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A novel Bass-type model for product life cycle quantification using aggregate market data

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ABSTRACT

Product Life Cycle (PLC) is a widely accepted concept that has been given significant attention in operations management and marketing literature. However, its quantification remains a major challenge. This study aims to develop a unique and original analytical model for quantifying PLCs using aggregate market data. The Bass diffusion model is used to forecast consumers' first purchases of the product. Next, the Novelty–Loyalty Based Consumer Utility (NLBCU) theory, which has a confirmed neuropsychological basis, is used to model repeat (or replacement) purchases. The unique contribution of this work is that it synthesizes the prevailing innovation diffusion theory and the NLBCU theory to provide a distinct, dynamic and endogenous perspective on consumer purchasing behavior across the entire PLC. The model's advantages include its simple mathematical formulation, its minimal use of data and its harmony with the predominating ideas of the innovation diffusion literature. Through simulation studies and empirical investigations, the descriptive power and data-fitting performance of the model are demonstrated.

1. Introduction

The Product Life Cycle (PLC) concept has been given significant attention in both operations management and marketing literature. It is universally accepted that determining the PLCs of a firm's and its competitors' products can be advantageous (Cox, 1967). However, quantifying PLC remains a challenge, primarily because it has displayed a variety of patterns in practice (e.g., Rink and Swan, 1979; Midgley, 1981). This prevents the concept from becoming a verified scientific theory. Therefore, finding a proper way to forecast PLC has significant implications for both managerial practice and theoretical development.

Previous attempts to quantify PLC have been made by many scholars, e.g., Cox (1967), Polli and Cook (1969), Bass (1969), Harrell and Taylor (1981), Easingwood (1987), Klepper (1996), Thomassey (2010), Qin and Nembhard (2012). One of the most influential modeling approaches is the Bass model (Bass, 1969), which is used to predict a product's first purchases (Bass, 1969; Dodds, 1973) using aggregate market data. However, due to the exclusion of *repeat purchases*, the Bass model is not suitable for long-term sales forecasting (Kamakura and Balasubramanian, 1987; Hyman, 1988) and is therefore unable to quantify the entire life cycle of a product.

Traditional approaches to repeat purchase modeling belong to one of the two types: (1) *depth-of-repeat* models that use consumer panel data and (2) *aggregate sales* models that employ aggregate market data. The depth-of-repeat models closely examine the repeat purchase process by categorizing consumers into different segments according to their respective repurchasing frequencies over a specific period (e.g., Fourt and Woodlock, 1960; Eskin, 1973; Kalwani and Silk, 1980; Goodhardt et al., 1984; Uncles et al., 1995). This type of model is considered data-intensive because many observations are required to construct the model (Olson and Choi, 1985). Aggregate sales models, however, use aggregate market data and require fewer observations (Olson and Choi, 1985). Dodson and Muller (1978) conducted the most influential work on repeat purchase modeling using aggregate market data, and their research was followed by a large number of relevant studies (e.g., Mahajan and Peterson, 1979; Lilien et al., 1981; Muller, 1983; Blackburn et al., 1984; Mahajan et al., 1984; Norton and Bass, 1987; Rao and Yamada, 1988; Hahn et al., 1994; Ataman et al., 2008; Chien et al., 2010). Most of these studies used the Bass model to predict the first purchases and assumed that the number of repeat purchases was proportional to the number of individuals in the current repeating population by including an exogenous constant coefficient (Olson and Choi, 1985). This procedure allows a reasonable interval of the PLC to be forecasted (Steffens and Balasubramanian, 1998). However, some scholars (e.g., Lawrence and Lawton, 1981; Olson and Choi, 1985; Kamakura and Balasubramanian, 1987) have criticized the *proportional-to-repeating-population* rule,

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claiming that a *repeat* specification is more consistent with the repeat purchase behavior observed for nondurable products, whose consumption is relatively quick; for durable products using the "replacement purchase" concept is more appropriate. The primary difference between the replacement purchase and repeat purchase concepts is that for the former, the service life of the durable product must be taken into account (Kamakura and Balasubramanian, 1987). In addition to the prevailing depth-of-repeat and aggregate sales models, Albuquerque and Nevskaya (2012) have recently proposed a model that uses individual-level data to explain product usage in categories characterized by frequent changes and progressive consumer involvement. This model does not retain the basic structure of the traditional Bass-type diffusion models and is quite data intensive because it requires individual level data.

Bass (2004) states that "simple and elegant mathematical models, often referred to as *beautiful*, that match well with the studied phenomenon will have appeal in the arena of competing ideas about the phenomenon". He attributes the influence of the Bass model in both operations management and marketing to this "beauty". To follow the track of Bass (1969), this study develops a simple but unique mathematical model using aggregate market data to address the PLC forecasting problem by (1) using the Bass model to forecast the first purchases and (2) using the Novelty–Loyalty Based Consumer Utility (NLBCU) theory to model repeat (or replacement) purchases. This model makes several key contributions to the literature. First, unlike the *proportional-to-repeating-population* rule adopted by the traditional aggregate sales models in which an exogenous constant repurchasing rate is assumed, the NLBCU theory postulates a time-varying repurchasing rate that depends on the time after product adoption (i.e., after the first purchase). This theory is supported by neuropsychological research and provides a distinct, dynamic and endogenous perspective for examining the repeat (or replacement) purchasing problem. This method reveals the underlying drivers of consumer repurchasing behavior across the entire PLC and addresses the sales forecasting problem by asking "why" rather than "how much". Second, compared to the depth-of-repeat models and Albuquerque and Nevskaya's model (2012), the model proposed in this study has a simpler mathematical formulation, requires fewer observations, and retains the basic characteristics of the Bass model, which makes it compatible with the predominating ideas of innovation diffusion literature. Finally, this model is capable of replicating many of the PLC patterns observed in the real world.

