotion, where promotion typically is a surrogate for short-term price competition. It also appears to be true in general that price competition is less of a factor whenever we are dealing with consumption experience effects (see, Nelson, 1970; Salop and Stiglitz, 1977).

We further assume that each firm (i) has a constant unit cost c_i and that all firms have the same discount rate ρ. Since we are dealing with mature markets we can also assume a fixed market size, which, with no loss of generality, is normalized at unity.

Specifically, we model each firm (i) as selecting piecewise continuous timepaths for a_i, the ratio of its advertising expense to unit sales and b_i, the ratio of its promotion expense to unit sales, in order to maximize the net present value of all future earnings. If we let $s_i(t)$ denote the market share of firm i at time t and use p as the price of the product, the maximant is:[1]

$$(1)\quad \int_0^\infty e^{-\rho t}\, s_i(t)\, (p-a_i(t)-b_i(t)-c_i)dt,\ i = 1, \ldots, n\ .$$

The accumulation of brand specific consumer experience, $x_i(t)$, is written in the standard linear fashion, although we assume existing experience to depreciate at a strictly positive rate θ. While this "forgetting" effect is assumed to be negligible in most models of production learning, perfect memory seems less realistic for consumption learning. Defining $\dot{x}_i(t) \equiv dx_i(t)/dt$, we obtain

$$(2) \quad \dot{x}_i(t) = s_i(t) - \theta x_i(t), \; i = 1, \ldots, n .$$

In our two-stage model of the effects of advertising, promotion, and experience, we highlight the different ways experience interacts with advertising and promotion. Consequently we focus on two paths through the brand choice process. In the first path, advertising and experience interact and in the second, promotion is involved in both stages. A key implication of our two-stage theory of brand choice is that the effectiveness of advertising (in terms of its influence on consumer choice) depends on the levels of consumption experience and promotion, while it is possible that promotion can determine consumer choice without "assistance" from consumption experience or advertising.

The net flow of customers from any firm i to any firm j is the sum of the flows through these two paths. Each of these flows is thought of as proportional to the difference between the forces with which the firms influence the consumer on the path. In particular, the effectiveness of firm i's promotion will be modelled as $G(b_i(t))$ whereas the effectiveness of its advertising is modelled as $F(a_i(t), s_i(t), x_i(t), x(t))$, where $x(t) \equiv (x_1(t), \ldots, x_n(t))$. Both G and F are twice continuously differentiable, growing and concave in $b_i(t)$ and $a_i(t)$ respectively. The concavity is necessary to guarantee satisfaction of the second order conditions on the differential game, and implies

decreasing returns to scale from both promotion and advertising. Finally, according to our theory, it is suggested that advertising would be more effective, the more consumption experience a brand enjoys:

$$(3)\quad \partial^2 F/\partial a_i \partial x_i > 0,\ \partial^2 F/\partial a_i \partial s_i \geq 0,\ \partial^2 F/\partial a_i \partial x_j \leq 0,\ i \neq j;\ i, j = 1, \ldots, n.$$

As in the Hendry model (Kalwani and Morrison, 1977), the flow of customers between any two firms is further assumed to be proportional to the market shares of the respective firms (c.f. also Urban, Johnson and Hauser, 1984). As an approximation to a more general functional form, this is more precise but also slightly more cumbersome than the $s_i(1-s_i)$ formulation, which has been widely used since first introduced by Phelps and Winter (1970). The double proportionality factor is realistic since a very small firm cannot give up a large number of customers and remain in business nor can it capture a large increment of customers in a short period of time. The chosen proportionality factor has the additional attractive feature of guaranteeing that the sum of the market shares remains constant at unity. Accordingly, we write the market share dynamics as:

$$(4)\quad \dot{s}_i(t) = \sum_{j=1}^{n} s_i(t)s_j(t)[F(a_i(t),s_i(t),x_i(t),x(t))-$$

$$F(a_j(t),s_j(t),x_j(t),x(t))+G(b_i(t))-G(b_j(t))],$$

$$i = 1, \ldots, n.$$

Given (1) - (4), we obtain the following proposition:

Proposition 1: In steady states of the game, defined by (1), (2), (3), and (4), a brand with more consumption experience will have a lower promotion to sales ratio than a brand with less consumer experience.

Proof: See Appendix.

We arrive at this proposition because consumption experience operates as a substitute for promotion. As seen from (4) a brand may maintain market share

with less promotion if it has more consumption experience (relative to competition). The contents of proposition 1 is also suggested by traditional theories of brand loyalty and learning. Learning models typically assume that each purchase of a given brand enhances the probability of future purchasing of that brand. Because promotion is a primary tool to induce brand switching by attracting nonusers, promotion models based on learning (e.g., Kuehn and Rohloff, 1967) suggest that more promotion expenditure is needed in order to affect switching from established brands in cases where consumers have stable purchase patterns (i.e., established habits).

