Model for Quality Improvement and Sales

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Many papers have discussed quality improvement, both in product quality or process quality. For companies, efforts to improve quality need to be viewed from a commercial perspective. This becomes important, because those efforts take time and considerable to be expensive. Therefore, we need to integrate all efforts have been made to improve the quality with the increase of product sales. Some studies have focused on these linkages. A study of this linkage was discussed in the form of mathematical models. The mathematical model of quality improvement and sales were critically analysed. The study indicated quality notions that related to sales is at the time that customers receive the products. In the stage the product is received by customers, there are three notions involved, namely: claimed quality, actual quality and perceived quality. In this paper we study the effect of these three quality notions on product sales. The basic theory of the model was investigated and analyzed to determine the variables that affect the models. Then these variables, studied further in order to see linkages with dimensions of product quality improvement. The diffusion theory provides a basis to develop a new model that characterises this effect. From the model data analysis, it can be concluded that from those three notions, the actual quality is the most affecting to the product sales. While, perceived quality mainly determined by the reliability performance of the products.

Keywords: claimed quality, actual quality, perceived quality, diffusion theory, quality improvement and sales

Introduction

There were many papers discussed several different notions of product quality. In context of marketing a new product, the three different notions of product quality of importance are the following: (1) claimed quality \( (q_c) \); (2) actual quality \( (q_a) \); and (3) perceived quality \( (q_p) \). These three are quality notions associated with the finished product sold to customers.

Our focus with regards these three notions of quality is in the context of the reliability of a product. Reliability cannot be assessed immediately at the time of purchase as reliability is performance over time. Operating the product over time provides data regarding failures and this is used to assess the reliability of the product. The time needed to assess product reliability depends on several factors. One of these is the speed at which customers can evaluate the relevant reliability characteristics of the product. As such the perceived quality is a dynamic variable. The initial value depends on several factors such as manufacturer’s reputation,

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technological feasibility etc.,. As time progresses, the customers get a better feel for the quality of the product.

The claimed quality can differ from the actual quality. This could be for two reasons. First, the manufacturer has not done enough testing to assess the actual quality. In this case, the claimed quality is based on the manufacturer’s judgment about the actual quality. Second, the manufacturer might know the actual quality but the claimed quality can differ from this for marketing purposes. The claimed quality can be lower or higher than the actual quality. The sales rate is influenced by the difference between the dynamically changing perceived quality and the claimed quality. This in turn has an effect on sales.

The outline of the paper is as follows. We begin with a brief review of the literature dealing with perceived quality where we discuss the relationship between perceived quality and some other marketing elements on product sales. In the next part we review the different diffusion models that have been reported in the literature, and following with the details of the new model formulation and carry out a qualitative analysis of the model.

**Perceived Quality: Review of Literature**

Perceived quality can be defined as the consumer’s judgment on the overall product excellence and superiority (Lewin, 1936). Hence, the concept of perceived quality is more subjective compared to claimed or actual quality. Perceived quality encompasses product performance, reliability and services associated with the product.

Several papers on perceived quality focus on the interaction between perceived quality and other marketing variables such as product prices, customer satisfaction, purchase intention, market share, and sales. Customers mostly indicate their preference regarding product quality based on the price and their satisfaction with the product. Etgar and Malhotra (1981) and Gerstner (1985) state that the price of product is commonly used as an indicator of product quality.

The relationship between price and quality (the P-Q relation) has received some attention. Geisfeld (1988), Hjorth-Andersen (1992), and Ratchford and Gupta (1990) examine this topic. They suggest that P-Q relation is influenced by the market condition—product competitiveness and how effective customers use their resources. Jackson and Narasimhan (2010) explored the price-quality connection in the context of competition, particularly for durable goods.

Zeitham (1988) deals with the relationship linking product price and perceived quality with perceived value of the product. Value can be defined as a comparison between what customers get and what they give. He classifies the consumer definition of value into four different groups: (1) value is low price; (2) value is whatever the customer wants in a product; (3) value is the quality the customer gets for the price paid; and (4) value is what the customer gets for what he/she gives. Sjolander’s (1992) research deals with product price and the perceived quality relationship taking into account the cultural boundaries (country and customer ages). He suggests that these two variables play an importance role in consumer behaviour.

