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A BAYESIAN SOLUTION

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Competitive Reaction in Test Marketing: A Bayesian Solution[1]

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ABSTRACT

The problem of deciding whether or not to test market a new product is re-considered against the possibility that competitors might be able to observe our test results and enter the market themselves. It is shown how the decision problem can be couched in terms of a Bayesian decision tree, where the competitive reactions are added outcomes. Some complications arise in assessing the competitive entry probabilities, however, since they cannot be seen as independent of market sales probabilities. Accordingly, the competitive entry probabilities are modeled as explicit functions of the testing firm's priors over market sales, and the test outcomes. The ensuing decision problem can be solved using stochastic dynamic programming. A numerical example is developed for a computer coded version of the model, and a sensitivity analysis of the optimal first-period decision is carried out.

Introduction

One problem that test marketing of new products gives rise to is when to stop the relatively expensive testing program and make a final decision to "go" or "drop" the product. This can be seen as a sequential sampling problem perhaps with a Bayesian interpretation (Bass, 1963; Green and Tull, 1970). Lately, one additional problem in test marketing has complicated a straightforward sampling approach, however. With the rapid increase in the availability of commercial market data during the sixties and seventies, the probability that one or more competitors will discover the tested product and its sale becomes often very high. As many new products are easily imitated and produced, these competitors may then decide to go nationwide even before the testing firm does.[1] Then the decision as to whether to go or drop or continue testing clearly becomes a matter not only of expected market sales, but also of the magnitude and timing of competitive reaction.

This paper shows how test marketing under these conditions can be handled as a dynamic programming problem incorporating both the ideas of Bayesian sampling and probabilistic competitive actions in developing the appropriate decision whether or not to test market, and when to stop testing.[2]

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[1]In many cases the test marketing is carried out for new markets or market segments. In such a case there would be no necessary delay in competitive response since the product already exists.

[2]Alternatively, the usual test marketing setup can be abolished in favor of an "in-home" testing approach which eliminates the problem of competitive discovery. The validity and reliability of the results generated by such an approach would generally be less than for the test market design, however

Modeling Framework

It is assumed that the choice alternatives open to the testing firm are to go nationwide (GO), to drop the new product (DROP), or to test market (TEST). The competitors will be assumed to either start production and distribution (COGO) at a given decision point or else wait for additional information (CONOGO) It is assumed that no competitor is planning a new product introduction or test marketing of his own before the testing firm has made the first period decision. Furthermore, competitive reaction after a GO or DROP decision is independent of the testing (it is presumably only dependent upon actual sales results) and thus not considered here explicitly.

It is further assumed that the testing firm can assess the reliability of the test market results fairly accurately. This assumption is not very unrealistic if, for example, the firm has done testing of new products earlier, or if standard statistical techniques are used. This paper will not be concerned directly with the issues involved in this research, but will treat choice of test area(s) and size of sample(s) (of stores and/or individuals) as given and fixed.

Throughout the discussion it will be assumed that the price of the product, and the promotional effort in the introductory stages will be the same regardless of the timing of the introduction; real world deviations from this assumption could be developed for the particular case, but yield nothing of principal interest in this context. It is also assumed that the test marketing is carried out for the purpose of ascertaining probable total sales, and that no alternative marketing mix programs are to be evaluated. Also, the effect of alternative marketing

programs either by the testing firm or its competitors upon the total market sales is assumed negligible.[1]

The basic model will first be developed, and a Bayesian solution to the sequential sampling problem indicated. The next sections deal with the incorporation of the competitive effects: the number of capable entrants, their expected payoffs, and their probability of entry. Finally, the complete model will be solved for a specific example using standard dynamic programming techniques.

The Basic Model

The test marketing problem can be conveniently represented through the decision trees in Figure 1 and Figure 2. In Figure 1 the conventional testing problem without competitive entry is depicted. The simplicity of the tree is readily apparent, with repeated acts and events following each other symmetrically. In Figure 2, on the other hand, the competitive entry is explicitly accounted for. Here the symmetry is broken by the fact that competitors are only of concern in certain situations.[2] We assume that competitors will become alerted to the potential market only via our testing or entry. Hence, it makes sense to postulate that after the first stage our testing firm has the first

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[1]There have been cases where competitors have "disrupted" test marketing areas by unusual promotional efforts. Such actions will clearly affect the accuracy of the test market results, and thus the test likelihoods. These actions are not considered in the present model.

