Integrated Segmentation of Supply and Demand with Service Differentiation

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Abstract The presented research addresses the integrated segmentation of supply and demand with service differentiation by means of service-level menus. To this end, it establishes a joint perspective on the market side—that is, prices and service levels—and the operations side—that is, the inventory management policy and the corresponding parameters. This joint perspective comprises analyzing when the introduction of a service-level menu increases profits over those of a single undifferentiated offering and how to design optimal service-level menus. Surprisingly, in many cases service differentiation does not increase profits significantly. One way to interpret this finding is that differentiating customers based on service levels alone is a weak differentiation lever only, that is, the price differences between offerings with differing service levels need to be small in order to prevent customers from switching to offerings with lower prices and service levels. Therefore, successful price differentiation requires service differentiations being supported by presence of additional conditions or measures (e.g., pricing restrictions or further differentiation levers). Indeed, it is possible to show that service differentiation can significantly increase profits if the company experiences pricing restrictions.

1 Introduction

This article presents the author's Ph.D. thesis [3], which has been awarded the dissertation price of the German Operations Research Society (GOR) during the OR conference 2016 in Hamburg. This thesis addresses the integrated segmentation of supply and demand with service differentiation by means of service-level menus. The following sections provide an introduction to the topic of service differentiation (Sect. 2) and an overview of some of the thesis' main findings (Sect. 3).

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2 Motivation and Introduction to Service Differentiation

Companies increasingly rely on third parties for raw materials, intermediate products, finished products, and spare parts. While this approach allows them to streamline internal processes and usually to reduce costs, it also requires that they control the risk that suppliers will not be able to deliver requested items on time and in full. Therefore, companies monitor their suppliers' delivery performance, measuring them in terms of the service levels that suppliers commonly guarantee for their customers through contractually stipulated service-level agreements. For instance, [7] report that 70% of the retailers in the consumer goods industry monitor their suppliers' service levels.

All customers prefer high levels of service, but some customers value high levels of service more than others and will trade product characteristics like price for higher service levels. For instance, reliable product availability is important for customers, who incur high shortage costs if an order is not fulfilled promptly, so paying a higher price is reasonable. However, other customers have lower shortage costs and attribute less value to product availability and more to price. Additionally, a single customer's requirements in terms of service levels may vary between different orders—higher when the customer places an emergency order and lower for standard orders that are less time-sensitive.

An example of variations in the required service levels concerns the provisioning of spare aircraft parts. Because airlines require spare parts to be available worldwide within few hours, the provisioning of these parts is usually handled by third-party spare-parts providers. Here, a particular challenge is that the importance of product availability varies not only between different customers but also between order types. In particular, the service levels required for emergency orders (which are usually termed "aircraft on ground") are higher than those for standard replenishments or scheduled maintenance.

Samii et al. [2] present an example for the varying importance of product availability from another domain. They discuss the case of influenza vaccines, where higher levels of vaccine availability are required for critical population segments (e.g., healthcare professionals, elders, and, children) while lower levels are acceptable for the general public.

As a consequence of the varying importance of product availability, the customers of companies that offer a single guaranteed service level frequently push for higher levels of service even at higher prices, while other customers demand lower prices without caring for availability. Clearly, standard service-level guarantees with a single service level for all customers cannot content all customers. Service-level menus overcome the shortcomings of single service-level guarantees: the company posts several combinations of prices and service levels and allows customers to choose from the options according to their needs.

The introduction of service-level menus changes how companies interact with their customers by allowing customers to choose among several offerings to match their needs. However, introducing several service-level guarantees also requires that

the offering company change how it operates, as the following example illustrates: A technology company recognized the necessity of offering several service levels for a range of their products. However, its production and distribution network could not provide more than one level of service. As a result, the company offered different service levels and charged different prices, but all customers received the best possible service. Providing this high level of service to all customers led to higher-than-necessary costs for the company, and the policy carried the risk of upsetting customers who paid higher prices while receiving the same level of service as those who did not.

As this example shows, the use of service-level menus requires adapting the supply chain in order to provide differing levels of service. This can be achieved via inventory rationing, especially through critical-level policies that protect certain parts of the inventory for orders (resp. customers) that require a higher level of product availability. Critical-level policies function in an intuitive and easily implementable way. One can think of a two-bin inventory-management rule in which each item of stock on hand is kept in one of two physically or virtually separated locations (e.g., bins). All demands are filled from the first bin until it is exhausted, at which time high-priority orders are served from the second bin, while low-priority orders are rejected or backordered. Here, the critical level corresponds to the contents of the second bin. This analogy can be extended to more than two customer classes (bins).