In order to analyze a special case in more depth, let us use special forms for F and G. We assume a multiplicative and thus symmetric relationship between the square root of a firm's advertising outlays and its share of consumer experience. F is thus given the form:

$$(5)\quad F(\cdot) \equiv (a_i(t)s_i(t))^{1/2}x_i(t)\left(\sum_{j=1}^{n} x_j(t)\right)^{-1},\ i = 1, \ldots, n\ .$$

Let γ be the positive number of consumers which take the promotion path every time one consumer takes the advertising and experience path. If the effectiveness of promotion increases with its square root, we obtain the following form for G:

$$(6)\quad G(b_i(t)) = \gamma b_i(t)^{1/2},\ i = 1, \ldots, n\ .$$

The actual size of γ is an empirical question, but given that firms on the average spend more on promotion than on advertising,[2] it seems reasonable to conjecture that if a brand has identical budgets for both promotion and advertising, promotion will be more effective. In the steady state, this means that:

$$(7)\quad \gamma > \max_i s_i(t)^{3/2}$$

The assumptions (5) and (6) transform the game to a linear-quadratic form which by far is the most common in the literature on differential games. In marketing, it has, for example been used by Deal (1979) and Teng and Thompson (1983). For the linear-quadratic game we can show:

Proposition 2: In the steady state of the game defined by (1), (2), (4), (5), and (6), a brand with more consumption experience will have a lower level of combined advertising and promotion to sales ratios than a brand with less consumption experience.

Proof: See Appendix.

We arrive at this proposition because the promotional savings, allowed by greater consumption experience, outweigh the effects of any additional advertising expenditure. The contents of proposition 2 is consistent with the analysis of Comanor and Wilson (1974) who suggest that the volume of selling expenditures required for brand switching typically exceeds what is required for (using our terminology) the reinforcement of an established habit. The difference between Comanor and Wilson and what is presented here lies in the treatment of information. In their framework, advertising, promotion, and experience are all given the same role. Consequently, Comanor and Wilson could not assess the impact of experience on advertising relative to promotion, which might have shed some light on their conflicting empirical results.

Equation (7) finally allows us to show:

Proposition 3: In the steady state of the game defined by (1), (2), (4), (5), (6), and (7), a brand with more consumption experience will have relatively lower promotion expenditures than advertising expenditures, if compared to a brand with less consumption experience.[3]

Proof: See Appendix.

This proposition tells us that although advertising effects may decrease with consumption experience, they decrease relatively less than promotion effects. Thus, a major implication of consumption experience is to reduce the

level of promotion. Equivalently, Proposition 3 suggests that the expenditures by less established brands are relatively greater for promotion than they are for advertising. In conjunction with the other two propositions, this is an interesting proposition. Not only does the established brand benefit from a lower expenditure (relative to sales) on promotion (Proposition 1), it also spends less on combined advertising and promotion (Proposition 2). And, since we can use Proposition 2 to rewrite Proposition 3 as:

$$\frac{a_i}{a_i + b_i} > \frac{a_j}{a_j + b_j}$$

where $s_i > s_j$, the implication in terms of communication mix allocation is that brands with more consumption experience will allocate relatively more to advertising whereas brands with less consumption experience allocate relatively more to promotion.

Overall, the theory presented here is consistent with much of the marketing literature on advertising and promotion effects and is similar to several consumer behavior models in the economics literature. Although promotion and advertising are usually conceptualized as interactive (the effectiveness of one depends on the level of the other), few studies have examined the interaction theoretically or empirically. At the empirical level, the experiment by Miller and Strain (1970) is an exception. In their study, various combinations of promotion and advertising on the sale of a new peach product were examined. It was found that advertising alone was not effective whereas promotion and advertising combined were. This is supportive of our assumption that advertising is not effective in isolation (in terms of its effect on consumer choice).

With respect to promotion without advertising, both Hinkle (1965) and Cotton and Babb (1978) found that price dealing (promotion) was more effective for new brands than for established brands. This too is consistent with our

theory. As to consumption experience, the conclusions of Lynk (1981), Comanor and Wilson (1974) and Schmalensee (1982) are similar with respect to the advantages of established brands. As mentioned, our theory is different in its treatment of interactions between advertising, promotion, and consumption experience. First, it does not treat advertising and promotion as having the same effect (as do Comanor and Wilson, 1974; and later Buzzell and Farris, 1977; and Farris and Buzzell, 1979). Second, it assumes that a nonzero level of promotion and/or consumption experience is necessary for advertising to affect consumer choice.

HYPOTHESES FOR EMPIRICAL TESTING

On the basis of the propositions above, three hypotheses that relate consumption learning to advertising (a_i) and promotional (b_i) expenditure can be formulated. Assuming, with no loss of generality, that brand i has more consumer experience we get:

1. H_0: $b_i = b_j$
   H_1: $b_i < b_j$

2. H_0: $a_i + b_i = a_j + b_j$
   H_1: $a_i + b_i < a_j + b_j$

3. H_0: $a_i - b_i = a_j - b_j$
   H_1: $a_i - b_i > a_j - b_j$.

According to the first research (i.e., alternative) hypothesis, we expect to find lower promotion to sales ratios for established brands with more accumulated consumption learning. We also expect that combined advertising and promotion to sales ratios will be less for established brands (Hypothesis 2). Finally, in Hypothesis 3, we expect to find that established brands place more emphasis on advertising relative to promotion and vice versa for less established brands.

The empirical examination of the hypotheses is not a critical test in the sense that it rules out all alternative explanations. In fact, as discussed earlier, there are other theories that, in part, predict the same results. Among them are learning theory (Kuehn, 1962; Kuehn and Rohloff, 1967), consumer sampling (Lynk, 1981), market pioneering theory (Schmalensee, 1982), theories of advertising and market power (Comanor and Wilson, 1974) as well as general managerial hypotheses about advertising and promotion (Wind, 1982; Kotler, 1980). None of these theories alone, however, leads to all three propositions derived above.