Another quality notions, besides perceived quality, that grouped into the customer perspective is aesthetics (Sebastianelli, 2002)

Perceived quality impacts on customer purchase intention and as such provides a means for assessing it. The interaction of perceived quality and customer purchase intention is influenced by customer satisfaction. Boulding
et al. (1993) states that perceived quality influences the customer purchase intention, while Cronin and Taylor (1992) state that the relationship of these two variables is indirectly through satisfaction. Taylor and Baker (1994) mention that the interaction between perceived quality and satisfaction has an effect on customer purchase intention.

Other variables that influence customer perception of quality are the brand and store name (Dodds, Monroe, & Grewal, 1991; Rao & Monroe, 1989), and the market share of a product (Hellofs & Jacobson, 1999). They indicate three mechanisms through which perceived product quality affects market share. These are: (1) network externalities; (2) signaling; and (3) inclusion as an attribute in consumers’ quality functions.

Models to evaluate the effect of influencing customer’s perceived quality on the profit generated need a sound methodologies. The methodologies to assess perceived quality in the service sector include SERVQUAL (Parasuraman, Zeitham, & Berry, 1988), SERVPERF (Cronin & Taylor, 1992), and EP (Teas, 1993). The methodology to measure consumer’s relative preference toward the different dimensions of a product’s quality using Analytical Hierarchy Process (AHP) has been studied by Karnes, Sridharan, and Kanet (1995). Llusar, Zornoza, and Tena (2001) proposed a method for measuring perceived quality with taking into account aspects related to service and product quality.

Product Sales: Review of Diffusion Models

Manufacturer needs to predict or forecast the sales over time for new products. Many different types of models have been developed (for example, see Chambers, Mullick, & Smith, 1971; Tseng, 2008) but we focus on a class of models based on the diffusion theory.

The study of diffusion theory began more than half century ago. The theory has been used in many different contexts as it can be seen from Rogers (1995). See also, Kalish and Sen (1986), and Mahajan and Muller (1979) where they discuss this briefly but focus mainly on the models based on diffusion theory in the context of marketing. The earliest model, based on diffusion theory, in marketing was proposed by Fourt and Woodlock (1960), and Mansfield (1961). The underlying principles of these two models were integrated into a single model by Bass (1969) and this in turn triggered an avalanche of new models.

The objective of diffusion models in the context of marketing is to describe the adoption rate (level of spread) and sales growth of new products. The model is to depict the successive increase in the number of adopters and predict the continued development of the diffusion process already in progress (Mahajan & Muller, 1979). The Bass model has been successfully implemented in retail industry, industrial technology, agricultural, education and consumer durable products (Mahajan & Wind, 1986). Also the model has been implemented in the release of new products (Yalcinkaya, 2008) and remanufactured products (Debo, 2006).

There are several hundred papers dealing with refinements, extensions and applications of the Bass model. A major review and discussion of these models has been carried out by Mahajan and Muller (1979) and Mahajan and Wind (1986). A more recent work by Mahajan, Muller, and Bass (1990) presents a framework to link this vast literature. Reviews of diffusion models dealing with marketing mix (i.e., pricing and advertising) can be found in Kalish and Sen (1986) and Mesak (1996) and market-share dynamics and market-size dynamics (Nguyen & Shi, 2006).
Mahajan and Peterson (1985) categorize diffusion models into the following three categories:

1. Fundamental diffusion models;
2. Flexible diffusion models;
3. Extensions of diffusion models.

In the remainder of the section we discuss some of these models and conclude with their limitations.

**Fundamental Diffusion Models**

Also known as basic diffusion models, these models consist of three types of models: the external-influence, the internal-influence and the mixed-influence diffusion models. These models deal with the first purchase of new products.

**External-Influence Diffusion Model**

This model was proposed by Fourt and Woodlock (1960). Here the adoption of the product diffuses in a specified buying population is influenced mainly by the effect of mass media communication or advertising. The cumulative number of adopters, $N(t)$ increases in an exponential manner so that the rate of adoption is given by the following differential equation:

$$\frac{dN(t)}{dt} = a[L - N(t)]$$  \hspace{1cm} (1)

where $dN(t)/dt$ is the adoption rate at time $t$, $N(t)$ the cumulative number of new adopters by time $t$ and $L$ is the total number of potential adopters. $L$ can be a function of the sale price and product quality. $a$ is called the “coefficient of innovation” and represents the effect of direct advertising (such as on television or in newspapers). Note that $N(0) = 0$ and $N(t)$ is monotonically increasing and approaches $L$ as $t \to \infty$.