[2]One could have made the tree completely symmetrically also here by allowing competitive event branches with probabilities of zero and one to be inserted. Since the number of branches increases very fast and thus computational costs increase fast, however, even without competitive entry, they have been eliminated wherever feasible.

opportunity to enter the market. If we decide to continue testing, however, the alerted competitors who are able to enter might do so without waiting for the second period's test results. This means that competitors can at the earliest enter in the second period, and that we have the opportunity to run at least one test period and still be the first entrant.

Another feature incorporated in the tree of Figure 2 is that once a competitor has entered, our test option disappears. It seems likely that there would never be a case where our testing should be continued in such a case (an exception might be where a contract has been signed with the testing organization, and a certain minimum number of periods has been posted) since the problem has presumably lost its importance. Finally, if we have decided to enter (or drop) the competitive reaction is seen as of no importance; as stated before, our market (not test) sales would presumably determine their reaction.

Figure 1 and 2 about here

The time period between the decision making points is equal to the time it takes for the test results to appear -- a common interval is two weeks to one month. It is assumed that the testing will not go on indefinitely; thus, the end stage of the two decision trees provides only the GO and DROP alternative actions.

Following the test results, the likelihoods of alternative sales and of alternative competitive reactions are computed -- it is the joint probabilities of these events that are of interest to the decision maker. Let us first concentrate upon the sales probabilities.

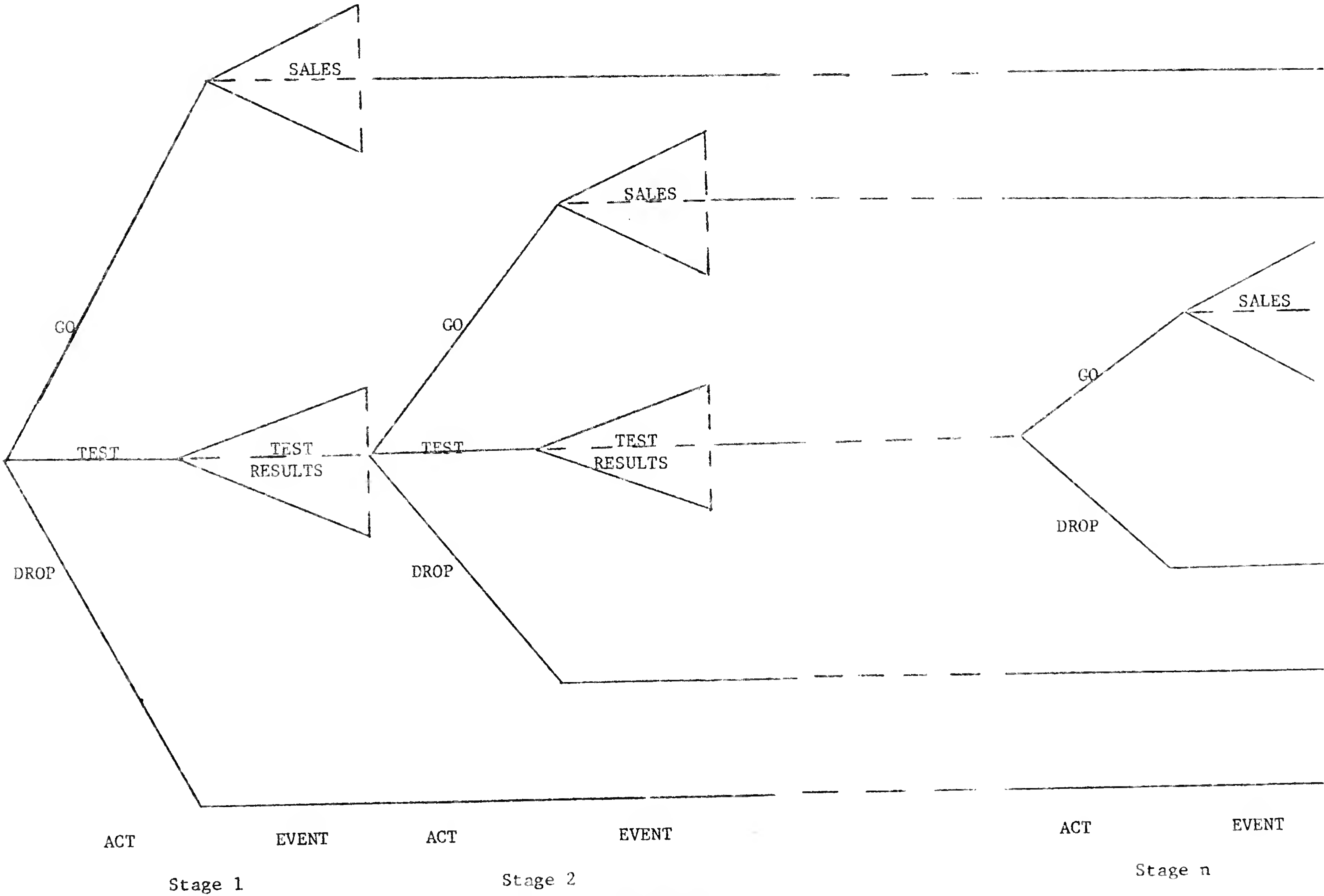
SALES
SALES
SALES
GO
GO
GO
TEST
TEST
TEST
RESULTS
TEST
TEST
RESULTS
DROP
DROP
DROP
ACT
EVENT
ACT
EVENT
ACT
EVENT
Stage 1
Stage 2
Stage n

