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## **Overview of New Product Diffusion Sales Forecasting Models**

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### **1. Introduction**

New product sales forecasting approaches can be as simple as "guesstimating" the first year sales of a given product, escalating it for future year forecasts by an annual growth rate until a specific level of saturation is reached. This simple approach assumes that sales will continually grow throughout the product's lifecycle. Is there justification for assuming that sales will grow in such a pattern other than it's the result of an inexpensive and easy-to-apply forecasting tool? Although there are a myriad of both qualitative and quantitative methods for new product sales forecasting from simple growth escalation to forecasting with econometrically-estimated demand functions, a question arises as to whether there is a causal theory of new product sales in the market research academic literature that lends guidance to the type of forecasting method chosen. The purpose of this report is to provide a brief summary of market research literature regarding the forecasting of sales of new products with guidance that goes beyond an ad hoc choice of a forecasting tool. The guidance provided by years of market research will lead to the recommendation of a forecasting model that has been developed from product adoption theory and rigorously tested in its ability to perform. Thereby, the justification

and documentation for the choice of such a model structure in a business plan is one that is based on market research theory and robust empirical testing.

## **2. New Product Sales Forecasting Models: Product Diffusion**

A large literature in marketing research strongly demonstrates that product sales life cycles follow an S-curve pattern. An S-curve pattern implies that new product sales initially grow at a rapid rate, then the rate of growth tapers off, and finally declines with time. Historical analysis of new product sales curves indicates this is one of the most common, if not the most common pattern of new product sales over time.

The new product sales model we will recommend explains this S-curve shape based on diffusion theory. Diffusion theory is actually a theory of communication regarding how information is dispersed within a social system over time. Because people place different emphases on how much they rely on media and interpersonal communication for new ideas and information, they "adopt" new products either earlier or later in a product's lifecycle. The consumer product adoption process based on relative adoption time categorizes individuals as innovators, early adopters, early majority, late majority, and laggards. Exhibit 1 shows the cumulative percentage of the potential market (i.e., total number of adopters) that has made an initial purchase of a new product. As you move up and to the right of the S-curve in Exhibit 1, i.e., as you look at the rate of adoption of a new product over time by first time purchasers, you initially have the innovators buying the product, then early adopters, and so on as you move up the S-curve, until you get to the point of market saturation, where the last set of first-time buyers are known as the laggards.

### **Exhibit 1: S-Curve Example**

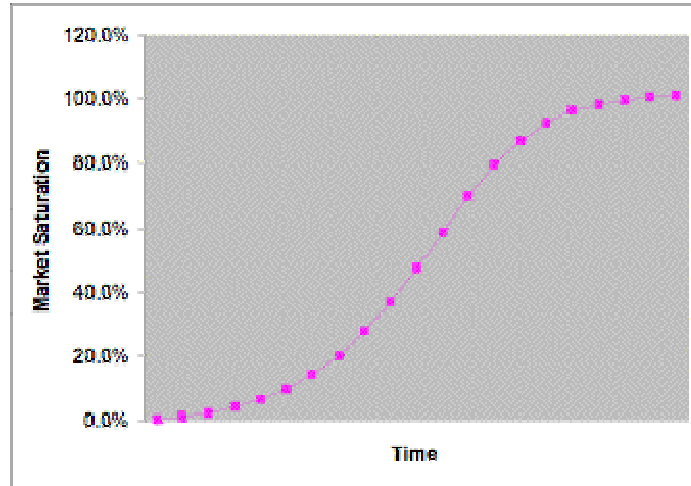
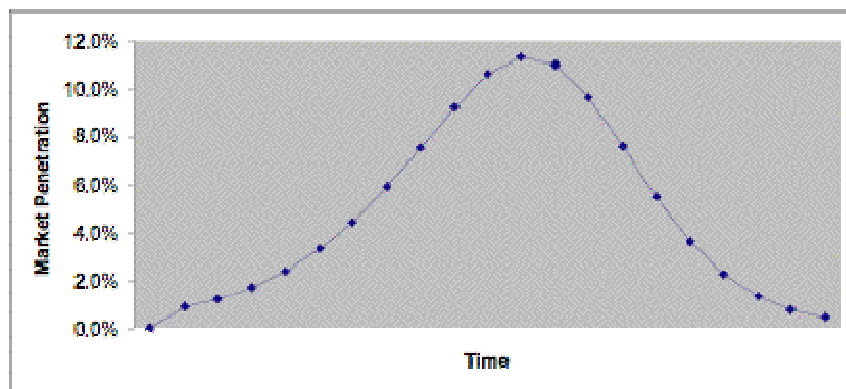