DATA

The theory from which the hypotheses stem places several restrictions on the markets to which it applies. Specifically it refers to consumer markets in equilibrium and assumes that advertising, sales promotion, and consumption experience are the only information sources available to the consumer. Thus, a meaningful empirical test would require a sample of brands in mature consumer markets where information from other sources is negligible.

We are not aware of any data base that satisfies all the above restrictions. However, despite several limitations, the data collected for the PIMS project (Buzzell et al., 1975) are probably the only available large-scale data base that come reasonably close. First, the PIMS overall sample is large enough to reduce the problem of improper pooling of cross-sectional data (Bass and Wittink, 1975) by allowing better theory-data correspondence and more homogeneous subsamples. Because the theory speaks of consumer goods, industrial manufacturers and service and retail businesses could be excluded. Because of the theoretical requirement that markets be in equilibrium, businesses in the introductory, growth, and decline phases of the product life

cycle could be excluded. The restriction stemming from the assumption that consumer information be available only via consumption experience, advertising, and promotion is perhaps more difficult to handle empirically. Following Schmalensee's (1982) reasoning, it was assumed that other potential information sources such as word-of-mouth, personal selling, and consumer test reports are of relatively minor importance for low-priced products. Consequently, the sample was further restricted to brands for which the typical purchase price is less than $10. The resulting subsample that was used in this study consists of 172 cases (46% of the total number of business units in mature markets) where the observations are four-year averages for all relevant firms which had reported at least one four-year period.[4]

In terms of the correspondence between theory and data, the empirical analysis suffers from the same problem that plagues many other studies (Comanor and Wilson, 1974; Buzzell and Farris, 1977; Phillips et al., 1983): the empirical unit of analysis is not the one specified by theory. The unit of analysis in PIMS is a business operating unit that sells a distinct set of products. The theory in its aggregate form refers to the brand level. The impact of the imperfect correspondence between data and theory is most serious for businesses that market many brands within the same product category and where the brands have vastly different relative levels of cumulative sales. To some extent, these problems are probably mitigated by the fact that we limit the analysis to mature markets where the variation in these factors is usually not substantial. Moreover, there is no compelling reason to believe that the variance among firms is due to anything other than random factors. Consequently, we know the direction of the bias that may result: it will increase the probability of making a type II error because of underestimation. To counteract

this problem, it may be appropriate to accept a higher probability of committing a type I error. Thus, if we raise the level of statistical significance at which the null hypotheses should be rejected above the standard level (i.e., .05), the probability of making a type II error would be reduced.

MEASURES

As indicated in the hypotheses and the propositions, the endogenous variables in this study are: (1) sales promotion expenditure as a percentage of sales revenue (b), (2) advertising plus sales promotion expenditure as a percentage of sales revenue (a + b), and (3) advertising minus sales promotion expenditure as a percentage of sales revenue (a - b).[5] The definitions of these variables are given in Table 1.

It is difficult to give a precise definition of what should be included in promotion expenditure. The PIMS approach is to take the difference between total communication expenditure (i.e., advertising and promotion) and media advertising. The problem with this is that is not possible to distinguish between consumer, distributor, and retail promotions. Again, we have no alternative but to treat the ensuing irrelevant variance (i.e., the variance in promotions to distributors and retailers) as random error variance.

The measurement of consumption experience poses a problem of a different kind. Consumption experience is an abstract construct that is not directly observable. At the individual consumer level, experience is directly related to the number of times the product has been used by a particular consumer. As suggested by Spence (1981) and Stigler and Becker (1977), the aggregate implication is that a high level of consumption experience is evident for brands with high cumulative sales. Clearly, experience in the aggregate must be greater for established brands with high cumulative sales than for new

brands (Comanor and Wilson, 1974). In equilibrium, then, brands with high market shares enjoy more consumption experience than brands with low market shares. However, consumption experience is a dynamic concept that might not be fully captured from market share data alone. In a study by Demsetz (1962), the length of time to which the market has been exposed to the product was used to operationalize consumption experience. While such an operationalization may satisfy the dynamic nature of the construct, it ignores the impact of the brand's market position. For example, a brand that has been in existence for a long period of time while catering to a small segment may have less aggregate consumption experience than a more recent brand with a strong market position.

Given fallible measures and the relevance of both "length of time in the market" and "market position," a multiple indicators approach was followed. Market position, which is a subjective estimate in the PIMS data base, is indicated by (1) market share, (2) market share rank, and (3) relative market share. The definitions of these variables are given in Table 1. Length of time in the market is indicated by "order of the market entry." The complete definition of this variable is also presented in Table 1.

Theoretically, it would probably be appropriate to model consumption experience as the product of market position and order of entry. However, the data contain several dummy variables and are therefore not well suited for this type of specification. Instead, we treat market position and order of entry as additive indicators whose weights are to be estimated.

Obviously, the measures of consumption experience are less than perfect. The error in measurement here is due to the difficulty of specifying the construct "consumption experience" and to the ambiguity about market boundaries in the market share measurements.[6] Again, however, we see no reason to assume

that this error is systematic. Thus, we will treat it as a random measurement residual to be accounted for in the analysis model and adjust for type II error accordingly.

ANALYSIS METHODS

Each of the three hypotheses was subjected to three different empirical tests: (1) analysis of mean differences; (2) simple structural equation modeling with measurement residuals; (3) structural equation modeling with measurement residuals and exogenous control variables.

