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# Estimation of Consumer Demand with Stock-Out Based Substitution: An Application to Vending Machine Products

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## Abstract

The occurrence of temporary stock-outs at retail is common in frequently purchased product categories. Available empirical evidence suggests that when faced with stock-outs, consumers are often willing to buy substitute items. An important implication of this consumer behavior is that observed sales of an item no longer provide a good measure of its core demand rate. Sales of items that stock-out are right-censored, while sales of other items are inflated because of substitutions. Knowledge of the true demand rates and substitution rates is important for the retailer for a variety of category management decisions such as the ideal assortment to carry, how much to stock of each item, and how often to replenish the stock. The estimated substitution rates can also be used to infer patterns of competition between items in the category. In this paper we propose methods to estimate demand rates and substitution rates in such contexts.

We develop a model of customer arrivals and choice between goods that explicitly allows for possible product substitution and lost sales when a customer faces a stock-out. The model is developed in the context of retail vending, an industry that accounts for a sizable part of the retail sales of many consumer products. We consider the information set available from two kinds of inventory tracking systems. In the best case scenario of a perpetual inventory system in which times of stock-out occurrence and cumulative sales of all goods up to these times are observed, we derive Maximum Likelihood Estimates (MLEs) of the demand parameters and show that they are especially simple and intuitive.

However, state-of-the-art inventory systems in retail vending provide only periodic data, i.e., data in which times of stock-out occurrence are unobserved or “missing.” For these data we show how the Expectation-Maximization (EM) algorithm can be employed to obtain the MLEs of the demand parameters by treating the stock-out times as missing data. We show an application of the model to daily sales and stocking data pooled across multiple beverage vending machines in a midwestern U.S. city. The vending machines in the application carry identical assortments of six brands. Since the number of parameters to be estimated is too large given the available data, we discuss possible restrictions of the consumer choice model to accomplish the estimation. Our results indicate that demand rates estimated naively by using observed sales rates are biased, even for items that have very few occurrences of stock-outs. We also find significant differences among the substitution rates of the six brands.

The methods proposed in our paper can be modified to apply to many nonvending retail settings in which consumer choices are observed, not their preferences, and choices are constrained because of unavailability of items in the choice set. One such context is in-store grocery retailing, where similar issues of information availability arise. In this context an important issue that would need to be dealt with is changes in the retail environment caused by retail promotions.

*(Demand Estimation; Maximum Likelihood; Vending; Poisson; Stock-Outs; Substitution; EM Algorithm; Inventory Management)*