Demand Learning and Dynamic Pricing for Multi-Version Products*

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Extended Abstract

Dynamic pricing deals with demand-management decisions and the required methodologies and systems for making these decisions. The demand function is an important element in such decision makings. While most papers assume that the provider is aware of the demand function, this is rarely the case in practice; indeed, market uncertainty is prevalent in most cases. This unrealistic assumption is one of the reasons that, despite the enormous amount of data made available to decision makers, intelligent systems that balance the supply and demand and improve profits have found limited use in the industry. In addition to the manager's experience of the market based on historic sales, managers incorporate sales to update demand estimates. This is known as demand learning.

A major source of motivation for this paper is the case of demand learning in the event management industry, where event tickets are priced over time and demand is uncertain. Events include, but are not limited to, sports, concerts, and theater shows. In particular, we consider tours of unique events that are organized in different cities. In these cases, uncertain demand plays a major role in decisions regarding new shows.

In this business environment, capacity provider needs to learn two elements of demand: market size and the core value of the event, to properly price different variants of the product. Market size means the expected number of interested

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customers for the event, or what is referred to as the arrival rate. The core value of an event refers to the value of the performance, i.e., the customers' willingness to pay to see the performance. The core value is usually unknown. Seats in specific locations are assumed to have values that are known multiplier of the core value. These multipliers depend on the seat location and are assumed to be the same for all events in a specific category. By analyzing previous event ticket sales data and owing to her experience, the capacity provider is usually aware of the premium/discount effect of each seat location, e.g., balcony compared to orchestra, on the total value of the event perceived by customers. We do not assume any specific relation between the core value and the provider's costs; we also assume that the provider's variable cost is negligible. We use market prices and sales information to learn the arrival rate and the core value during the sales horizon.

To model this situation, we consider a capacity provider who offers multiple versions of a single product, such as different seat locations for an event. We assume that the different versions share an unknown core value and command a known premium or discount relative to the core value. Customers arrive at an unknown arrival rate during a finite sales horizon. We assume that the provider has some initial belief and prior knowledge about the arrival rate which is updated using Bayesian rule. Estimates of the core value are updated using maximum likelihood estimation. We describe an analytical framework to model the process of learning and pricing and apply this framework to address a practical problem. The main contributions of this paper can be summarized as follows.

First, we apply our framework to cases where there exist more than one version of a product. This is in contrast to the models of most previous studies that assume a single version. The literature focus on one-version products is, in part, due to the fact that models considering customer behavior when choosing from different versions of a product are relatively new. In the present study, we use the theory of multinomial logit (MNL) choice to model customers' behavior in choosing from different versions. This theory not only accurately models the real world by capturing the stochastic nature of customers' choice but is also analytically tractable, and can be easily estimated.

Second, we consider the case where both the arrival rate and the core value are unknown and should be estimated. Most previous studies assume that there exists only one unknown feature of demand: either the arrival rate or the core value. The reason behind this limitation may be the mathematical complications that arise from the combination of learning two unknowns. If we are not aware of the arrival rate and the core value, we cannot estimate the missed demand, i.e., interested customers who choose not to buy any version of the product because they cannot afford to buy it. This case is more realistic because the missed demand usually cannot be estimated in practice.

In this paper, we propose a method to learn demand and price a multi-version product. We show how to simultaneously estimate the unknown parameters as the sales evolve and how to price the products to maximize revenues under a rolling horizon framework. The following figures show the effectiveness of the proposed method in this case when demand is time variant. The demand is assumed to be of the quadratic form, consistent with Bass models. As we can see, the error percentage converges to zero as time increases. Moreover, we observe that with the increase of the prior coefficient of variation, C.V., the learning becomes more effective and the gap between the prior assumptions and the reality decreases more quickly. This means that a more diffuse prior, or a higher C.V., results in faster convergence. A higher C.V. can be interpreted as a lower confidence in the prior parameters.