The test of group means treats each hypothesis independently. The simple structural equation model tests the three hypotheses simultaneously and treats consumption experience as an unobserved variable measured with error. The third test is similar to the second with the exception that a number of empirical control variables are included in the model.

Each of these three analyses provides a different perspective on the data and each has a different set of assumptions. The group means analysis provides a useful descriptive overview concerning the differences in sales promotion expenditures between firms with strong vs. weak market positions and between pioneering vs. late entry firms. In the group means analysis, all variables remain in their original form whereas the structural equation models estimate a weighted aggregate from the four indicators of consumption experience. Further, the group means analysis makes no assumptions about the functional form governing the relationship between sales promotion expenditures and consumption experience. On the other hand, the inferences one can draw from this type of analysis are restricted by the strong ceteris paribus assumption involved as well as by the rather arbitrary categorization of continuous variables.

In subjecting the data to the simple structural equation, we test the degree to which the results are consistent with the group means analysis when (1) the variables are considered simultaneously, (2) consumption experience is explicitly modeled as a weighted aggregate of the indicators of market position and order of entry, and when (3) it is assumed that the relationships are linear.

The final analysis is an attempt to falsify the results by examining their robustness when additional variables are considered. Although the simple structural equation model represents the propositions derived from our theory, it is not meant to account for the total variation in sales promotion expenditures. The theory speaks only of order differences--not total variations. Clearly, there are factors other than consumption experience that also affect promotional expenditures. To see whether or not the relationships between consumption experience and advertising/promotion expenditures remain when variables are added to control for customer, distributor, industry, and business characteristics, another structural equation was estimated. The additional variables were obtained from Buzzell and Farris (1977). Their study was selected because it used the PIMS data to explain (a + b) expenditures for consumer goods industries. Here the same control variables are also used for the (b) and (a-b) equations. This decision is based on two considerations. First, to the best of our knowledge, no study has explained (b) & (a-b) ratios for a broad cross-section of consumer goods businesses. Consequently, control variables tailored specifically for these equations could not be located. Second, when considering control variable selection (assuming adequate degrees of freedom), it is generally preferable to err on the side of including irrelevant explanatory variables rather than excluding relevant explanatory variables. Certainly, since many of the control variables are correlated with

consumption experience as well as promotional expenditure, their inclusion reduces the risk of finding spurious relationships. Again, however, they increase the risk of making a type II error. The control variables used in this study are defined in Table 2.

THE BASIC MODEL

We can write the simple structural equation model as:

$$\begin{bmatrix} b \\ (a+b) \\ (a-b) \end{bmatrix} = \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \end{bmatrix} \xi + \begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \zeta_3 \end{bmatrix}$$

where,

γ_1-γ_3 are parameters to be estimated,

ξ is consumption experience, and

$\zeta_1,\ldots,\zeta_3$ are error terms.

We make the standard assumptions that $E(\underset{\sim}{\xi}\ \underset{\sim}{\zeta}') = E(\underset{\sim}{\zeta}\ \underset{\sim}{\zeta}') = 0$. Consumption experience is an unobservable construct with several indicators. Because market share, relative market share, market share rank, and order of market entry are assumed to cause consumer experience, these variables are modeled as formative indicators (see Fornell and Bookstein, 1982):

$$\xi = [\pi_1\ \pi_2\ \pi_3\ \pi_4] \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix}$$

where,

x_1 is market share,

x_2 is relative market share,

x_3 is market share rank 1 (dichotomous variable),

x_4 is pioneer in product category (dichotomous variable), and

$\pi_1,\ldots,\pi_4$ are parameters to be estimated.

ξ is specified as a weighted aggregate of the indicators x_1 through x_4, the measurement residuals for the indicators are given by θ_i = var (ξ) - cov (ξ, x_i), i=1,...,4.

In order to form a composite "consumption experience" variable that (along with control variables) minimizes the trace of the variance-covariance matrix of $\underset{\sim}{\zeta}$, partial least squares (PLS) developed by Wold (1982) was used to estimate parameters of the model. PLS estimation does not require assumptions of metric data, multinormality, or independence of observations (which our data obviously do not satisfy). More details about PLS can be found in Wold (1982), Fornell and Bookstein (1982), and Jöreskog and Wold (1982). Essentially, it can be viewed as a two-stage estimation technique. In the first stage, through an iterative process, a weighted average of the indicators is estimated to give case values of the unobservable theoretical variables. These estimates are approximate but asymptotically consistent (Wold, 1982). The second stage obtains the structural estimates via OLS estimation.

RESULTS

Group Means

The results of the group means test are presented in Table 3. Two null hypotheses are consistently rejected at the .05 level:[7] established brands do appear to have lower promotion-to-sales ratios than brands with less consumption experience (H_1),[8] and brands with more consumption experience tend to allocate significantly more resources to advertising relative to promotion (H_3) (compared to brands with less consumption experience).

Although all the differences are in the hypothesized direction, the results concerning the combined advertising and promotion expenditure variable (H_2), with the exception of the relative share measure, have rather low z-values. This appears to be due to the high standard errors. Before drawing any conclusion about the data, let us examine how robust the findings are. After all, the simple bivariate analysis suffers from the confounding of measurement variance and true variance and involves a rather arbitrary categorization of variable levels.