Figure 1

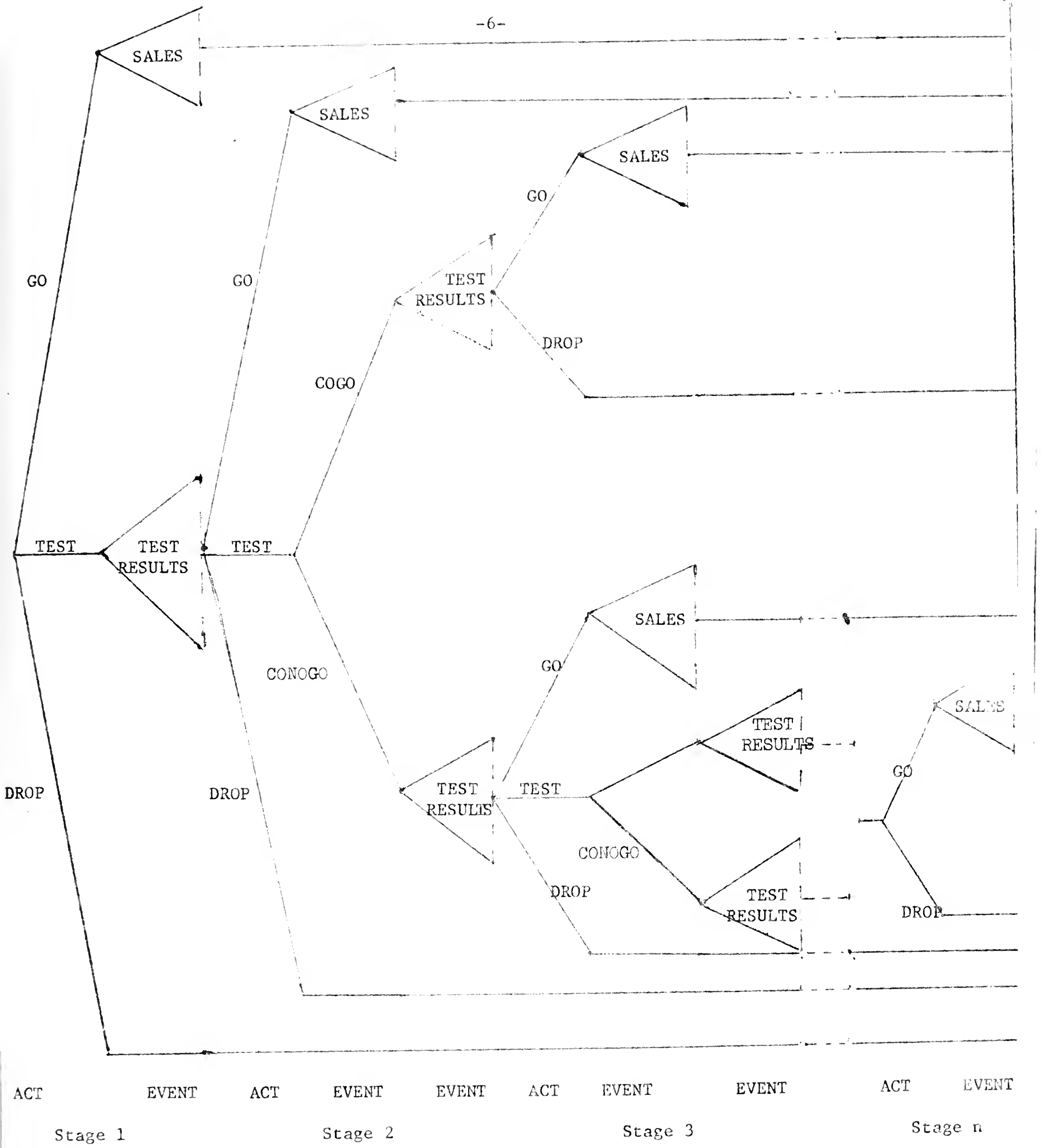
SALES
SALES
SALES
GO
GO
GO
TEST
RESULTS
DROP
COGO
TEST
TEST
RESULTS
TEST
SALES
CONOGO
GO
TEST
RESULTS
SALES
DROP
DROP
TEST
RESULTS
TEST
GO
CONOGO
DROP
TEST
RESULTS
DROP
ACT
EVENT
ACT
EVENT
EVENT
ACT
EVENT
EVENT
ACT
EVENT
Stage 1
Stage 2
Stage 3
Stage n

