We study the effects of uncertainty in consumer spending due to economic volatility on the product line decisions of a firm with limited resources. We consider a firm that offers products with differing qualities, unit production costs, and resource consumption rates. Consumers are heterogeneous in their purchasing behavior. First, the firm decides its capacity investment for each product given the limited resources and the probability distribution for the parameter of the consumers’ willingness-to-pay distribution. Next, the parameter is realized and the firm determines quantities and prices for each product, subject to the allocations made in the first period.

Keywords: Product Line, Limited Resources, Uncertain Consumer Willingness-to-pay, OM-Marketing Interface

INTRODUCTION

Product lines, which can be defined as “a quality-differentiated spectrum of goods of the same generic type” (Mussa and Rosen 1978), are very common in practice. Almost every product or service comes in a variety of models distinguished by the number and level of attributes provided. In addition, consumers generally differ in their willingness-to-pay for quality, which implies that the products that make up a product line are not perfect substitutes. For example, an executive officer who plans to attend a meeting right off the plane will likely value the comfort of the larger seat more than a student traveling to his hometown on a tight budget. Product lines take advantage of this heterogeneity in consumer preferences by enabling the manufacturer to offer a broad range of quality levels and price points in order to capture a wider audience and to segment the market.

Firms have long recognized the value of such quality-based segmentation. However, traditionally, product mix choices have been made without regard to capacity limitations. In reality, few firms operate with unlimited resources. In practice, resource capacity constraints can take a number of different forms: for an airline, the space in an aircraft; for a telecommunications service provider, the total bandwidth; for a bank, the number of customer service representatives; and for a durable goods manufacturer, the amount of labor and equipment within the manufacturing facility. In addition, products of different quality levels will generally consume different amounts of the limited resource. In particular, a unit of high quality
product (e.g., a first class seat on an airplane) will usually consume more of the critical resource (space) than a unit of low quality product (an economy class seat). Thus, when designing its product mix, it is essential for a firm to understand the implications of these capacity limitations and differing resource consumption rates.

When designing its product mix, a firm must also take into consideration its consumers’ purchasing behavior and how that behavior varies across the market and across time. In this paper we focus on consumers’ willingness-to-pay for quality as a key aspect of purchasing behavior in a vertically differentiated market. Generally, this willingness-to-pay will vary across the market. We refer to this variation in willingness-to-pay as the distribution of willingness-to-pay. While most of the existing approaches to product line design take the distribution of willingness-to-pay as fixed and known, in reality there can be significant shifts or fluctuations in this distribution due, in part, to changing economic conditions. For example, most products are considered to be normal goods, which means that an increase (decrease) in income will lead to an increase (decrease) in the individual's willingness-to-pay for the good (Feigenbaum and Hafer 2013). Thus, if changes in the economy lead to widespread changes in income, one would see a shift in the distribution of willingness-to-pay. In addition, during economic downturns consumers often focus on “value-for-money” and become more conservative in their spending, substituting more economical, low quality products for more expensive, high quality products (Williamson and Zeng 2009). Such behavior would lead to a downward shift in the distribution of willingness-to-pay. In contrast, in times of economic growth, we may see an upward shift in the distribution of willingness-to-pay. For example, during the most recent recession, “value-for-money” became a major imperative. Furloughs and job losses forced many consumers to become value-shoppers, shifting the willingness-to-pay downwards. As a result, in Western Europe, economically-priced store brands stole market share from premium labels by two percentage points during 2007 (Williamson and Zeng 2009).

Unfortunately, predicting these fluctuations in consumer spending is a challenging task.

An article published in Economist on November 15, 2007\(^1\) summarizes the situation as follows: “In 1929, days after the stock market crash, the Harvard Economic Society reassured its subscribers: ‘A severe depression is outside the range of probability.’ In a survey in March 2001, 95% of American economists said there would not be a recession, even though one had already started. Today (2007), most economists do not forecast a recession in America, but the profession’s pitiful forecasting record offers little comfort...”