Simple Structural Equation

The simple structural equation consists of three endogenous variables (the ratio of promotion expenditure to sales revenue b, the ratio of advertising plus promotion expenditure to sales revenue (a + b), and the ratio of advertising minus promotion expenditure to sales revenue (a - b) and one exogenous variable (consumption experience); the latter is measured by four indicators (order of entry, market share, relative market share, and market share rank). The basic differences between this test and the means test are that the variables are considered simultaneously, measurement residual variance is modeled for the consumption experience indicators, and it is assumed that the relationships are linear.

The results are found in Table 4. From the correlation matrix (where the correlation coefficients are equivalent to standardized γ-coefficients) it is evident that all consumption experience coefficients have the hypothesized sign and that they are significant. The correlation between experience and promotion is the strongest at -.30; the other correlations are at -.21 and .22, respectively. With the exception of the market share rank variable, it is also clear that the indicators of consumption experience contain a substantial

amount of error variance. In fact, the indicators, taken together, barely pass the criterion of having 50 percent average valid variance (Fornell and Larcker, 1981). Nevertheless, the hypothesized relationships seem to hold when the variables are analyzed simultaneously and the associations expressed as correlation.

Structural Equation with Control Variables

The results presented in Table 5 show that the basic findings are also robust when several other variables that have been used in previous research (Buzzell and Farris, 1977) are controlled for. All coefficients for consumption experience have the proper sign. The coefficients in the b and (a + b) equations are both significant at the .01 level, and the coefficient in the (a - b) equation is significant at the .12 level. Within the context of the caveats discussed earlier (Footnote 7), this may well be an acceptable level for rejecting the null hypothesis in view of the relatively large amount of random noise in the data. It is also worth noting that the explanatory power is reasonably high for the first two equations as measured by R^2's of .31 and .52. The third regression is substantially weaker with an R^2 of .16.

The effect of including additional exogenous variables is greatest in the third equation (a - b) where the consumption experience coefficient drops by 50 percent (from .22 to .11). This is probably due to the collinearity between consumption experience and the variable measuring the competitive environment. This variable was obtained from the Buzzell and Farris (1977) study and is composed of market share data for the industry (see Table 2). Since consumption experience is, in part, composed of business unit market share data, it follows that there is a high correlation (by definition) between consumption experience and competitive environment for oligopoly industries. The reason that the

effect of this collinearity is most drastic in the (a-b) equation is that the control variables are less well suited for this particular equation as evident by their low explanatory power. When the competitive environment variable was deleted from the model, the three consumption experience coefficient estimates are essentially the same as those in Table 4.

For (a + b), the consumption experience coefficient drops by a mere 10 percent (from -.21 to -.19), and for b, it drops by 27 percent (from -.30 to -.22) when additional variables are included. Overall, consumption experience has one of the strongest relationships (as measured by the standardized beta coefficient) of all the exogenous variables in all three equations. Only the price/cost variable shows a consistently larger estimated association. The fact that this variable is strong is not surprising in view of the proposed theory. In terms of the consumer evaluation of the cost-performance of a brand, price/cost would play the same role as promotion (i.e., change consumer cost).

SUMMARY AND DISCUSSION

In essence, our theory draws upon prior work (Schmalensee, 1972, 1982; Spence, 1981; Stigler and Becker, 1977) in suggesting consumption experience or information advantages for established brands relative to less established ones. Also similar to earlier work, our theory considers advertising and promotion as information substitutes. Where we differ from other theories is in the nature of substitutive effects. We suggest that advertising is weaker concerning direct effects on consumer choice, because the effectiveness of advertising is highly dependent upon the levels of consumption experience.

Promotion effects, on the other hand, are postulated to be less dependent on other information sources. In fact, a sufficiently high level of promotion

will make a brand not only (1) a challenger to an established brand but possibly (2) a replacement for the established brand (at least on a trial basis).

Limitations of the Theory

In addition to the fact that our theory concerns the steady state condition, it has the following limitations:

- It ignores possible heterogeneity in promotion effects (see Quelch, 1982; Quelch, et. al, 1983, for a discussion of such effects). In fact, we treat promotion effects as price effects. However, this does not appear to be a serious limitation. Recall that our theory is restricted to consumer markets in equilibrium where consumer information from sources other than advertising, promotion, and consumption experience is negligible. Indeed, the empirical evidence seems to support the treatment of promotion effects in the way suggested by our theory.

- It relies upon the open loop equilibrium concept. Clearly, it would be more realistic to allow for changing market shares and consumption experience levels to affect advertising and promotional expenditure rather than assuming that these expenditures are set as a function of time. However, most comparisons show very small differences between open and closed loop controls (e.g., Spence, 1981), and analytical ease certainly favors the open loop option.

- It ignores the possibility of different degrees of economies of scale in advertising and promotion. To the extent that this can be incorporated without violation of the second order conditions on the game, our conjecture is that if there are greater economies of scale in advertising than in promotion, as is often suggested, the results will not change. However, at present there is simply not enough empirical or theoretical knowledge available regarding economies of scale in advertising, let alone in promotion.

Empirical Problems

The empirical testing of the theory faced several difficulties. Due to the various data limitations, the empirical evidence should be interpreted with caution. The problems can be summarized as:

- All consumer information sources other than advertising, promotion, and consumption experience are assumed to be negligible. To approximate this requirement (as well as that of equilibrium)

empirically, the data were limited to businesses in the mature stage of the life cycle that sell convenience consumer goods at prices below $10.