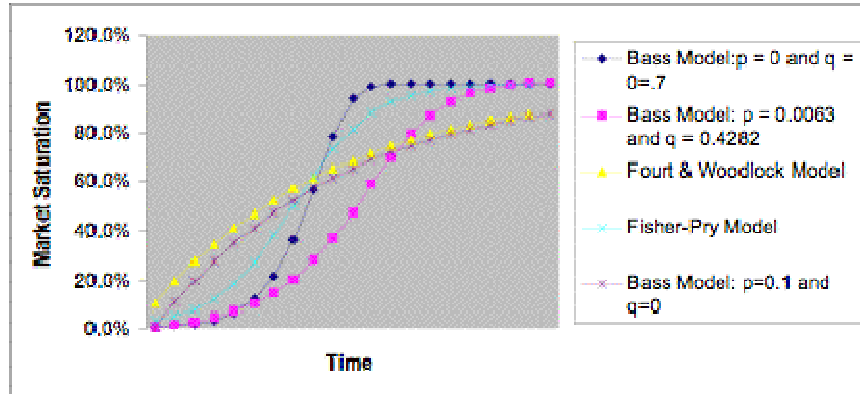
Exhibit 2 shows the time of adoption of buyers for the product. If the buyer is to the left of the vertical line in their time of adoption they are innovators, early adopters or part of the early majority, if to the right they are the late majority or the laggards.

Exhibit 3 displays different types of S curves developed from alternative types of product sales forecasting models. They will be discussed in detail in a latter section of this investigation.

**Exhibit 2: Time of Adoption of Innovation**



**Exhibit 3: S-Curves for the Diffusion of Innovations**



The "S-curve" model is what is known as a "single purchase" model in that it forecasts sales of products that are typically bought just once, or infrequently, such as consumer durables or industrial products such as mainframe computers. In addition, the model can be used to forecast trial or first time purchases for repeat purchase goods such as snack foods and detergents, but it does not provide a forecast of repeat purchase levels. In order to estimate repeat purchase sales and differentiate them from trial sales, businesses would typically need to carry out test markets or simulated test markets and apply different forecasting methods that would provide a steady-state market share estimate rather than a time-based adoption curve as is provided by diffusion models. However, all products, regardless of how often they are purchased, have a first-purchase sales volume curve (Mahajan and Wind 1986).

Diffusion models are dependent on a number of assumptions, each of which should be considered prior to implementing such models. The assumptions include:

- 1) The product whose sales are being forecast by the model is a product that is destined to be a successful new product introduction. Estimates of new product failure rates vary from 33% (Booz, Allen & Hamilton, Inc. 1982) to 60% (Silk and Urban 1978) or higher. The present model is appropriate only for successful new product entries. The present model cannot predict which new product launch will be successful; it is instead designed to project sales volume over time for those product launches that are successful.

- 2) Potential market size. The model requires that the user input an estimate for the total market size for the particular brand within the product category (i.e., total number of adopters of the branded product). To the extent that this estimate is inaccurate, the new sales forecasts will also be inaccurate. The user firm may choose to use

historic sales data, however it needs to produce an estimate of potential market size, and then estimate the brand's share within the market.

3) The nature of the competition. When the user estimates their brand's market share within the product category, a number of underlying assumptions about competitive response underlie such an estimate. It is possible that competitive response, such as imitative competitive alternatives, or heavier promotional responses, will adversely affect the share of the new product's sales. Again, to the extent that the market share estimate is inaccurate, the new product sales estimates will also be inaccurate.