Figure 2

If sales a priori is assumed to have a certain (say, normal or lognormal) distribution with specified mean and standard deviation, the test information can be used to derive an appropriate posterior. The existence of a prior distribution with specified parameters is no unrealistic assumption here; presumably a product to be test marketed has shown some initial promise.

In assigning the weight of the new test information relative to the priors, the reliability of the testing has to be assessed. This hinges directly on the likelihoods of the test: the probabilities of various test outcomes, given alternative true market sales.

These probabilities can be directly assessed when the test information can be seen as coming from a random sample; the standard errors serve directly to indicate the appropriate probabilities. In the case where the test market only yields one observation on sales for a period, the updating can be done by defining the likelihoods directly (see, e.g. Bass, 1963, p. 78).

Let us turn then to the possibility of competitive reaction. It is clear that a fairly large potential market -- uncovered by the test market information -- will be less attractive in proportion to the amount of competition and consequent decrease in market share. Accordingly, the posterior probabilities should be adjusted by the probability of competitive reactions.

<u>The Problem of Competitive Entry</u>

First a preliminary overview. It will be assumed that the testing firm ("our" firm) can establish a list of N <u>potential</u> entrants besides itself. Many of these will not be <u>capable</u> of entering the market directly.

However, as the number of stages of testing approaches the end of the planning horizon T and thus time increases, successively more of them will become capable of entering with their own product. Their willingness to enter hinges primarily on two factors. One is the market sales, as indicated by the test results. Another is the differential of these sales that accrue to the first entrant. If this latter "bonus" is small, for example, the competitors might well wait until our firm enters full-scale. Conversely, if the bonus is high, the competitors able to enter might attempt a risky early entry which is compensated by the large gains possible.

Similarly, these two factors will affect our firm's entry decision. In addition, however, the early firms, especially ours, would derive some additional gains from entering before other firms are capable of entering. This gain would be reduced by the others' later entry, but will constitute an initial gain that could be quite substantial at times.

The Number of Capable Entrants

The simplest approach to the determination of the number of capable entrants, $N'(t)$, $(N'(t) \leq N)$, $t = 1, 2, \ldots, T$, is to develop a checklist of the factors that affect a firm's ability to develop the new product and market it. Then a particular firm can be rated on the checklist factors, and only those firms scoring higher than some critical level on all the factors will be moved into the "capable" or "active" group. Since over time many firms will be able to develop the necessary capabilities, the critical question to ask for each factor is how many time periods will elapse before the requisite critical level is reached.

Checklists similar to this are common in much of business decision making (see, for example, Kotler, 1971, pp. 113, 271, and 326). For the particular product our firm should have little difficulty in developing the appropriate factors to check. As an example, the factors incorporated in Figure 3 would generally be of importance. In the figure a particular company will go into the group of entrants corresponding to its longest time lag.