- The concept of "consumption experience" is not readily transformed into a measurable quantity. To address this problem, a multiple indicators approach was used. The length of time to which the market has been exposed to the product was first used by Demsetz (1969) as a measure of consumer experience and was also used in this study, but as only one of four indicators. Certainly, consumption experience is affected not by time only but also by "space," in the sense that a brand with a strong market position has more consumption experience than a brand with a weaker market position. Therefore, three indicators of market position were also used to tap the construct "consumption experience."

- There is a less than perfect correspondence between theory, propositions, and data with respect to the unit of analysis. The theory refers to the consumer level with implications at the brand level, whereas the data refer to a business operating unit. Thus, the business unit that sells many brands of the same product category with great variety of consumption experience and advertising and promotion relative to sales among the brands, will introduce noise into the data. The effect of this (which we assume is random, since there is no reason to believe otherwise) is to bias the overall relationships downward. In part, this noise should be captured by the measurement residuals of the indicators of consumption experience. To the extent that measurement error is partialed out in the exogenous variable, the structural estimates (λ) are not affected by measurement error in the endogenous variables. Nevertheless, the correlation would still be underestimated. Since we did in fact discover differences for all relevant variables (when consumption experience variance was separated into valid and residual variance), the noise in the data was not substantial enough to totally obscure the true variances.

Conclusion

Despite their limitations, the theoretical and the empirical evidence presented here do provide support for the proposed theory. The theory is parsimonious and presents a consistent framework for explaining differences in promotion relative to advertising expenditure among brands with various levels of consumption experience. Brands with a high level of consumption experience seem to enjoy savings in promotion and in advertising and promotion combined.

Manufacturers of these brands also seem to place proportionately more emphasis on advertising relative to promotion.

With respect to the conflicting empirical results in the literature regarding the relationship between advertising and market share and the previous absence of a theoretical explanation for both negative and positive relationships, our theory suggests a solution: the relationship between advertising/sales and market share is dependent upon the parameter γ, the number of consumers responding to promotion relative to advertising. Thus, our theory suggests that it may not be meaningful to examine the relationship between advertising/sales and market share without taking the effect of promotion into account. Depending on the relative effectiveness of promotion, one may observe high advertising-to-sales ratios for well-established brands and low ratios for less-established brands, and vice versa. This suggests that future studies of advertising expenditure should include promotion and its relative effectiveness before conclusions can be drawn about the relationship between market share and advertising.

FOOTNOTES

[1]Although the notion of consumption experience refers to the consumer level, our formal model is at the brand level. It is possible to model the two-stage brand choice process at the individual level, but the complexity of such a model makes aggregation to the market level extremely complicated. Virtually all differential game models of advertising (e.g., Jorgensen, 1982; Teng and Thompson, 1983; Deal, 1979) suffer from the same problem. Nevertheless, we will endow the brand level functions with properties similar to those of individual demand functions.

[2]In the PIMS database, the mean levels of advertising to sales and promotion to sales ratios are .041 and .055, respectively.

[3]We could have derived a set of sufficient conditions for Propositions 2 and 3 in the context of the market share dynamics given by (4). One way to do this is to formally consider steady state market shares as exogenous and cost differences as endogenous. Using the implicit function theorem on the equations defining steady states, one can then derive (very complex) expressions for $\partial a_i/\partial s_i$ and $\partial b_i/\partial s_i$. Alternatively, one can use the monotonicity of F and G and their derivatives to define a host of composite inverse functions in terms of which a and b can be found from the equations defining steady states. Unfortunately, neither of these avenues lead to intelligible conditions and we have not been able to find a tight set of conditions on particulars which can guarantee Propositions 2 and 3. These difficulties are of course the reason for the widespread use of the linear-quadratic form in the literature.

[4]In the PIMS data base both two-year and four-year averages are provided. The four-year averages were selected because they presumably include more reliable information than a two-year average.

[5]While in our theory a and b are measured by expenditures per unit sold, we here scale them by the unit price to get expenditures as percentages of revenues. Since our theory posits that all competitors charge the same price, everything remains consistent. From here on, a and b, are understood in this new sense.

[6]Each business in the PIMS data base develops its own definitions of the served market. Thus, the market share data are not based on a uniform definition of what constitutes a market (for a discussion of this, see Buzzell, 1981).

[7]The PIMS data base is not generated from a probability sampling procedure. As a result, the significance tests cannot be interpreted in the classical inference sense. At best, the sample can be considered to define a hypothetical population of brands with certain characteristics (mature markets, convenience goods). It is in this context the significance tests address the question of whether or not sampling error can account for observed differences between expected and observed values of the statistics, given that the hypothetical population exists. The fact that one can easily challenge the assumption of independent observations also cautions against too much reliance on the outcome of significance testing in this study. On the other hand, one can make the argument that the cases in the PIMS data base are themselves of sufficient interest and that statistical generalization are therefore not critical.

[8]Where consumption experience is suggested by market pioneering, by a market share greater than 30%, by a relative market share greater than 75%, and by a market share rank of one.