The model recommended here has been developed from theoretical work in the area of diffusion processes and the customer new product adoption process. Diffusion process models attempt to forecast the market penetration rates of innovative products (air conditioners, cell phones, the internet, hybrid gas/electric cars, a new brand of coffee, etc.) over time. The customer adoption process refers to differences among customers in the degree to which they are innovative, and thus willing to try a new product. Some customers are very innovative and are the first to try new products, whereas others are less so, and typically wait until many of their neighbors, etc. have already bought the new product before they do the same. The speed of adoption of a new product has been shown to be a function of several factors including (Rogers 1983, 2003):

- The product's relative advantage over existing products
- The degree to which the new product is compatible with existing operations and attitudes
- The degree to which the new product is simple (rather than complex)
- The degree to which the new product can be tried on a limited basis
- The degree to which the product is observable.

To the extent that a new product possesses each of these characteristics, its likelihood of success in the market is improved. The first two factors, relative advantage and compatibility are particularly critical (Rogers 2003). However, models that have attempted to use managers' input regarding these factors have not fared particularly well.

### **3. Types of Product Diffusion Models**

There are at least three major types of models that have been

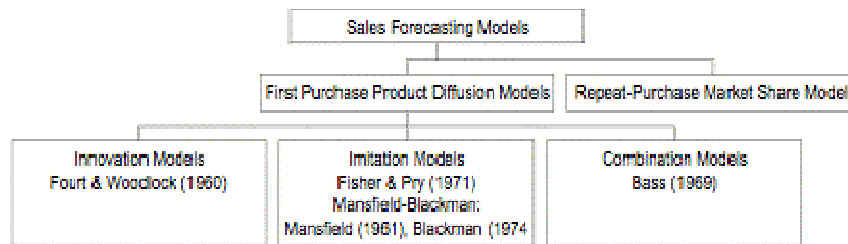
proposed for forecasting new product first purchase sales (models are discussed below):

1. Pure Innovative Models (e.g., Fourt and Woodlock 1960)
2. Pure Imitative Models (e.g., Fisher and Pry 1971, Mansfield 1961)
3. Combination Models (e.g., Bass 1969)

This investigation focuses on first purchase product models for application in forecasting initial product sales of a newly introduced product. Exhibit 4 displays the types of diffusion models, including the highly adopted Bass (1969) model (hereafter referred to as the "Bass Model") that combines the innovation and imitation properties into one increasingly generalized model.

### Exhibit 4

#### Product Sales Forecasting Diffusion Model Types



The *innovation* model of Fourt and Woodlock (1960) is a market penetration curve that was developed retrospectively after analyzing the market penetration curves of a number of new products. Pure innovative models assume that cumulative sales exhibit an exponential curve shape and that adoptions are based on individuals' exposure to external information sources such as marketing expenditures in mass media, rather than on word-of-mouth or other imitative effects. The equation that they found to be a reasonable approximation of these product curves is (see Exhibit 3):

where:

$$f_t = rM(1 - r)^{t-1}$$

$f_t$  = (change in cumulative sales at time  $t$ ) /  
(potential sales)

$r$  = rate of penetration of potential sales

$M$  = (total potential sales) / (all buyers), or market saturation percentage

All of the above variables are assumed to remain constant throughout the product sales life cycle, except for time,  $t$  and  $f_t$ . As an example, assume that the market saturation for a new luxury durable good was 50% of all households and that  $r = 10\%$ , therefore the annual rates of new buyer penetration are:

$$\text{1st Year: } f_t = rM(1-r)^{t-1} = 0.2 (0.1) = 0.02 \text{ or } 2\%$$

$$\text{2nd Year: } f_t = rM(1-r)^{2-1} = 0.2 (0.1) (0.8) = 0.016 \text{ or } 1.6\%$$

$$\text{3rd Year: } f_t = rM(1-r)^{3-1} = 0.2 (0.1) (0.8)^2 = 0.0128 \text{ or } 1.28\%$$

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$$\text{20th Year: } f_t = rM(1-r)^{20-1} = 0.2 (0.1) (0.8)^{19} = 0$$

Note that the incremental cumulative sales as a fraction of potential sales exponentially declines in every time period from the initial product introduction year and that the curve flattens out at the time that the market saturation level of 50% is reached.

