Demand Estimation When There Are Unobservable Substitutions Amongst Choice Alternatives

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ABSTRACT

Product stock-outs and the resultant purchase of substitutes by customer is common in retail. These stock-out lead to censored sales data; the observed demand for products with stock-outs could be lower that the true demand for the same while the observed demand for the substitutes could be inflated. If historical sales data is used to forecast future demand for a product without accounting for stock-outs, it could lead to errors in demand forecasting on account of misspecification. In this paper, we demonstrate the need and the benefits of data unconstraining and develop a data unconstraining method to address the dual issues of estimation of demand and substitution rates when there are unobserved substitutions among choice alternatives. We compare the effectiveness of the proposed technique by comparing it against the popular techniques available in extant literature.

KEYWORDS
Censored Data, Data Unconstraining, Demand Estimation, Retail Assortment Planning, Substitution Rates

INTRODUCTION

Stock Keeping Unit (SKU) level demand forecasts provide critical inputs to the retailers for a variety of category management decisions such as those related to managing the assortment and inventory (Agrawal and Smith 1996; Anupindi, Dada et al. 1998). However, obtaining these SKU level forecasts is inherently difficult. Other than macro-economic factors, seasonality, trend, and actions linked to marketing and trade promotions that may impact different SKU’s differently, the fact that the SKU level historical sales data could be censored further complicates the forecasting problem. Temporary stock-outs at retail stores and the resulting substitutions that the customers make impacts the observed sales of SKUs-the sales data of SKUs that encounter a stock-out; their observed sale data are right-censored while the sales of other products that were available during the time period are inflated because of substitutions. If historical sales data is used to forecast future demand for a product without accounting for stock-outs in it and its closest substitutes, it could lead to errors in forecasting on account of misspecification (Stefanescu 2009). The goal of unconstraining right-censored sales data (in the present context) is to systematically derive accurate demand forecasts from the observable sales data-some of which may be censored.

Stock-out is a regular phenomenon for grocery shoppers. The percentages of stock-out occurrences regularly vary among 5% (The Netherlands), 7% (France), and 8% (United States) of the total SKU

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level of supermarkets (Andersen Consulting 1996; Food Magazine 1999; Roland Berger Strategy Consultants 2002). Several previous studies (Mason and Wilkinson 1976, Progressive Grocer 1968a and 1968b) report similar or higher levels of stock-outs at retail in grocery markets and high level of resultant substitution (48%–83%). Gruen et al., 2002 report that stock-outs happen on about 8.3% of the purchase occasions and substitution occurs on 45% of these purchase occasions. Anupindi et al., 1998 found that demand rates estimated naively by using observed sales rates are biased even for items that have very few occurrences of stock-outs. The need for data unconstraining is therefore neither rare nor is it insignificant for retailers who have low levels of stock-outs. If no attempt is made to unconstraint censored data prior to using it in estimating demand, then there may be undesired consequences. Sources from the airline industry showed that use of censored historical booking data for demand forecasting results in a poor strategy that leads to a systematic degradation of revenue management (RM) controls over time known as ‘revenue spiral down’ (Cooper, Homem de Mello et al. 2006). Weatherford and Polt (2002) showed that upgrading the unconstraining process can lead to revenue gains of 2-12 percent by means of actual booking data from a major US airline. Therefore, it is important to unconstraint censored data in forecasting demand.

In this paper, we develop an algorithm that un-constrains the censored sales data and generate accurate SKU level demand estimates. We visualize this problem as one de-convoluting the true historical demand and the spilled demand from the historical sales data. Given censorship (inventory levels), historical sales data for all products in a category, and the complete substitution rate matrix, this paper build on the approach presented in (Kökk and Fisher 2007; Vulcano, van Ryzin et al. 2010) to provide a systematic approach to de-convolute the true historic demand and the spilled demand.

The rest of the paper is organized as follows. We describe the various methods that are used for data unconstraining in the revenue management (RM) and retail sector in Section 2. Thereafter, we describe our proposed data unconstraining approach in Section 3 and compare its performance with results obtained from using some of the key approaches that are presented in Section 2. Section 4 also provides the comparison of estimation results for different substitution structures. Conclusions and future research are provided in Section 5.

**BACKGROUND**

Demand estimates are crucial to many research and application areas, such as assortment planning, revenue management, and inventory management. The potential for demand estimation to create significant savings for firms (see Talluri and Van Ryzin 2004; Stefanescu 2009; Agrawal and Smith 1996; Zhang and Wang 2017) has led to strong interest in research for improving the accuracy of the estimation. However, this task is inherently difficult. This is because a consumer’s demand is influenced by many factors such as manufacturer’s pricing and marketing, competitive actions, seasonality, and changes in macro-economic trends. In the context of assortment planning and revenue management, the possibility of stock-out induced censoring and substitutions further complicates the estimation. Stock-out induced abandonments and substitutions cause the recorded sales of products with stock-outs to be lower (truncated) than the actual demand while the recorded sales of products that did not encounter stock-outs could be higher than the actual demand. Therefore, the historic sales data can be systemically different from the demand and this could lead to biased forecasts if no corrections are made.

Currently, researchers either take a pure statistics/data driven approach or a consumer behavior centric approach to estimate the demand side parameters using truncated data. The pure data driven approaches are more popular in revenue management where the focus is more on the accuracy of estimation of demand and less so on the substitution probabilities between options. The assortment planning literature however also focuses on understanding the drivers of consumer preference and the substitution structure within a known choice set and hence consumer behavior centric approaches are preferred. In this paper we focus on consumer behavior centric approaches to estimating the demand
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