Table #1

Key Variables and Definitions

Variable	Definition
% Advertising (a)	Media advertising expenditure as a percentage of sales revenue.
% Sales Promotion (b)	Sales promotion expenditure as a percentage of sales revenue. Sales promotion expenditures include (1) catalogs, (2) exhibits and displays, (3) premiums, (4) coupons, (5) samples, and (6) temporary price reductions for promotional purposes.
Consumer Experience	
Market Share (x_1)	Ratio of a business unit's dollar sales to the total dollar sales of the served market.
Market Share Rank (x_2)	Market share rank for a business within the served market.
Relative Market Share (x_3)	The market share of a business divided by the combined share of its three largest competitors.
Order of Market Entry (x_4)	At the time this business first entered the market, was it (1) one of the pioneers in first developing such products or services, (2) an early follower of the pioneer(s) in a still growing, dynamic market, or (3) a later entrant into a more established market situation?

Table #2

Control Variables and Definitions

Variable	Definition
1) Customer Characteristics	
% Household Consumer Sales	Percentage of business output used by households or individual consumers.
2) Purchase Patterns	
Low Importance to User Dummy	1 if the product typically accounts for less than .25 percent of end users' total annual purchases, 0 otherwise.
High Purchase Frequency Dummy	1 if a typical consumer buys the product weekly or more often, 0 otherwise.
Low Purchase Amount Dummy	1 if the typical purchase amount is less than $10, 0 otherwise.
Consumer Durable Dummy	1 if the product is durable, 0 otherwise.
3) Distribution Channels	
% Wholesaler Sales	Percentage of sales made to wholesalers.
4) New Product Activity	
% New Products	Percentage of sales accounted for by products introduced during the three preceding years.
5) Regional Marketer	
Regional Marketer Dummy	1 if the business serves a regional rather than a national market, 0 otherwise.
6) Competitive Environment	
Big 3 Market Share	Sum of the three largest competitors market shares.
Big 3 Market Share Squared	The squared value for Big 3 Market share.
Competitive Turmoil	Average yearly Big 3 Market share point change.

Table #2 (continued)

Variable	Definition
7) Price/Cost Structure	
Trading Margin	Total sales revenue less purchasing and manufacturing expenses divided by total sales revenue.
Relative Price	Average level of this business' selling price relative to the average price of the three largest competitors.
Capacity Utilization	Percentage of standard capacity utilized.

Table #3

Test of Group Means: Promotional and Advertising Expenditure

Promotion/Sales (b)	Mean (%)	Standard Error	Z
Pioneer	4.76	.42	
Late Entrant	6.67	.90	
Difference	-1.91	.99	-1.93*
High Share[1]	4.32	.42	
Low Share[2]	6.38	.97	
Difference	-2.06	1.06	-1.94*
High Relative Share[3]	3.81	.42	
Low Relative Share[4]	6.85	.80	
Difference	-3.04	.90	-3.38*
High Rank[5]	3.90	.35	
Low Rank[6]	6.46	.97	
Difference	-2.56	1.03	-2.49*
Advertising/Sales + Promotion/Sales (a + b)			
Pioneer	8.61	.73	
Late Entrant	10.44	1.34	
Difference	-1.83	1.53	-1.20
High Share	8.46	.92	
Low Share	9.77	1.42	
Difference	-1.31	1.69	- .78
High Relative Share	7.68	.93	
Low Relative Share	10.92	1.23	
Difference	-3.24	1.54	-2.10*
High Rank	7.87	.76	
Low Rank	9.72	1.38	
Difference	-1.85	1.58	-1.17
Advertising/Sales-Promotion/Sales (a - b)			
Pioneer	- .90	.51	
Late Entrant	-2.91	.75	
Difference	2.01	.91	2.21*
High Share	- .17	.64	
Low Share	-2.98	.75	
Difference	2.81	.99	2.84*

Table #3 (Continued)

High Relative Share	.06	.63	
Low Relative Share	-2.77	.81	
Difference	2.83	1.03	2.69*
High Rank	.08	.53	
Low Rank	-3.21	.82	
Difference	3.13	.98	3.19*

1) High market share is > 30%.
2) Low market share is < 10%.
3) High relative share is > 75%.
4) Low relative share is < 25%.
5) High market share rank is 1.
6) Low market share rank $\leq$ 4.

*Significant at .05 or better.

Table #4

Simple Structural Equation: Consumption Experience

Correlation Matrix[a]

Consumption Experience (ξ_1)	1.00			
b	-.30*	1.00		
(a + b)	-.21*	.83*	1.00	
(a - b)	.22*	-.57*	-.01	1.00

Measurement Model[b]

	Loading[1]	Measurement Residual (Θ_ε)
Market Share (x_1)	.62	.62
Relative Market Share (x_2)	.60	.64
Pioneer (x_3)	.56	.69
Market Share Rank 1 (x_4)	.97	.06
Average Variance Extracted[2]	.50	
Average Measurement Residual		.50

[a]The correlation coefficients in this model are equal to the structural coefficients.

[b]All variables are standarized.

*Significant at .05 or better.

1) The vector of loadings is $R_{xx} \pi$

2) This is a summary measure of how the model partitions out measurement residual variance (for formulas, see Fornell and Larcker, 1981).

Table #5

Structural Equations: Consumption Experience and Other Exogenous Variables[1]

	Structural Coefficients[2]					
	b		(a + b)		(a - b)	
Key Variable						
Consumption Experience	-.22	(-2.69)[3]	-.19	(-2.83)	.11	(1.20)
Control Variables						
Customer Characteristics	.19	(2.75)	.21	(3.67)	-.03	(-.35)
Purchase Pattern	-.18	(-2.55)	-.18	(-3.03)	.06	(.75)
Distribution Channel	.01	(.18)	.04	(.70)	.04	(.49)
New Product Activity	.08	(1.16)	.10	(1.82)	.01	(.16)
Regional Environment	.04	(.54)	.05	(.82)	.00	(.04)
Competitive Environment	.18	(2.18)	.11	(1.62)	-.16	(-1.72)
Price/Cost Structure	.26	(3.59)	.52	(8.52)	.30	(3.74)
R^2	.31		.52		.16	

1) The correlation coefficients and the loadings are the same as in Table 4.

