A Reference Point Logit Model for Estimating Substitution Probabilities Using Point of Sale Data

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ABSTRACT

This article presents a practical approach to estimate the substitution probabilities between products at a retail store by using the store’s point of sale data and prospect theory based structural restrictions on the consumer choice behavior. The prospect theory-based reference dependent preference structure imposed on the consumer choice behavior (a) accounts for how consumers make their original choice as well as how they substitute, (b) eliminates the IIA and IPS assumptions that the standard utility theory based models impose on consumer choice, and (c) alleviates the need for inventory information for estimating the substitution probabilities. Simulations and empirical studies have been used to show that the estimates of the substitution probabilities are efficient and are robust to stock-out rates.

KEYWORDS

Assortment Planning, IIA, IPS, Reference Dependent Preferences, Substitution Probabilities

1. INTRODUCTION

Assortment planning helps retailers decide what products and how many units of each product to stock. It presents an opportunity for retailers to improve profitability through reducing stock-out linked abandonment, decreasing the frequency and depth of markdowns, decreasing the variance in forecasts, and improving the overall efficiency of their supply chain. Several researchers have shown the link between improved assortment plans and improvements in financial metrics. For example, Kök and Fisher (2007) report gains of $155 million in profitability for a grocery chain through improved product availability. Rajaram (2001) reports a 40% increase in profits for a catalog retailer through reduced markdown, and Fisher et al. (2001) report a 100% increase in profits for a large retailer through assortment optimization. Besides these immediate benefits, results also suggest that improvements in assortments lead to an increase in the satisfaction levels amongst buyers which has long-term implications for the retailer (Broniarczyk et al. 1998; Sloot et al. 2006).

Accurate estimates of the demand side parameters, namely the future demand for products and the substitution probabilities among products are two key inputs for generating good assortment plans. However, the task of estimating these two quantities can be difficult due to the limitations in the data collected at most retail stores. Information on non-purchase occasions’ and whether the product that was sold was what the consumer actually wanted or if it was a substitute is seldom collected by retailers. Therefore, the recorded sales of products that encounter stock-outs are lower than the demand for those products (and the data presents truncated demand information) while the recorded

DOI: 10.4018/IJISSCM.2018100102

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sales of products that are used as substitutes are exaggerated. Cooper et al. (2006) show that ignoring the truncation and/or the exaggeration in sales while using historical sales data for making future assortment plans could lead to a systematic increase in the gap between what the consumers want versus what the retailers think they want and this gap impacts the retailer’s revenues. Estimation of the demand side parameters therefore relies on supplementing the sales data with extra information such as the inventory data and non-purchase rates to account for the unobserved truncations as well as substitutions. However, these datasets are oftentimes unavailable or even inaccurate. Our objective in this paper is to develop a practical approach to estimate the substitution probabilities between products using store level point of sale (POS) data that is supplemented with structural restrictions on the consumer’s choice behavior. The structural restrictions account for the impact of the unobserved truncation and substitutions.

In this paper, we propose a prospect theory-based reference dependent preference structure to model a consumer’s choice. Prior research has established that (a) prospect theory offers a realistic framework for modeling a consumer’s choice when there is limited information and/or time pressure (Thaler 1980), and (b) the inclusion of reference dependency in preferences unifies the concepts of consumption utility and gain-loss utilities under one framework (Köszegi and Rabin 2006) thereby making the classic utility a special case of the prospect theory based preference. The reference dependent preference structure also enables the relaxation of two contentious (in assortment planning literature) assumptions of independence of irrelevant alternatives (IIA) and invariant proportion of substitution (IPS) that classic utility theory-based models such as the multinomial logit (MNL) models impose on a consumer’s choice behavior.

The proposed reference dependent preference structure makes two modifications to the classic reference point models. First, it makes the reference “point” to be product dependent and yields a set of reference points, one for each product in the consumers’ choice set. This modification enables us to explicitly incorporate into the model the assumption that when consumers substitute, they are likely to give a higher preference to products that are similar to their original choice. These product-specific reference points also make the substitution probabilities product dependent.

Next, the proposed reference dependent preference structure uses the link between substitutability and similarity of products (Gaur and Honhon, 2006) to define the reference points in terms of substitution probabilities. The proposed model can therefore estimate the substitution probabilities between products without the need for tracking and tagging stock-outs and alleviates the need of inventory information for estimation.

The paper is organized into five sections. Section 2 provides a brief literature review. Section 3 provides information about the proposed reference point logit (RPL) model and the estimation procedure. The results are presented in Section 4. We use simulations to establish: (1) that the parameters of RPL are identified; (2) that RPL leads to efficient as well as robust estimates; (3) precision of the substitution probabilities estimated using RPL converge asymptotically to the precision obtained under the hypothetical condition of availability of complete information about the consumers’ choices process; and (4) RPL performs better than the MNL as well as other models that rely on exogenously imposed substitution structures. We also exemplify the use of RPL through two empirical studies that use actual POS data on coffee and potato snack categories. Though researchers such as Karabati et al. (2009) have addressed the issue of estimating the demand side parameters using POS data, issues such as identification and efficiency are not addressed for finite size data. Only claims of “satisfactory” as against efficient estimates have been made. We present the conditions under which the RPL estimates are efficient under the assumption of finite sample size. Section 5 outlines the conclusions, limitations and topics for future research.
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