The *imitative* model of Fisher and Pry (1971) contains the notion that a new product replaces an older type of product, and that the rate of adoption of the new product is dependent on the percentage of the old product still in use. The Fisher and Pry (1971) model is the classic logistic S-shaped curve:

where: 
$$f = \frac{1}{1 + e^{-b(t-t_0)}}$$

$f$  = percentage of market that adopted new product

$b$  = growth to potential constant

$t$  = time since introduction

The above equation can be re-written in log-linear form as:

$$\left(\frac{f}{1-f}\right) = e^{b_0 + b_t}$$

The Mansfield-Blackman model [Blackman, Seligman, and Solgiero (1973), Blackman (1974), Mansfield (1961, 1968)] adapts the Fisher and Pry (1971) model to include the upper limit in market share or saturation level of the newer product:

$$\left(\frac{f}{L-f}\right) = e^{b_0 + b_t}$$

where:

$L$  = market saturation percentage

This adaptation provides a constraint on the maximum level of market share that the newer product can attain.

The two basic types of models described above, the pure *innovation* model and pure *imitation* model have been combined into one more generalized model, the Bass (1969) model, to capture both the innovative and imitative aspects of product adoption. The Bass model captures the innovative characteristic with its coefficient,  $p$ , and the imitative characteristic with its coefficient,  $q$  (described in more detail below). In the Bass model, when  $p=0$ , the model defaults to the Mansfield (1961) model, and when  $q=0$ , the model defaults to the Fourt-Woodlock (1960).

The Bass (1969) model is an aggregate demand model that represents an empirical generalization or "a pattern or regularity that repeats over different circumstances and that can be described simply by mathematical, graphic, or symbolic methods" (Bass 1993, 1995). It is designed to be used as a pre-launch forecasting model that is estimated prior to the introduction of a new product, that is, before preliminary sales figures have been obtained. Formulations of the Bass model have been used by corporations such as Kodak, IBM, RCA, Sears and AT&T (Rogers 2003, p. 208).

The Bass model is similar in some respects to models of infectious diseases or contagion models, in that it attempts to estimate how many customers will buy a new product as the new product gains more acceptance over time. The model represents not the spread of a disease, but the impact of communication efforts about a new product, whether those efforts are external in nature, such as mass advertising, or more informal in nature, such as via word-of-mouth communication or observation and imitation. The model assumes

that there are differences among customers in terms of how innovative they are in their tendencies to adopt new products, and which types of information about a new product are most persuasive prior to adoption. When a new product is introduced, there exists uncertainty in the minds of potential adopters regarding how superior the new product is versus existing alternatives. Individuals attempt to reduce this uncertainty by acquiring information about the new product. More innovative customers tend to acquire such information via mass media and other external outlets. More imitative customers tend to acquire such information from interpersonal channels such as word-of-mouth communication and observation. The relative influence of these two basic types of customers is captured in the Bass model.

The Bass model thus assumes that new product adopters are influenced by two types of communication: mass media and interpersonal communication, and that the mass media effects, which have a greater impact on innovative customers, will be greater at the outset of the product launch, whereas the interpersonal communication effects, which have a greater impact on the much larger number of imitative customers, will be greater during the later periods of the diffusion process (Rogers 2003).

There have been over 150 published extensions of this model (see Mahajan et al. 1990 for a review), where one or more variables are altered or added, but the basic S-shaped Bass model continues to prove to be a robust method for forecasting new product sales among real world applications (Mahajan, Sharma, and Bettes 1988). Jeuland (1994), for example, fit the basic model to 35 different datasets for varying time periods and across different countries and typically found R-squared values greater than .9, suggesting very good fits (The R-squared statistic measures the degree of fit of a regression model to the data. An R-squared of 1.0 is a perfect fit.)