2) Standarized variables.

3) The values in parentheses are critical ratios (structural coefficient estimates divided by standard errors).

APPENDIX

Proof of Proposition 1

Consider firm i and use the symbols $\mu_{ij}(t)$ and $\phi_{ij}(t)$ to denote the values (at t) of its current value dual variables governing the jth equations in (2) and (4). We can then write its current value Hamiltonian as:

$$s_i(t)(p-a_i(t)-b_i(t)-c_i) + \sum_{j=1}^{n} \mu_{ij}(t) \sum_{k=1}^{n} s_k(t)s_j(t)(F_j-F_k + G_j-G_k) + \sum_{j=1}^{n} \phi_{ij}(t)(s_j(t) - \theta x_j(t))$$

where F_j and G_j are shorthand for $F(a_j(t),s_j(t),x_j(t),x(t))$ and $G(b_j(t))$, $j=1,\ldots,n$. Consequently, we can write the first order conditions on a_i and b_i as:

$$(A1) \quad -s_i(t) + (\mu_{ii}(t) - \sum_{j=1}^{n} \mu_{ij}(t)s_j(t))\, s_i(t) \frac{\partial F_i}{\partial a_i} = 0 \qquad , i=1,\ldots,n$$

$$(A2) \quad -s_i(t) + (\mu_{ii}(t) - \sum_{j=1}^{n} \mu_{ij}(t)s_j(t))\, s_i(t) \frac{\partial G_i}{\partial b_i} = 0 \qquad , i=1,\ldots,n$$

where $\partial F_i/\partial a_i$ and $\partial G_i/\partial b_i$ are understood to be valued at $(a_i(t),s_i(t),x_i(t),x(t))$ and $b_i(t)$ respectively. Assuming a nondegenerate solution we therefore have:

$$(A3) \quad \frac{\partial F_i}{\partial a_i} = \frac{\partial G_i}{\partial b_i} \qquad ; i=1,\ldots,n$$

In steady states, where all flows have come to a halt, we also know that

$$(A4) \quad F_i - F_j + G_i - G_j = 0 \qquad ; i,j=1,\ldots,n \ .$$

Assume now that $s_i(t)>s_j(t)$ and $x_i(t)>x_j(t)$. We intend to show that $b_i(t)<b_j(t)$.

Suppose $b_i(t)\geq b_j(t)$: In this case $G_i\geq G_j$ and $\frac{\partial G_i}{\partial b_i} \leq \frac{\partial G_j}{\partial b_j}$. Furthermore (A4) gives us $F_i\leq F_j$ and thus $\frac{\partial F_i}{\partial a}\Big|_{a_i(t)} \geq \frac{\partial F_j}{\partial a}\Big|_{a_j(t)}$. By (3), this implies $\frac{\partial F_i}{\partial a_i} > \frac{\partial F_j}{\partial a_j}$

which by (A3) contradicts $\frac{\partial G_i}{\partial b_i} \leq \frac{\partial G_i}{\partial b_j}$. Q.E.D.

Proof of Proposition 2

Note first the $x_i(t)(\sum_{j=1}^{n} x_j(t))^{-1} = s_i(t)$ in the steady state; this allows us to write (A4) as:

$$(A5) \quad a_i(t)^{1/2} s_i(t)^{3/2} - a_j(t)^{1/2} s_j(t)^{3/2} + \gamma(b_i(t)^{1/2} - b_j(t)^{1/2}) = 0 \qquad i,j=1,\ldots,n.$$

Furthermore, (A3) here specialize to:

$$(A6) \quad a_i(t)^{-1/2} s_i(t)^{3/2} = \gamma b_i(t)^{-1/2} \qquad ,i=1,\ldots,n.$$

It is tedious but trivial to use (A5) and (A6) to get

$$(A7) \quad a_i(t) + b_i(t) = (a_j(t) + b_j(t))\,(s_j(t)^3 + \gamma^2)\,(s_i(t) + \gamma^2)^{-1} \qquad i,j=1,\ldots,n.$$

such that we see that $s_i(t)>s_j(t) \Rightarrow a_i(t) + b_i(t) < a_j(t) + b_j(t)$.

Q. E. D.

Proof of Proposition 3

Again using (A5) and (A6), we get

$$(A8) \quad a_i(t)-b_i(t) = (a_j(t)-b_j(t))(s_i(t)^3-\gamma^2)(s_j(t)^3-\gamma^2)^{-1}(s_j(t)^3+\gamma^2)^{-2}$$
$$(s_i(t)^3+\gamma^2)^{-2}$$

The second and third factor on the r.h.s. are negative by (7) and the product of the last four factors is bigger than one if

$$(A9) \quad (\gamma^2-s_i(t)^3)(s_j(t)^3+\gamma^2)^2 < (\gamma^2-s_j(t)^3)(s_i(t)^3+\gamma^2)^2$$

which clearly is the case for $s_i(t) > s_j(t)$. So in this case $a_i(t)-b_i(t) > a_j(t)-b_j(t)$.

Q. E. D.

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