Figure 3 about here

In what follows, it will be assumed that there has been derived a vector N' of values on $N'(t)$, $t = 1, 2, \ldots, T$, with $N'(1) \leq N'(2) \leq \ldots \leq N'(T) \leq N$. These numbers are treated as deterministic, but could equally well be regarded as the expected values of the $N'(t)$.[1]

The Payoffs to Entry

Given that a competitor is able to enter, his actual behavior depends upon the evaluation of the test results. Most likely, the action taken depends upon the forecasted sales in the market and the market share he thinks he can get:

$$(1) \qquad P(COGO|T) = \sum_S P(COGO|S)\, P(S|T)$$

where $P(S|T)$ can be derived in the same manner as for our firm, and

$$(2) \qquad P(COGO|S) = f(S, MS_n) \quad ,$$

where MS_n denotes the n'th firm's market share ($n = 1, 2, \ldots, N$).

[1]The probabilistic interpretation would be especially appropriate if it was assumed that not all competitors might observe the test results.

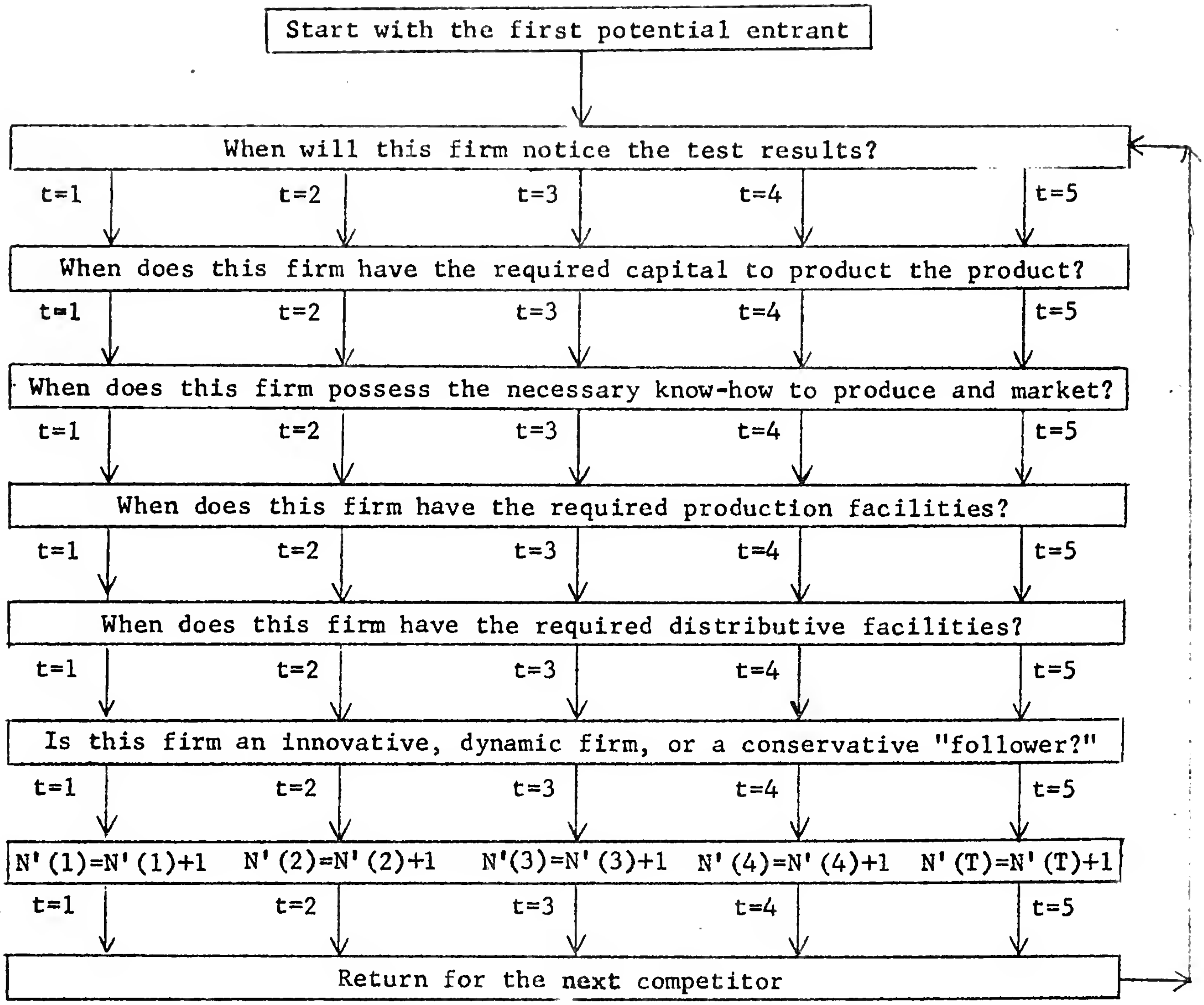

Figure 3

Checklist for deriving N'(t), t = 1,2,...,T.