**Internal-Influence Diffusion Model**

This model was proposed by Mansfield (1961), and assumes that adoption is only influenced by word-of-mouth or interpersonal/communication and interaction from adopters and potential adopters. The model is given by the following differential equation:

$$\frac{dN(t)}{dt} = bN(t)[L - N(t)]$$  \hspace{1cm} (2)

where $b$ is the coefficient of imitation or represents the “word-of-mouth” effect. As before $N(0) = 0$ and $N(t)$ is monotonically increasing and approaches $L$ as $t \to \infty$.

**Mixed-Influence Diffusion Model**

The mixed-influence model was initially proposed by Bass (1969) and takes into account the diffusion processes of the earlier two models. The model is given by the following differential equation:

$$\frac{dN(t)}{dt} = [a + bN(t)][L - N(t)]$$  \hspace{1cm} (3)

Note that when $b = 0$ it reduces to the external-influence diffusion model and when $a = 0$ it reduces to the internal-influence diffusion model. Bass (1969) used this model successfully forecast the sales of consumer durables such as television sets, dishwashers, and clothes dryers. This model is often referred to as the Bass model.
The Bass model contains two parameters and the shape of \( dN(t)/dt \) versus \( t \) (or of \( N(t) \) versus \( t \)) depends on the values assigned to the two parameters. Initially, one assumes some nominal values (based on earlier products and the intuitive judgment of the model builder) and as sales data is collected the estimates are revised. For more details, see Mahajan and Wind (1986).

**Flexible Diffusion Models**

Flexible models are models which contain additional parameters. As such, they allow more complex shapes for \( dN(t)/dt \) versus \( t \) (or of \( N(t) \) versus \( t \)). For most of these models, the diffusion is modelled using \( F(t) = N(t)/L \) which is the fraction of population who have adopted the product by time \( t \) relative to the total potential adopters.

Finally, the inflection point occurs at the time instant when the second derivative \( d^2N(t)/dt^2 \) changes sign. A flexible diffusion model is said to be symmetric if the model \( F(t) \) corresponding to the inflection point is 0.5. If not, it is called a non-symmetric model. Let \( t_i \) denote the inflection point.

**The Floyd Model**

This first flexible diffusion model was proposed by Floyd (1968) and is given by the differential following equation:

\[
\frac{dF(t)}{dt} = bF(t)(1 - F(t))^2 \quad (4)
\]

The model is a non-symmetric model since \( F(t_i) = 0.33 \).

**The Sharif-Kabir Model**

This model was first proposed by Sharif and Kabir (1976) in the context of modeling the diffusion of industrial innovation. The model combines the internal-influence diffusion concept with the Floyd model and is given by the following differential equation:

\[
\frac{dF(t)}{dt} = \frac{bF(t)(1 - F(t))^2}{1 - F(t)(1 - \sigma)} \quad (5)
\]

where \( \sigma \) is a constant with \( 0 \leq \sigma \leq 1 \). The model can be symmetric or non-symmetric since \( 0.33 \leq F(t_i) \leq 0.5 \).

**The Jeuland Model**

Jeuland (1981) proposed a model to overcome the assumption of Bass model that the potential adopters are homogeneous in their inclination in adopting the new product. He proposed the following model:

\[
\frac{dF(t)}{dt} = [a + bF(t)][1 - F(t)]^{1+\gamma} \quad (6)
\]

where \( \gamma \geq 0 \). When \( \gamma = 0 \), the model gets reduced to Bass model. The model can be symmetric and non-symmetric depending on the model parameters.

**Non-symmetric Responding Logistic (NSRL) Model**

This flexible model was proposed by Easingwood, Mahajan, and Muller (1981) which was to overcome the assumption that the impact of internal-influence between adopters and potential adopters remains constant over the entire diffusion process.
\[
\frac{dF(t)}{dt} = bF(t)^\delta [1 - F(t)]
\]  
(7)

where \( \delta = (1 + \alpha) \) and known as the non-uniform influence factor. The model can be symmetric and non-symmetric model and with the points of inflection lie between 0 to 1.0, which means the maximum purchase may occur at any time during the diffusion.