Considerable research across many disciplines including marketing, agriculture, sociology, and anthropology, suggests that most successful innovations have an S-shaped rate of adoption, although the slope of the curve varies (Rogers 2003). The Bass model adjusts the slope of the S-shaped curve according to two main parameters:  $p$  and  $q$ , the coefficient of innovation and the coefficient of imitation. Since most innovation diffusion processes tend to be very social in nature, typically the coefficient of imitation is considerably more important in determining the rate of adoption. Some innovations, such as VCR's and cell phones, have required only a few years to reach their maximum or near-maximum penetration levels, exhibiting a relatively steep S-curve, whereas others can

require decades, such as use of the metric system in the U.S. (Rogers 2003).

The formula for the Bass model requires that a business manager or group of business managers provide a single estimate for first year sales and total product lifetime sales (i.e., year one adopters and total adopters). Since few new products enjoy monopoly status or enjoy it for long, manager(s) need to estimate total product category adopters in light of competitive alternatives and responses. Parameter estimates of  $p$  and  $q$  are then estimated to produce the following equation:

$$Q_t = p(M - A) + q\left(\frac{A}{M}\right)(M - A)$$

The above can be simplified to:

$$Q_t = \left[ p + q\left(\frac{A}{M}\right) \right] (M - A)$$

where:

$Q_t$  = number of adopters or unit sales at time  $t$

$p$  = coefficient of innovation, or "the likelihood that somebody who is not yet using the product will start using it because of mass media coverage or other external factors" [Van den Bulte (2002)]

$q$  = coefficient of imitation, or "the likelihood that somebody who is not yet using the product will start using it because of "word-of-mouth" or other influence from those already using the product" [Van den Bulte (2002)]

$M$  = market size, or ultimate number of adopters or unit sales

$A$  = cumulative number of adopters or unit sales to date

The coefficient of innovation (i.e.,  $p$ ) captures the relative importance of innovative customers in generating sales for the new product. The coefficient of imitation (i.e.,  $q$ ) captures the relative

importance of imitative customers in generating sales for the new product. The model operates such that, regardless of the values of  $p$  and  $q$ , as more and more customers adopt or buy the new product, the relative impact of imitative customer purchases takes on greater importance in determining the sales curve. The S-curve that is then produced represents cumulative sales to date. A meta-analytic-based algorithm can be used to provide both a point or exact numerical estimate for sales in each time period, as well as an error band<sup>1</sup>, within which sales are expected to fall. Thus, a "feasibility space" can be provided [Mahajan, Muller and Bass (1995)] for managers to forecast new product sales. For more rigorous risk analysis of market projections, Monte Carlo analysis can be used by including differing estimates of  $p$ ,  $q$ ,  $A$ , and  $M$  combined with their probabilities of occurrence can provide scenario analysis of sales and different states of the market environment. Historical analogies are often a more accurate method for estimating the necessary parameters, because prior efforts to fit curves based on just a few periods of early sales (e.g., three to four periods) have enjoyed limited success and accuracy (Pae and Lehmann 2003) and usually there are not enough data points for statistical significance of the  $p$  and  $q$  estimates. Studies also suggest that the coefficients  $p$  and  $q$  are relatively constant over time, within a given industry (Norton and Bass 1987, Pae and Lehmann 2003). The  $p$  and  $q$  coefficients from academic publications are typically estimated post-hoc, that is, after a particular product innovation has been fully or nearly fully adopted throughout a market.