S refers to market sales and T to test information. We make the assumption that $P(S|T)$ is the same for the competition as for our firm, which implies that we ascribe our priors to them. Such an assumption is not unrealistic if these potential entrants are at all similar to our firm. This they might very well be since they are all capable of producing the product by the time they are grouped into the active category dealt with here. Let us then focus upon the second relationship, the $P(COGO|S)$.

Basically, the total market can be seen as divided up into two categories of customers. One consists of these buyers who stay loyal to the first entrant whoever he may be. The customers in this group will often belong to the "pioneers," those willing to try out a new product and then staying with it as imitations appear. The other group comprises the buyers who basically develop their brand preferences on the basis of comparative trials of several brands. Unless better forecast data are available to our firm, we will assume that this portion of the total market will distribute itself between the entered brands in proportion to these brands' market shares in related markets. Since these relatively easily imitated products for the most part constitute product line extensions, such an assumption relating to existing competitive situations is not very unrealistic. If no existing markets similar to the one contemplated exists, subjective evaluations by management will have to be established.(on such subjective evaluations, see the procedures developed by Schlaifer, 1969).

That group of customers not loyal to the first entrant will comprise some buyers who would perhaps buy a competing brand not yet in the market, rather than the one actually bought. This will not change until the

new brand enters, and thus in the meantime, the early entrants (including our firm) will capitalize on the situation. It seems likely that this share of the market will also divide itself up between the existing brands according to their market shares in related markets. As we can assume that the firms entering will be those in the active group, we divide this "transient" part (DS) of the market according to:

(3) $$DS_{nt} = (100\text{-}DMS)*S*(100\text{-}MSS_{N'(t)})*MS_n/MSS_{N'(t)}$$

where

$$MSS_{N'(t)} = \sum_{n=0}^{N'(t)} MS_n \quad ,$$

with MS_n denoting our firm's market share, and the subscripts in DS_{nt}, denoting the entering firm n at t, $n = 0, 1, 2, \ldots, N'(t)$, $t = 1, 2, \ldots, T$. Here DMS denotes the share, in percentages, of the total market that goes to the first entrant ($0 \leq DMS \leq 100$).

Since this transient share of the market will not stay constant over time as competitors enter, it becomes necessary to compute an average payoff for each period within the planning horizon. This average will differ depending upon the time period of entry. If we denote the time of entry as t*, $t^* = 1, 2, \ldots, T$, we can compute the rate at which DS_{nt} decreases as[1]

(4) $$TR(t^*) = 1 - \left(\sum_{t=t^*}^{T} \sum_{n=1}^{N'(t)} MS_n\right)/(T+1-t^*) \quad , t^* = 1, 2, \ldots, T.$$

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[1]A discount factor could be easily introduced to account for preferences over timing of payoffs, but is suppressed here.

The total expected sales for the n'th potential entrant becomes:

(5) $$S_{nt} = (100-DMS)*S*MS_n + DS_{nt}*TR(t*=t) + (DMS)S \quad ,$$

if the n'th firm is the first, and

(6) $$S_{nt} = (100-DMS)*S*MS_n + DS_{nt}*TR(t*=t) \quad ,$$

if the n'th firm is not first, with $t = 1, 2, \ldots, T$, and $n = 0, 1, 2, \ldots, N'(t)$.

In the model presented the competitors and our firm are treated symmetrically. One advantage accruing to our firm, however, is the possibility we have of entering as soon as one competitor has entered. In addition, if our firm decides to enter relatively early, there will be no competition about the DS share until some other firm is capable of entering. In some cases where the "tooling up" for entry is time consuming, such an advantage could of course be decisive.

One last feature of the model is needed before most real world situations are appropriately accounted for. Because the new product might need a fairly long period of introduction (before reaching the growth stage), it will sometimes be useful to incorporate a market sales curve over the planning horizon which can take on a non-linear shape. Since it is hardly likely that the saturation level of the life cycle curve will be encountered within the T time periods, the most attractive alternative to a constant level:

(7) $$S_{t'+1} = S_{t'} \quad ,$$

would perhaps be

(8) $$S_{t'+1} = S_{t'}^{(t'+1)b} \quad ,$$

where t' measures the number of time periods from the time of introduction, and where b, ($b \geq 0$), indicates the rate of increase in the slope. The initialization of S_t, would be computed on the basis of the test results at t' = 1.