Because the company chooses which service levels and which prices to offer and customers self-select from the various offerings of the service-level menu, the company's profits and the customers' level of satisfaction should both increase. However, a decision-maker who is considering introducing such a service-differentiation strategy must first answer several questions: First, the decision-maker should determine whether such a service-differentiation strategy is likely to significantly increase profits. Second, if this is the case, the decision-maker must determine the number of service levels to offer and the corresponding prices and service levels. Third, the decision-maker must determine the parameters of the corresponding critical-level policy.

Although inventory-rationing strategies in general and critical-level policies in particular have been well-studied (cf. [1] for research in a multi-period setting and [2] for research in a single-period setting), the existing research on service differentiation considers only the third of the three questions for decision-makers. The next section explains how to address the other two.

3 Summary of Findings

Because developing an integrated perspective on the supply and demand sides of service differentiation involves the study of various complex and interrelated problems, the presented research proceeds in three steps. The first step focusses on the operations side, studying how to manage multiple service levels and how additional customer classes (or offerings) affect the required inventory. The second step addresses

the relationship between the market side and the operations side by studying the joint optimization of price and inventory (without service differentiation). The third step concerns when the introduction of a service-level menu increases profits over that of a single undifferentiated offering and how to design optimal service-level menus.

To this end, one analytical setting is maintained throughout the discussion: A profit-maximizing, monopolistic firm supplies a single product from a single warehouse over a finite period of time to a set of heterogeneous customers. Prior to the selling period the firm purchases a number of units of the product. During the selling period, individual customer demands follow a Poisson process, as does the total of all customer demands because sums of Poisson processes are Poisson processes. Whether a given customer demand is fulfilled depends on the current pricing policy and the current inventory. Any remaining units of stock at the end of the selling period are either salvaged or held for future sale such that the company incurs either a salvage value or holding costs.

The first step (cf. [6]) addresses the question of inventory management. Assuming that a number of customers (or customer classes) and the corresponding demand rates and service-level guarantees are exogenously given, we develop an approach by which to determine the minimum required starting inventory and the corresponding critical levels and explore how the number of customer classes affects the required inventory. In order to determine the minimum required starting inventory, closed-form expressions for α and β service levels for an arbitrary number of customer classes and given system parameters are derived. As a byproduct, the derivation of the closed-form expressions characterizes the service levels in terms of when the critical levels are hit. Based on the service-level expressions and additional structural insights, we provide an algorithm with which to derive numerically the parameters of a critical-level policy (i.e., the minimum required starting inventory and the associated critical levels) using demand rates and service-level guarantees as input parameters. Schulte and Pibernik [6] also includes an extensive numerical study in which the system parameters, including the number of customer classes, vary.

The second step (cf. [4]) addresses the integration of pricing and inventory management without service differentiation, that is, the integrated optimization of price and inventory in a single-period make-to-stock or procure-to-stock setting with Poisson demand. In particular, I develop an analytical solution approach that covers a broad class of demand functions, including linear and iso-elastic demand, and explains how to use piece-wise linear approximations to handle the complex and/or discontinuous price-demand relationships that may occur in real-life situations.

Building on the aforementioned results, the third step (cf. [5]) addresses the question concerning how to design optimal service-level menus while considering the underlying inventory-management policy. Because such service-level menus allow the firm to price-differentiate based on its customers' service-level preferences, we term this service-level-based price differentiation "SLBPD". The contribution of our research is threefold:

- First, we provide an analytical formulation for the integrated optimization problem of designing a service-level menu and determining the corresponding parameters

of the underlying inventory-rationing policy, a problem that has not, to the best of our knowledge, been studied before.
- Second, our research reveals analytical and conceptional insights that are relevant beyond the scope of our research. In particular, we develop an equivalent problem formulation that links SLBPD and dynamic pricing, allowing us to use the rich body of research on dynamic pricing in order to gain a better understanding of SLBPD and helping to put service differentiation in perspective and to interpret our results.
- Third, building on these insights, we study when SLBPD is profitable and how best to design a service-level menu. In particular, our analytical and numerical insights show that, in many cases, service differentiation does not increase profits significantly.

One way to interpret this finding is that differentiating customers based on service levels alone is a weak differentiation lever only, that is, the price differences between offerings with differing service levels need to be small in order to prevent customers from switching to offerings with lower prices and service levels. Therefore, successful price differentiation requires service differentiation's being supported by presence of additional conditions or measures (e.g., pricing restrictions or further differentiation levers). Indeed, our research also shows that service differentiation can significantly increase profits if the company experiences pricing restrictions.

These results have immediate relevance for companies that consider to use SLBPD. In particular, decision makers from such companies learn that the potential profitability of SLBPD depends on the relationship between their current price and the optimal monopolistic price, the price-setting newsvendor price. If their current price is greater (or not significantly smaller) than the price-setting newsvendor price, then they should not pursue service-differentiation further. However, if (e.g., due to regulation, competition, customer expectations, or other influences) the current price is significantly lower than the optimal monopolistic price, then service differentiation has the potential to increase profits significantly.

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