**Non-Uniform Influence (NUI)**

This Non-Uniform Influence (NUI) model was proposed by Easingwood, Mahajan, and Muller (1983). He proposed the following model:

\[
\frac{dF(t)}{dt} = [a + bF(t)^\delta][1 - F(t)]
\]  
(8)

The model has similar advantages to those of NSRL model and with the addition of external influence coefficient \( a \) in the model. The model reduces to NSRL model when \( a = 0 \).

**The Von Bertalanffy Model**

This model was developed by Von Bertalanffy (1957) and addresses the coefficient of internal influence as systematically changing over time as a function of penetration level. The model is given by the following differential equation:

\[
\frac{dF(t)}{dt} = \frac{b}{1 - \theta} F(t) [1 - F(t)^{(1-\theta)}]
\]  
(9)

with \( \theta \geq 0 \) and the model reduces to Mansfield model when \( \theta = 2 \) and Gompertz curve as \( \theta \) approaches 1. This model gives both symmetrical and non-symmetrical curves with the range of the points of inflection throughout the adoption process, from 0 to 1.0.

However, unlike the NSRL and NUI models which cannot provide simple explicit solution, this model gives solution of \( F(t) \) as follows:

\[
F(t) = \left[1 - e^{-(c+bt)}\right]^{\frac{1}{1-\theta}}
\]  
(10)

where \( c \) is a constant.

**The Nelder Model**

This model is proposed by Nelder (1962) and later addressed by McGowan (1986). The model is identical to Von Bertalanffy model when substituting \( \phi = \theta - 1 \) into the model. The model is given by the following differential equation:

\[
\frac{dF(t)}{dt} = bF(t)\left[1 - F(t)^\phi\right]
\]  
(11)

with an explicit solution as follows:

\[
F(t) = \frac{1}{1 + \phi e^\frac{c+bt}{\phi}}
\]  
(12)

**Flexible Logistic Growth (FLOG) Model**

This model was suggested by Bewley and Fiebig (1988). The model deals with dynamic internal influence in the diffusion process and given by:
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\[
\frac{dF(t)}{dt} = q \left[ (1 + kt)^k \right]^{n-k}
\]  

(13)

where \( \mu \) and \( k \) are constants. This model offers a closed-form solution and at the same time, allows flexibility in the internal influence like NSRL and NUI models.

A more detailed study on the comparison of flexible diffusion models, see Mahajan and Peterson (1985) and Mahajan et al. (1990).

**Diffusion Models’ Extensions**

Although the flexible diffusion models have provided better fits of new product growth curves. Bass model only includes advertising and word-of-mouth parameters and has a fixed number of potential adopters. Therefore the efforts to extend and refine both the fundamental and flexible diffusion models are enormous as discussed below.

**Market Potential**

The Bass model also assumed that the number of potential adopters, \( L \) is constant. However, there are various causes of the change of the market potential, such as the change of price (Kalish, 1985), number of households (Mahajan & Peterson, 1978), population growth (Sharif & Ramanathan, 1982), product profitability (Lackman, 1978), growth in the number of retailers (Jone & Ritz, 1991), as well as income distribution, price, and product uncertainty (Horsky, 1990).

In this category, where the market potential, \( L \) is dynamic function of time, the rate of adoption is given by the following differential equation:

\[
\frac{dN(t)}{dt} = [a + bN(t)][L(t) - N(t)]
\]  

and when \( L(t_0) = L_0, \ N(t_0) = N_0 \), the explicit solution (Mahajan & Peterson, 1978, 1982) is given as follows:

\[
N(t) = \frac{-a}{b} + \left( \frac{b}{a + bN_0} \right) + b \int_{t_0}^{t} e^{a(x-t_0) + bW(x)} dx
\]  

(15)

where \( W(t) = \int_{t_0}^{t} L(x)dx \).

The function \( L(t) \) will vary and in many cases, has to be determined empirically in the parameter estimation. In this case, in evaluating the adoption of washing machines in the United States, Mahajan and Peterson (1978) relate \( L(t) \) to the number of the households which depends on the growth of population \( P(t) \) which is given by:

\[
L(t) = k_1 + k_2 P(t)
\]  

(16)

This function is to provide a more accurate forecast on the adoption of innovations.

Kalish (1985), however, explored the occasion when the change in price would affect the number of potential adopters in the following way:

\[
L(t) = \int_{v=0}^{\infty} F_v(v)dv
\]  

(17)
where \( F_1(v) \) is the proportion (density) of individuals with valuation of product \( v \).