Other key estimates that can be made with estimated parameters include the two following. These expressions have been obtained by taking the first derivatives of the Bass Model and solving for the optimal time to peak sales and size of peak sales:

Time to Peak Sales: 
$$t^* = \frac{1}{(p + q)} \left[ \ln \left( \frac{q}{p} \right) \right]$$

Size of Peak Sales: 
$$s^* = M \left[ \frac{(p + q)^2}{4q} \right]$$

The Bass model with the mean values of  $p = 0.0063$  and  $q = 0.4282$  from Pae and Lehmann (2003) result in the Bass curve that is shown on Exhibit 3. Note that when  $q = 0$ , i.e., there is no imitation, the diffusion curve defaults to the pure innovation curve of Fourt and

Woodlock (1960), which is the declining growth exponential model. The Bass curves in Exhibit 3 are shown with differing values of  $p$  and  $q$ . Note that relatively higher values of  $q$  will result in an accelerated Bass curve where market saturation is reached faster. As the sales process continues over time, imitators increase over time relative to innovators whose numbers decrease over time.

Also, the model defaults to a pure imitative one when  $p = 0$ . Exhibit 3 demonstrates that in this case, the Bass curve has a similar shape as the Fisher-Pry imitative model. Note that the Bass curve with innovative and imitative properties embodied in the curve, i.e., when neither  $p$  nor  $q$  equal 0 reflects both forces affecting market sales projections.

This investigation finds that the Bass Model is the model of choice based on its theoretical characteristics, its widespread use by business sales forecasters, and the exhaustive academic literature that addresses many tests, applications, validity of its theoretical foundations, and its forecast performance. Finally, the main caveats are discussed then the conclusions follow.

#### **4. Caveats of the Bass Model**

There are a number of assumptions underlying use of the Bass model, which should be considered prior to and during its application. These include (Mahajan and Wind 1986):

- The size of the potential market of total number of adopters remains constant over time. This may not be true if the new product gains in popularity either by spawning more competitors than anticipated, for example.
- There is only one product bought per new adopter. This is clearly not true for frequently repeated purchase products, or those that may break down or need replacement before the end of the product's lifecycle.
- The coefficients of innovation and imitation remain constant over time. This may not be true if, for example, need or desire for the product suddenly increases midway through the product lifecycle.
- The new product innovation itself does not change over its life cycle. This would not be the case if the firm introducing the new product updated or improved the product during early stages of its life.
- The innovation's sales are confined to a single geographic area. This would not be true if, for example, due to the product's success, the firm decided to launch the same

- product overseas.
- The impact of marketing strategies by the innovator are adequately captured by the model's parameters. Historical analogies, on which the model's forecasts are based, may not be applicable if, for example, the firm launching the new product supported it with atypically large promotional support or if an aggressive pricing strategy is being deployed.
  - There is no seasonality in sales of the new product.
  - The application of the model presumes that the statistically-estimated parameters of the model used to develop  $p$  and  $q$  (involves the estimation of three regression coefficients) are statistically significant. Otherwise the  $p$  and  $q$  may not be representative of the true model and may lead to larger sales forecast errors. The Phase II of the project will discuss the statistical estimation of the Bass curve when historic sales data are available.

#### 4. **Conclusions**

This investigation has involved the analysis and research of the major S-curve models, sometimes known as diffusion curves, to make a recommendation on which model(s) to use for product sales forecasting. Each and every "S" or logistical model type has not been reviewed as there are many models that have been proliferated in the sales forecasting literature, all addressing (or claiming to address) some unique property of a product sales forecast. This investigation searched for the model that has received the most attention in terms of research, testing, application, and ability to understand and apply. The choice of the "best" model depends on many characteristics, many of which have not been discussed in this report. Although the focus is narrowed to the Bass curve, there are many dimensions for choosing the most appropriate values of  $p$  and  $q$ . One example that can impact  $p$  and  $q$  is what type of countries the firm is targeting its product. These will certainly be different for emerging economies v. mature economies. The market size and first year sales must also be estimated as model inputs in the absence of sales data. The purpose of the focus on S-curves is to obtain a systematic sales forecasting methodology based on marketing, economic, and statistical theory, analysis, research, and practice. There are many simple and complex forecasting methods that are ad hoc and are not based on any systematic approach to understanding

and modeling the structure of a market. Although the diffusion curve literature is no panacea for sales forecasting issues, it is based on sound marketing, mathematics, economics, and statistical principles. It is always better to have more information and well-developed, systematic methods for obtaining the most accurate forecast possible.

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