The paper is organized as follows: first, we introduce the theoretical background for product repurchase modeling. Next, we present two versions of the model with repeat and replacement purchases respectively, to account for both nondurable and durable products. We also conduct numerical simulations to demonstrate the descriptive power of the model. Then, we conduct empirical studies on real data sets to demonstrate the model's data-fitting capacity. Finally, we discuss results and draw conclusions.

2. Theoretical background

Novelty seeking and loyalty seeking are human instincts that pervade the human behavior. The most striking example of these instincts in operation is the phenomenological conflict between the *Coolidge effect* and *pair bonding*. The Coolidge effect describes a phenomenon demonstrated by all mammalian species, namely, that individuals exhibit renewed sexual interest in new sexual partners but become unresponsive to the ones that they have mated with (Reber et al., 2009). Paradoxically, monogamy, not polygamy, is the dominant form of marriage in modern human society, which suggests the power of pair bonding. Another prominent example of the influence of these instincts is observed in the consumer behavior. Consumers exhibit novelty-seeking by desiring new product attributes (e.g., Faison, 1977; Hirschman, 1980; Manning et al., 1995; Kahn, 1995; Coombs and Avrunin, 1977; Menon and Kahn, 1995; Caro and Martínez-de-Albéniz, 2012). However, they also build purchasing loyalty to specific products or brands (e.g., Dick and Basu, 1994; Bowen and Chen, 2001; Alhabeeb, 2007). There is a genetic explanation for the two conflicting instincts: while dopaminergic genes, like D4DR and C-521T, motivate the human novelty-seeking behavior (Ebstein et al., 1996; Benjamin et al., 1996; Okuyama et al., 2000; Munafò et al., 2008), the neurohypophyseal peptide oxytocin stimulates contrary behaviors, including affiliation, trust, love and loyalty (Young et al., 1998; Kosfeld et al., 2005; Kringelbach and Berridge, 2009; Academy and Rubino, 2011). In other words, novelty-seeking and loyalty-seeking are co-existing but contradictory human instincts controlled by "hormones" whose interaction forms the neuropsychological basis of the NLBCU theory. Hereafter, the terms *novelty effect* and *loyalty effect* will be used to represent the novelty-seeking and loyalty-seeking motivations which govern the consumer repurchasing behavior. The NLBCU theory is also analogous to the satiation and habit formation (SH) theory in consumer psychology. The SH theory explains how satiation and habit formation affect the utility of consumption (e.g., Solomon, 1980; Becker, 1992; Read et al., 1999). Building upon the SH theory, Baucells and Sarin (2010) proposed a utility prediction model in which the time-dependent consumer desire for repeat consumption is determined by the joint effects of satiation and habit formation. As the time goes, the satiation level of the consumer on the product will increase (i.e., the novelty effect will decrease), and the habituation level (i.e., loyalty effect) will increase. Here, it should be noted that the NLBCU theory is not completely equivalent to the SH theory because loyalty-seeking is slightly different from habit formation. First, loyalty-seeking is an active behavior, while habit formation is essentially passive. Second, loyalty-seeking stresses the pleasant feelings that affiliation, trust, love and loyalty can inspire (positively oriented), while habit formation focuses on the discomfort of changing one's habitual consumption patterns (negatively orientated), no matter if the habit can still bring enjoyment. According to the famous Freudian pleasure principle, "people seek pleasure and avoid suffering in order to satisfy their biological and psychological needs" (Snyder and Lopez, 2006). Just as it is assumed that most people remain married because it provides a feeling of happiness (and is not just a habit), consumers who are loyal to a product are also assumed to obtain enjoyment from it (e.g., in terms of function familiarity for ease use, happiness from emotional attachment). Although there are theoretical differences between the NLBCU and SH theories, because the underlying principles in terms of modeling are highly correlated, the two theories will be treated interchangeably in this paper.

In this study, we first use the Bass model to predict the first purchases in the market. According to their respective time of the first purchases, consumers are categorized into different *purchasing segments*. The repurchasing rate (i.e., the average number of repurchased units at a time point) depends on the novelty and loyalty effects which are decreasing and increasing functions of the time duration after product adoption (i.e., the first purchase). Therefore, consumers who have adopted the product at the same time point will have the same repurchasing rate over the time horizon. Like most studies on aggregate sales models, this study assumes that the consumers in the market are homogeneous. Fig. 1 shows a demonstration example (a discrete analog) of the time-varying repurchasing rate for consumers who have adopted the product in period 5.