These potential adopters are spread over uncertainty of product's experience attributes, that \( v \) is represented by the ratio of the value of the uncertain product to the value under certainty. In the further model proposed by Kalish (1985) with the risk reduction over time, the potential adopters become:

\[
L(t) = L_0 e^{-k_1 P(t) + k_2 N(t) / L_0}
\]

where \( P(t) \) is the product price at time \( t \) and \( k_1 \) and \( k_2 \) are constants.

Horsky (1990) further the development of potential adopter estimation by involving the income distribution and willingness of the potential adopters to purchase based on the market price of products and given by:

\[
L = \frac{1}{\bar{w} + p + K - \delta}
\]

where \( \bar{w} \) is the average wage rate in the society, \( p \) is the average market price of the durable, \( K \) represents the importance or necessity of the product and \( \delta \) is the dispersion parameter on the distribution of individual wage.

Marketing Mix

This extension on marketing mix has been more widely studied than the other extensions due to the nature of the diffusion models themselves, which will include advertising, promotion and personal selling in both external and internal influences. As the presence of the price, advertising, promotion and personal selling, as well as distribution will affect the growth and diffusion of products directly. A review on price and advertising is conducted by Kalish and Sen (1986) but Mahajan and Wind (1986) argued that they lack empirical validation. Other extended models represent promotion or advertising (Horsky & Simon, 1983; Horsky & Mate, 1988; Simon & Sebastian, 1987), brand positioning (Krishnan & Bass, 1990), the impact of price (Horsky, 1990; Kalish, 1983a; 1985; Bass, et al., 1994; Mesak & Berg, 1995), distribution and integrated price, advertising and distribution (Mesak, 1996).

Promotion/Advertising. This is one of the most important components and has been integrated in the fundamental of diffusion model. However, the promotion and advertising is merely represented by a parameter for the external influence.

Horsky and Simon (1983) specifically evaluated the diffusion model in the advertising variables by looking into the relationship between the advertising expenditure and adoption of products. The model is given by the following differential equation:

\[
\frac{dN(t)}{dt} = (a + \zeta \ln A(t) + bN(t))[L(t) - N(t)]
\]

where \( \zeta \) is the parameter to measure the effectiveness of the advertising and \( A(t) \) is the level of producers' advertising expenditure at time \( t \).

Based on their research they also derived an optimal advertising policy, which shows that the manufacturer should advertise heavily in the initial periods to inform innovators about the existence of their products. Later, when the word-of-mouth effect become more significant, the advertising may be gradually reduced.

Simon and Sebastian (1987) further conducted an empirical study on the effect of advertising (based on the
expenditure of advertising) using data from an advertising campaign of the German telephone company. This model is improved in providing a more general case in the advertising expenditure by Dockner and Jørgensen (1988) and given as follows:

\[ \frac{dN(t)}{dt} = (a + \zeta f(A) + bN(t) + \tau f(A)N(t))[L(t) - N(t)] \]  
where \( f(A) \) is the advertising efficiency function at time \( t \) while \( \zeta \) and \( \tau \) are parameters to describe the effectiveness of the advertising on respective targets.

The proposed model fits the previous model by Horsky and Simon (1983) where \( f(A) \) is a logarithmic function and the value of \( \tau \) is zero. In the case of the model proposed by Thompson and Teng (1984), the advertising efficiency function, \( f(A) \) is linear or \( f'(A) \) equals 0.

**Price.** In the previous studies, research on the influence of price have focused on the way price affects the decision making in adopting innovations. The main groups in the affects are based on the influence of price change to the size of potential market, to the rate of diffusion, and to the coefficients of internal and/or external influences.

From the first group, Mahajan and Muller (1979) divided the total market into three categories:

1. untapped market, which thinks that the innovation is at an unaffordable price, i.e., the price is higher than the reservation price at time \( t \);
2. potential market, which thinks that the innovation is at an acceptable price but hopes that the price will decline, i.e., the price is equal to the reservation price at time \( t \);
3. current market, which has already adopted the innovation at time \( t \).

This is further elaborated by Kalish (1983b, 1985) who demonstrated the demand as a function of price and cumulative sales, representing the word-of-mouth and saturation effects. He proposed a model in which customers buy if the price of the product is less than its value to the customers, \( v \). He proposed the function of the market potential at price \( P \) as follows:

\[ N(P) = N_0 \int_{v=P}^{v} F_v(v) dv \]  
where \( F_v(v) \) is the proportion (density) of individuals with valuation \( v \).

