Integrated Advertising and Supply Chain Plans for an Innovative Product under Uncertainty

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***Abstract*— Demand for an innovative product typically follows a diffusion process. Prior advertising research on the innovative new product assumes an infinite capacity and a deterministic demand situation. However, capacity constraints are common for the new products. Also, the demand for the new product is extremely difficult to predict before its launch. Nonetheless, a firm that deals with the new product mostly has to take initial advertising and production planning decisions under an uncertain demand and capacity constrained situation. After observing the initial demand, the firm generally adjusts its marketing and production plans as per the demand realized. In this paper, we suggest the use of a two stage stochastic programming with recourse to analyze this situation. Our results show how the operational characteristics such as inventory holding and back order costs can significantly influence the advertising under different diffusion patterns.**

***Index Terms*— supply chain management for new products under uncertainty, innovation diffusion process, advertising and pricing models.**

I. Introduction

Several operations and marketing models have been proposed in this context [1]. From an operations perspective, [2] developed a production planning model for the new product considering the diffusion process and capacity constraints. [3] and [4] developed integrated production and sales planning models and showed situations where delayed sales and initial inventories can be optimal decisions. None of these papers however considered the influence of the marketing levers and advertising while developing the integrated supply chain models for the new products. Nonetheless, it is a common knowledge that the firms adjust their advertising policies to manage the diffusion process [1].

From a marketing perspective, several advertising models have been proposed in the context of the new products exhibiting diffusion process [5]. This stream of research critically discusses different advertising and pricing policies such as increasing, decreasing, increasing-decreasing. However, this research assumes that the firm has an infinite capacity. In contrast, capacity constraints are common for the new products. Prior work did not address one interesting issue: How will inventory and backorders that result from mismatch between capacity and demand over time affect the optimal advertising and pricing policies. Therefore, the main objective of this paper is to understand the behavior of optimal advertising policies for the new products exhibiting diffusion process in the presence of capacity constraints.

Also, the above research streams assume that the demand for the product is deterministic. This is in contrast to realistic situations where the demand is stochastic in nature. In this paper, we propose a two stage stochastic programming model with recourse to compute integrated robust supply chain and advertising plans for the new products facing uncertain demand diffusion process.

II. Model Developments

[6] modeled the demand process using the following differential equation.

$$d(t)=\left\{p+\frac{q_1}{m}D(t)\right\}\left[m-D(t)\right] \qquad (1)$$

where $d(t)$ is instantaneous demand at time t, p and q are constants$\in$ (0,1), which represent the effects of mass media and the adopters on the potential adopters respectively. D(t) is the cumulative number of adopters at time t while m is the market potential. Now, we extend the original Bass model to include advertising decision.

An empirical study by [7] has shown that p, the coefficient of an external influence could be represented as a function of advertising expenditure with diminishing returns.

$$p(t) = p_1 + p_2 \log A(t) \qquad (2)$$

where p_1 is the effect of the mass media as in the Bass model while p_2 denotes an advertising effectiveness. A(t) denote advertising expenses incurred in time t. Now, we rewrite the Bass model (equation 1) to capture the advertising effects by using equations 2 as

$$d(t)=\left\{p_1 + p_2 \log A(t)+\frac{q_1}{m}D(t)\right\}\left[mP_t^{\varepsilon} - D(t)\right] \quad (3)$$

Equation 3 assumes that the firm can correctly estimate the parameters of the diffusion process. But, as discussed in the introduction section, these parameters are subject to randomness. We believe that the impact of pricing and advertising can be measured from past experience (experience with similar markets and similar category of products), but it is very unlikely that past performance will be able to estimate the original Bass model parameters in a precise manner. At best, by using the past data on similar products and the feel of the market, initially, the firm can generate a set of demand

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scenarios. For example, management can consider scenarios where the market potential is likely to be low, moderate and high. Similarly, the timing of peak can be early or late and peak demand during peak can be high or low. This information can be subsequently used to estimate the Bass model parameters. Now, we rewrite the demand equations in the presence of the uncertainty as below.

$$d^s(t) = \left\{ p_1^s + p_2 \log A(t) + \frac{q^s}{m^s} D^s(t) \right\} \left[m^s P_t^{\varepsilon} - D^s(t) \right] \quad (4)$$

$$R^s(t) = \sum_{t=1}^{T} d^s(t) P(t) - A(t) \quad (5)$$

This results in a stochastic bass model where s represents a demand scenario.

Two-stage stochastic programming model used to solve such stochastic problems is based on the following assumptions. First, random events related to the demand process occur with probabilities that are independent of the first stage decisions. Second, the truth regarding the diffusion process is revealed before the start of the second stage so that the firm can use an appropriate contingency plan in the second stage. Third, the overall objective is to maximize the expected profits over the two stages. Fourth, because there always exist a contingency plan, which is a combination of advertising, backorders, and inventory decisions, the feasibility is always ensured. The two stages only conceptually divide the product life cycle into two parts based on demand uncertainty and therefore each stage can consist of several periods. In our model, we assume that the first stage consists of the first period while the second stage consists of the remaining periods.