Key Words: Demand Learning, Dynamic Pricing, Multinomial Logit Choice, Bayesian Update, Maximum Likelihood Estimation.

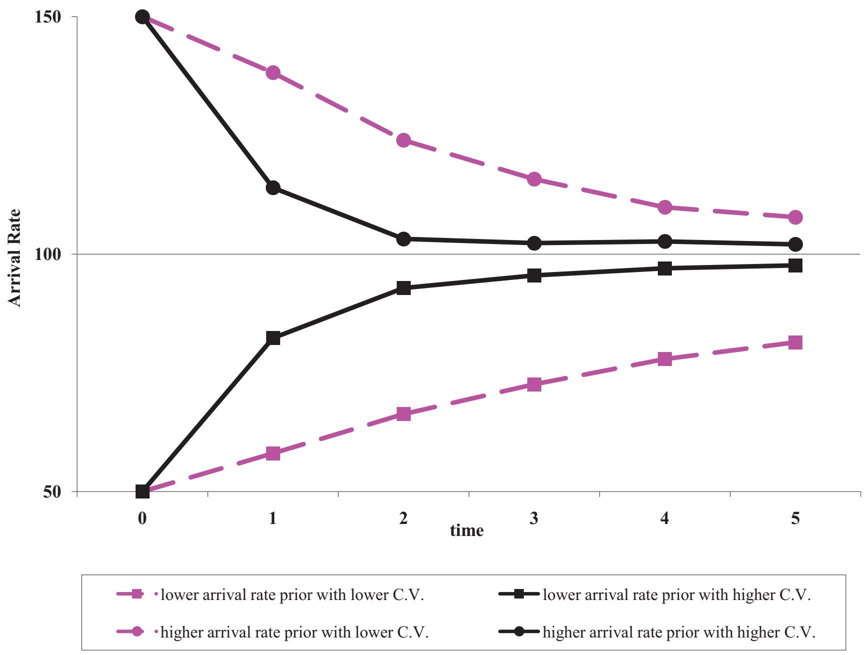

Figure 1: Effect of prior C.V. on learning arrival rate

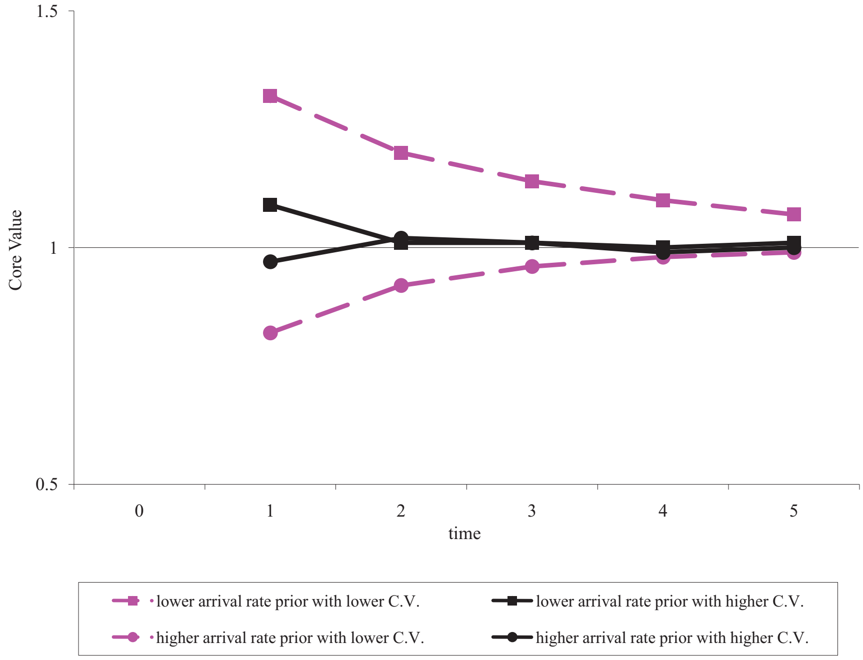

Figure 2: Effect of prior C.V. on learning core value