This second group of studies on how price effects the diffusion model was initiated by Robinson and Lakhani (1975) who introduced price into Bass (1969) model as follows:

\[ \frac{dN(t)}{dt} = [a + bN(t)][L - N(t)]e^{-\omega P(t)} \]  
where \( \omega \) is a price sensitivity parameter and \( P(t) \) represents the price at time \( t \).

Parker (1992) proposed the diffusion model to include the price elasticity dynamics in either of the following cases:

\[ \frac{dN(t)}{dt} = [aP(t)^n(t) + bN(t)][L - N(t)] \]  
\[ \frac{dN(t)}{dt} = [a + bP(t)^n(t) N(t)][L - N(t)] \]  
where the price elasticity is defined as follow:
\[ \eta(t) = \eta_0 + \eta_1 t + \eta_2 t^2 \] (26)

With these two groups of price effects, we should be able to combine them to obtain a more accurate estimation in the diffusion process.

**Distribution.** There are only few papers dealing with the extension of diffusion models in distribution. The Bass (1969) model assumed that consumers are in control of their adoption process while the manufacturer functions only as provider of products. However, in the real life, adoption process is highly influenced by the distribution link in the market.

The difficulty in observing the distribution influence on the fundamental diffusion models is due to the lack of data in the retailers and/or distributors adoptions. Jones and Ritz (1991) proposed a study with the assumption that there are two similar adoption processes for any new product, one with the retailers adoption and another one with the consumers adoption processes. Internal and external information will flow from manufacturing to influence potential market of retailers in order to sell the product. Once the retailer has adopted the product for sale, they will influence potential market of consumers to purchase the product.

In their model, Jones and Ritz (1991) dealt mainly with the external-influence (advertising) diffusion model. The external-influence diffusion model applied here is given by:

\[ \frac{dN(t)}{dt} = a[pR(t) - N(t)] \] (27)

where \( R(t) \) is the cumulative number of retailers at time \( t \), and \( p \) is the number of adopters available through each retailer.

They proposed two mathematical models to describe the adoption process of distribution of new products:

First, simple mathematical model:

\[ R(t) = \bar{R} + (\bar{R}_0 - \bar{R})e^{-rt} \] (28)

The explicit solution becomes:

\[ N(t) = p\bar{R}(q - e^{-at}) + \frac{pa(\bar{R} - \bar{R}_0)}{a - r}(e^{-at} - e^{-rt}) \] (29)

where \( \bar{R}_0 \) is the initial penetration among retailers, \( \bar{R} \) is the total maximum potential retailers, and \( r \) is the individual transfer rate for retailers.

Second, advance mathematical model:

\[ R(t) = \bar{R} + (\bar{R}_0 - \bar{R}) \left[ \frac{1 - e^{-rt}}{1 + ke^{-at}} \right] \] (30)

The explicit solution becomes:

\[ N(t) = pe^{-at} \int_0^t R(u)e^{au} \, du \] (31)

In the same case, this model was found to provide a good fit to combined retailer-consumer data.

As Jones and Ritz have recognized, this field of research requires more data in the retailer adoptions of new products to enable interactive model above to be effective.
Model Limitation

From the above discussions on the review of diffusion models and the assumptions, there are many limitations to the models. However, further studies and research in diffusion models will grow and improve these models.

Since diffusion models have been primarily used to forecast and model product life cycle (Boswijk & Franscess, 2005), Mahajan and Wind (1986) compared the Bass model with other forecasting techniques, such as the Box-Jenkins approach. Although both of them can be used for short-term forecasting, diffusion model is theory-based with only a few data points required for parameter estimation while the Box-Jenkins is a data-driven model with more sophisticated parameter estimation.

For the derivations of diffusion models, Bass et al. (1994) provided some outline of principles:

1. The model should reduce to the Bass model under commonly observed conditions;
2. Diffusion curve with different set of decision variables would have similar shape to the Bass model, although curve would have been shifted;
3. Model should track irregular deviations of actual data from the smooth curve of the Bass model;
4. Model should maintain the essential carry through properties of the Bass model, such as an adoption today would increase adoption tomorrow through the influence of imitation (internal influence);
5. Model should yield a closed-form solution;
6. Model should be flexible and encompass a great variety of shapes.