The Probability of Competitive Entry

Sofar we have assessed which competitors would be capable of entering, and what their expected sales (S_{nt}) would be given market sales (S). The next step is to predict the probability of competitive entry on the basis of these figures.

First the sales estimate, S_{nt}, has to be translated into profits (assuming sales alone is insufficient) taking into account cost figures as well as possible non-linearities of the competitors' objective functions. In the absence of specific data on the competitors, the costs can be taken as proportional to ours, and the objective function the same as ours. Where more data on the competitors exist, appropriate changes in these assumptions are straightforward to accomodate. Thus, we can write

(9) $$\pi_{nt} = S_{nt} - C_{nt} \quad ,$$

and

(10) $$U_{nt} = a_0 + a_1 \pi_{nt} - a_2 \pi_{nt}^2$$

where π_{nt} stands for firm n's profit from entering first at t, C_{nt} and U_{nt} similarly for costs and objective function respectively, and a_0, a_1, and a_2 constants (non-negative) of the objective function.[1]

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[1]Strictly speaking, only a_1 and a_2 are needed since a_0 does not enter the maximization argument. If the objective is linear in profits, we might as well work with profits directly.

Once the U_{nt} has been derived for firm n, the next step is to translate the payoffs into a statement of the probability that firm n will enter. Generally, the higher the payoff the more likely would be an entry. It seems quite likely, furthermore, that for relatively low utilities the probability of entry should stay low, whereas reasonably high payoffs might push the probability close to one. A functional form which exhibits these characteristics and which also limits the probability to the necessary 0-to-1 range is the following logistic:

$$(11) \qquad P_{nt}\ (COGO|S) = b_0 U_{nt}^{b_1} / (1 + b_0 U_{nt}^{b_1}) \quad ,$$

where b_0 and b_1 are constants $b_0 > 0$ and $b_1 > 1$.[1]

Thus, for a given level of market sales (S) we can compute the different $P_{nt}(COGO|S)$, $n = 1, \ldots, N'(t)$, at any time period t. These probabilities will generally vary between firms, since their DS_{nt} in (3) will differ. The probability that no competitor will enter at t is equal to

$$(12) \qquad P_t\ (CONOGO|S) = (1 - P_{1t}(COGO|S))(1 - P_{2t}(COGO|S)) \ldots\ldots (1 - P_{N'(t)t}(COGO|S)) \quad ,$$

and the probability of entry becomes

$$(13) \qquad P_t(COGO|S) = 1 - P_t(CONOGO|S).$$

Finally, we use our distribution of S from the priors and later updated as posteriors to compute the desired probability in (1):

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[1]This probability function and the previous objective function are both weighting the basic profit figures, and could clearly be consolidated into one function by substitution. Conceptually, the segregated approach becomes much more enlightening, however, which would generally be to the advantage of the management.

$$(14) \qquad P(COGO|T) = \sum_S P_t(COGO|S)\ P(S|T) \quad ,$$

for the probability of competitive entry after the test results are in, and

$$(15) \qquad P(CONOGO|T) = 1 - P(COGO|T) \quad ,$$

for the corresponding probability of no entry. These are the probabilities we need to complete the specification of the decision tree in Figure 2. Once they are derived, the usual backward induction approach of stochastic dynamic programming can be utilized for the assessment of optimal first-stage decision, and later-stage decisions conditional upon test outcomes.

It is clear that in the case where management is relatively certain regarding its judgment of the probability of entry, this elaborate modeling need not be carried out. Nevertheless, it should be pointed out that a clear specification of what steps logically have to be taken in order to arrive at the probabilities will often help to clarify where particular bits of information and judgment should be properly placed. As always in the analysis of future competitive actions, no determinate and failsafe formula is possible to produce, but it is to be hoped that models such as the one presented here will assist management in making more enlightened decisions.