Let,

Indices

t time, 1…T and c = capacity options available, 1…C

Parameters

D_t^s demand in period t under scenario s as a function of advertising (equation 4)

α production cost per unit

h_t inventory holding cost per unit in period t

w_t backorder cost per unit in period t. For the final period, it denotes lost sales cost

F_c plant size if the capacity option c is selected

I_c capacity investment cost if the capacity option c is selected

β discounting factor

ϕ_s probability of occurrence of scenario s

P_1 price in stage 1 **and** P_2^s price in stage 2 under scenario s

Variables

First stage variables

Y_c binary variables would take value 1 when the capacity of size c is selected

X_1 production quantity in stage 1 (period 1) and A_1 **is** advertising in stage 1

i_1^s inventory at the end of stage 1(period 1) in scenario s

b_1^s backorder at the end of stage 1(period 1) in scenario s

Second stage variables

A_2^s advertising in stage 2 under scenario s

X_t^s production quantity for the period t (in stage 2) under scenario s

i_t^s inventory at the end of the period t (in stage 2) under scenario s

b_t^s backorder at the end of the period t (in stage 2) under scenario s

$$\sum_{s=1}^{S} \phi_s (P_1 D_1^s) - A_1 - \alpha X_1 - \sum_{c=1}^{C} I_c Y_c - \sum_{s=1}^{S} \phi_s (h_1 i_1^s + w_1 b_1^s) \quad \{first\ stage\}$$

$$+ \sum_{s=1}^{S} \sum_{t=2}^{T} \phi_s \beta^{t-1} (P_2^s D_t^s - A_2^s - \alpha X_t^s - h_t i_t^s - w_t b_t^s) \quad (6)$$

Subject to

First stage constraints

$$X_1 \le \sum_{c=1}^{C} F_c I_c \quad (7)$$

$$\sum_{c=1}^{C} I_c = 1 \quad (8)$$

$$X_1 - i_1^s + b_1^s = D_1^s \qquad s = 1,...,S \quad (9)$$

$$X_1, P_1, A_1, i_1^s, b_1^s \ge 0 \quad (10)$$

Second Stage Constraints

$$X_t^s \le \sum_{c=1}^{C} F_c I_c \qquad t = 2,...,T \quad s = 1,...,S \quad (11)$$

$$X_t^s + i_{t-1}^s - b_{t-1}^s - i_t^s + b_t^s = D_t^S \quad t = 2,...,T \quad s = 1,.,S \quad (12)$$

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$$P_2^s, A_2^s, X_t^s, i_t^s,$$
$$b_t^s \geq 0 \qquad \forall t = 1,...,T, s = 1,...,S \qquad (13)$$

The objective function (eq. 6) maximizes the discounted expected profits by subtracting investment costs, expected production costs, expected inventory and backorder costs from expected revenues. Constraints (eq. 7 and 11) keep production in each period below the manufacturing capacity under all scenarios. Constraints (eq. 9 and 12) are inventory and backlog equations for each period under each scenario. We assume that the demand is completely backlogged until the last period where it results in the lost sales due to insufficient capacity. So, backlog cost per unit in the period T is the lost sales cost per unit and inventory holding cost per unit in the period T is the salvage value per unit.

III. Results and Discussion

We solve the above model by varying advertising level, inventory cost and backorder costs between high and low levels to understand the interactions. We report below some of the findings from the computational experimentation. We found that advertising decision for the first stage however depends upon the per unit backorder cost. When the backorder cost is low, then the firm uses advertising (in our case high advertising level = 50) to accelerate the diffusion process to minimize the inventory holding costs in the initial periods. However, as the backorder costs increase, the firm aims to build inventory in the early stages that can be used to meet the demand during the peak demand and hence does not accelerate the product growth by increasing the advertising expenditure (in our case low level = no advertisement) in this situation.

When the discounting is high, there is an incentive for the firm to advertise in the first stage because it results in demand acceleration which subsequently results in the increased discounted revenues. Hence, the firm selects a higher advertising level (50) in the first stage.

We found that in the second stage, the firm has chosen a lower advertising level (no advertising) when there is no discounting. When there is no discounting, it is not beneficial for the firm to encourage customers to purchase the product early from a revenue perspective. As discussed earlier, higher advertising tends to reduce the inventory holding costs if the inventory increases in the absence of advertising. However, in the second stage, because the inventory does not increase much, there is no incentive for the firm to increase advertising. As a result, the firm prefers zero advertising option.

IV. CONCLUSION

In this paper, we provided an integrated framework for linking marketing and supply chain decisions for a short life cycle product. We suggested the use of a two stage stochastic programming with recourse to model the problem. Our computational experiments demonstrated the importance of including the stochastic diffusion process and marketing decisions in the production planning model of the new product. Optimal advertising and pricing decisions depended upon the operations characteristics. For example, when the discounting was low, then in the first stage, the optimal advertising was low (high) when backorder costs were high (low).

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