Since the application of diffusion models is very extensive, the above principles should be used as guidelines for further extensions and refinements of the models.

Another important limitation of the models which has not been addressed is the uncertainty because new products lack of predictability, of structure, of information on the performance (i.e., success rate) of the product or technology. Consumers as potential adopters must often choose from among several available products to satisfy a particular need.

A New Model for Sales and Quality

In this section, we develop a new model for sales which incorporates the effects of claimed quality \( (q_c) \), actual quality \( (q_a) \) and perceived quality \( (q_p) \) on new product sale.

Potential Buyer Population

The potential population is comprised of two groups—“initiators” and “adopters”. Let \( L_1 \) and \( L_2 \) denote the number of potential initiators and adopters.

Initiators. The initiators buy the product based solely on the advertising and promotional effort of the manufacturer through the claimed quality. The total number of potential initiators, \( L_1 \), is a function of \( q_c \) and other marketing variables such as sale price \( (p) \), advertising effort etc. In the simple model we only consider quality and price as these two to capture the notion of value for money in the purchase decisions of initiators. As a result let the total potential initiators is given by \( L_1(q_c, p) \) with \( \partial L_1(q_c, p)/\partial q_c > 0 \) and \( \partial L_1(q_c, p)/\partial p > 0 \). \( L_1(q_c, p) \) is bounded (has an upper limit \( \bar{L}_1 \)) to reflect the fact that only a small fraction of the population are initiators.

Adopters. These are the potential buyers who buy the product only after the initiators have used the product
and communicate their perceived assessment of product quality. As such, the sales for adopters does not start till time \( T \) by which time the initiators who have purchased the product are able to assess the quality. \( T \) depends on the actual quality \( q_u \). As an example, if product quality refers to product reliability then \( T \) could depend on mean time to first failure or some other reliability measure. The total number of potential adopters, \( L_2 \), is a function of \( q_p(t) \) and other marketing variables such as sale price \( p \), advertising effort etc. As before, in the simple model we only consider quality and price as these two to capture the notion of value for money in the purchase decisions of adopters. As a result let the total potential adopters is a function of \( (q_c, q_u, q_p(T), p) \). The form of this will be discussed later in the section.

**Perceived Quality**

Perceived quality, \( q_p(t) \), changes with time. The initial perceived quality, \( q_p(0) \), is influenced by several factors and these can include manufacturer’s reputation as seen through the quality of earlier products. As the initiators use the product, they learn more about its actual quality. As a result, the perceived quality at time \( t \), \( q_p(t) \) is a function of the actual quality and a learning parameter \( \lambda \). We assume that \( q_p(0) < q_u \) so that the initiators, although willing to try the new product, are conservative in their initial perceived quality. A simple way of modeling the learning effect is through a first order differential equation given below:

\[
q_p(t) = q_p(0) + [q_u - q_p(0)][1 - e^{-\lambda t}]
\]

(32)

Note that as time progresses \( q_p(t) \to q_u \) so that the true quality is revealed. \( \lambda \) (\( > 0 \)) is the learning parameter. Smaller the value of \( \lambda \), longer is the time that customers need to get a good assessment of the actual quality. Note that \( T \) and \( \lambda \) are inversely related to each other and we assume \( T = 1/\lambda \).

**Effect of Actual and Claimed Quality on Potential Adopter Population**

The claimed quality can be different from the actual quality for reasons discussed earlier in the section. This has a significant impact on the potential adopter population. The perceived quality at \( T \) provides information whether \( q_c > q_u \), \( q_c = q_u \) or \( q_c < q_u \). If \( q_c > q_u \), then it should lead to a reduction in \( L_2 \) due to the negative effect since the manufacturer’s claimed quality is not true. However, when if \( q_c < q_u \), it should lead to an increase in \( L_2 \) due to the positive effect that the actual quality is better than the manufacturer’s claimed quality.

We model this as follows through a variable \( z \) defined as follows:

\[
z = \left[ \frac{q_p(T) - q_p(0)}{q_u - q_p(0)} - \frac{e - 1}{e} \right]
\]

(33)

From equation (32) we have:

\[
\frac{q_p(T) - q_p(0)}{q_u - q_p(0)} = \frac{e - 1}{e}
\]

(34)

Using equation (34) in equation (33) yields:

\[
z = \frac{[q_p(T) - q_p(0)][q_u - q_c]}{[q_c - q_p(0)][q_u - q_p(0)]}
\]

(35)

As a result, we have the following:

1. \( z = 0 \) when \( q_c = q_u \);
2. \( z > 0 \) when \( q_c < q_u \);
(3) $z < 0$ when $q_c > q_a$.