A Numerical Example

To see how the model framework presented can be used in an applied setting, a computer code was written and a simulated case was run. Apart from the priors over various market sales outcomes and the test likelihoods, inputs of DMS, the share going to the first entrant, of the N' vector of the number of capable entrants, and of the market shares in related markets (the MS_n, n = 1,..., N) were needed. These parameter

values and the values assigned the parameters of the objective functions and the probability functions are exhibited in Table 1. In addition to the run at initial values, a sensitivity analysis was carried out for the N'(t), and for the DMS values, using the values that are indicated in Table 2. Clearly, additional sensitivity analyses could be carried out for the other parameters as well (and should be done in a real application), but for the model developed the parameters chosen represent less common concepts and would thus be of special interest.

The results of the runs are presented in Table 2. For the initial parameterization, the optimal first-period decision is to "GO"--the possible entry of the competitors in successive periods makes testing a non-optimal choice. To see how sensitive this solution is to the assumption of possible competitive entry, a similar run was made but with no entry possible. As can be seen in the Table, the result is that the test marketing should be carried out. Thus, if the assessment of the likelihood of competitive entry is correct, the firm would do better on the average not to test market the new product, although the standard analysis points in the other direction. Although Table 2 only shows a limited set of runs, it is clear that the optimal decision is quite sensitive to competitive entry.

In Table 2 are also presented the results from some runs using alternative levels of DMS, the share going to the first entrant. As can be seen, as long as no competitive entry is possible within the four-period horizon, the DMS level does not matter. This is of course as expected, since it means that we can take our time before entry and still count on the DMS share. As can be seen from the Table, the DMS becomes important, however, when the number of possibly entering competitors goes up. It is interesting to note that in the case where the

DMS is relatively low, but the number of competitors able to enter is high, the preferred decision is to drop the product from further consideration. Clearly the threat of competitive entry combined with fairly low gains makes the new product opportunity of little promise.

Discussion

Clearly, these sensitivity results are of limited generality. Nevertheless, they point out the fact that the possibility of entry by competitors on the basis of test market sales data needs to be considered by the new product tester. The approach suggested here basically presents a flexible framework within which the question of such competitive entry can analyzed. As such, it serves the function of isolating the many considerations which have to be taken into account when a firm analyzes and attempts to predict its competitors' behavior. Also, for the case where reasonable parameter values can be assessed by managers, the solution can easily be obtained.

Several extensions are possible. First, the possibility of competitive reactions other than entry could be accounted for. This refers particularly to the case mentioned earlier where competitors change their marketing mix in the test areas, thereby severely affecting the reliability of the sales figures observed. Such a procedure will have to be accounted for by modeling the test likelihoods as functions of competitive actions. A second extension is to use the program interactively, so that management decision makers can easily simulate the effects of changing parameter values. This last possibility offers the best chance of management acceptance of the model, and also allows for continual updating as new information and experiences are incorporated.

TABLE 1

A Numerical Example

Parameter Values for the Initial Run

No. of Decisions: 3 (GO, TEST, and DROP)
No. of Sales Levels: 2
No. of Test Outcomes: 2
No. of Drop Outcomes: 1
No. of Competitive actions: 2 (GO, NOGO)
No. of Periods: 4

Priors: P(sales=high) = .55
P(sales=low) = .45

Test Likelihoods:

$P(\text{test high} | \text{sales high}) = .8$
$P(\text{test low} | \text{sales high}) = .2$

$P(\text{test high} | \text{sales low}) = .3$
$P(\text{test low} | \text{sales low}) = .7$

Payoffs: Sales high = 140.0
Sales low = 10.0

Drop = 35.0

Test cost per period: 21.0

Number of competitors considered: 4

DMS = .25

$MS_1 = .25$; $MS_2 = .15$; $MS_3 = .35$; $MS_4 = .15$; $MS_5 = .10$

(MS_1 is our firm)

Entry ability: N': (1 2 3 4)

Parameters of the competitors' probability function: $b_0 = .01$; $b_1 = 1.1$

Our objective function: Linear
Competitors objective function: Linear

Discount rate applied: 0.0

Market Sales overtime: $S_{t'+1} = S_{t'}$, $t' = 1, 2, \ldots, T$.

TABLE 2

Results from the Numerical Example: Optimal First-Period Decision

		Alternative N'			
		(1 1 1 1)	(1 1 1 4)	(1 2 3 4)	(1 5 5 5)
Alternative DMS	.20	TEST	TEST	DROP	DROP
	.25	TEST	TEST	GO *	GO
	.30	TEST	TEST	GO	GO

*Initial run.

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