We model $L_2$ as a function of $z$ (an indicator of manufacturer's claimed quality relative to the actual quality) and the sale price $p$ so that is given by $L_2(z, p)$. $L_2(0, p)$ represents the potential adopter population when the manufacturer reveals the true quality so that the claimed quality is the same as the actual quality. $L_2(z, p)$ decreases as $z$ gets more negative (capturing the negative effect resulting from claiming the quality better than the actual) and increases as $z$ gets more positive as shown in Figure 1.

Note that there is an upper limit, $L_{2,\text{max}}$, to $L_2(z, p)$ as $z$ gets more positive implying that the manufacturer can increase his potential sales only by a finite amount by using the strategy $q_c < q_a$. If $q_c > q_a$ then the potential adopter population can become zero.

![Figure 1. Effect of $z$ on the potential adopter population.](image-url)

**Modelling Sales Over Time**

**Sales to initiators.** The sales to initiators start from the time instant at which the product is launched on to the market. Let $t = 0$ represent the time of the launch and let $N_1(t)$ is the number of sales to initiators by time $t \geq 0$. We model this using the Fourt and Woodlock model so that the sales rate at time $t$ is given by the following model:

$$\frac{dN_1(t)}{dt} = a_1[L_1(q_c, p) - N_1(t)]$$

with $N_1(0) = 0$. The parameter $a_1$ is a function of advertising effort but in the simplest model it can be treated as a constant. $L_1(q_c, p)$ is the total initiator population and its structure has been discussed earlier.

**Sales to adopters.** The adopters do not buy till time $\bar{t}$. Let $N_2(t)$ be the number of adopters who have bought the product by time $t \geq \bar{t}$. The sales rate is modeled by the Bass diffusion model so that it is given by:

$$\frac{dN_2(t)}{dt} = \{a_2 + b_1N_1(t) + \bar{b}_2N_2(t)\}[L_2(z, p) - N_2(t)]$$

with $N_2(\bar{t}) = 0$. The parameters $b_1$ [$\bar{b}_2$] represent the word-of-mouth effect resulting from the initiators.
[adopters] who have bought the product by time \( t \). In the simplest model these can be treated as constants. In a more complicated model, they can be functions of variables such as \( z \) and others.

**Total sales over time.** The total sales over time is given by:

\[
N(t) = \begin{cases} 
N_1(t) & t < \bar{t} \\
N_1(t) + N_2(t) & t \geq \bar{t}
\end{cases}
\]  

(38)

**Model analysis.** It is not possible to derive analytical expressions for \( N(t) \). One would need to use computational scheme to obtain a plot of it for a specified set of parameter values.

**Conclusion**

In this paper we studied the effect of the three product quality notions that are associated with marketing of a new product—claimed quality \((q_c)\), actual quality \((q_a)\) and, perceived quality \((q_p)\), on product sales. Our focus with regards to these three notions is in the context of the product reliability. As reliability is performance over time, then perceived quality \((q_p)\) changes with time.

There are two groups of potential buyer population, initiators and adopters. The first group is the one who buy the product based on the advertising and promotional effort of the manufacturer through the claimed quality. The second group is the potential buyers who buy the product only after the initiators have used the product and communicate their perceived assessment of product quality.

In our simple model the total number of potential initiators, \( L_1 \), is a function of \( q_c \) and sale price \((p)\). While the total number of potential adopters \( L_2 \), is a function of \( q_p(t) \), \( q_c \), and \( q_a \). Perceived quality at time \( t \), \( q_p(t) \) is a function of \( q_a \) and customer’s learning. The \( q_c \) can be different from the \( q_a \). It could be either \( q_c = q_a \), \( q_c > q_a \) or \( q_c < q_a \). If \( q_c > q_a \), then it should lead to a reduction in \( L_2 \) due to the negative effect since the manufacturer’s claimed quality is not true. However, when if \( q_c < q_a \), it should lead to an increase in \( L_2 \) due to the positive effect that the actual quality is better than the manufacturer’s claimed quality. Therefore, the study shows that to improve the total number of sales, in the context of product quality improvement, manufacturers need to increase the actual quality \((q_a)\).

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