Figure 1\(^2\) shows annual U.S. consumer spending as a percentage of gross domestic product as a function of time. The figure demonstrates the magnitude and nature of the variation in consumer expenditures over an eight year period. When consumer spending exhibits such unpredictable shifts, firms must carefully consider their capacity allocation decisions. For example, while allocating significant capacity to a high quality product may be beneficial when consumer spending is good, doing so could be quite costly if it turns poor. In practice, such capacity allocation decisions are strategic, long term decisions. Thus, they must often be made well before the economic conditions, consumer spending, and the distribution of willingness-to-pay for quality are known. In a business report, IBM Consulting Services discuss how careful consideration of consumer valuation during the planning process can increase profitability (Meckley and Toscano 2005). They note that “improved decision-making for spending scarce resources can have significant impacts on growth, risk and profitability”. Not all companies are adversely affected by economic downturns. For example, companies like General Electric, Kellogg, and Procter & Gamble took advantage of the Great Depression, became successful

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2. Published by Federal Reserve Bank of St. Louis, Economic Research Department, http://research.stlouisfed.org/fred2/graph/?g=hh31#
market leaders by delivering appropriately targeted products and services, and by carefully managing their resources (Williamson and Zeng 2009).

Therefore, in this paper, we introduce uncertainty regarding the consumer spending (represented by the willingness-to-pay distribution) into the product line design problem and investigate its impact on a resource constrained firm's optimal product mix. Our model and analysis also provide insights into how to manage these resources after the uncertainty is resolved.

**PROBLEM STATEMENT**

In this paper, we extend the existing literature on product line design to consider the impact of (i) resource capacity constraints and (ii) uncertainty regarding the distribution of willingness-to-pay for quality. Specifically, we consider a firm that produces two product types with differing qualities, unit production costs, and resource consumption (capacity utilization) rates. Consumers are assumed to be heterogeneous in their willingness-to-pay for quality, i.e., the willingness-to-pay follows some distribution across the set of consumers. Prior to making its capacity allocation decisions, the firm does not have precise knowledge regarding the parameters of this distribution. Thus, we consider a two-period model. In the first period, the firm decides its capacity allocation for each product type given the limited available resources (capacity) and the firm's beliefs regarding the distribution of willingness-to-pay for quality, which are represented as a probability distribution on the location parameter (i.e., upper bound) of this distribution.

In the second period, the distribution of willingness-to-pay for quality is realized, and the firm determines optimal production quantities and prices for each product, subject to the capacity allocations made in the first period.
Our model captures the reality that firms must often make their strategic capacity allocation decisions when there is still significant uncertainty regarding consumer preferences. In addition, these strategic capacity allocation decisions are generally made well before the production quantities and product prices are determined. The amount of capacity that is initially allocated to a product serves as a constraint on the number of units of that product that can be produced and sold in the market. Thus, the initial capacity allocation, together with the realized consumer willingness-to-pay distribution, determine optimal prices and production quantities for the firm in the second stage.

RELATED LITERATURE

There has been a significant amount of research on vertically differentiated product line design in the marketing and economics literature. Most of this literature makes the following assumptions. There is a single distinguishing attribute, referred to as “quality”, and consumers agree that more quality is always preferable to less quality. There are several different (or a continuum of) consumer types, where the types differ in the intensity of their preference for quality. Consumers act to maximize their consumer surplus, where consumer surplus is the difference between the consumer’s utility for the product, measured in dollars, and the selling price of the product. Mussa and Rosen (1978) were among the first to consider the product line design problem in this setting. They demonstrate how a monopolist can get consumers to self-select into the highest quality product closest to their willingness-to-pay. Moorthy (1984) considers a similar model. However, consumer preferences are nonlinear, there are a finite number of market segments, and the number of consumers of each type is known. Bhargava and Choudhary (2001) study the impact of the cost structure (i.e., cost to quality ratio) on a monopolist’s choice between offering a set of vertically differentiated products and a single product. Desai (2001) considers how differences in consumers’ tastes affect the impact of cannibalization on product line choice. However, with the exception of Yayla-Kullu et al. (2013) and Yayla-Kullu et al. (2011), who consider product line design in a competitive environment and from the perspective of a social planner, respectively, this previous literature generally ignores the effects of limited capacity and product-dependent resource consumption rates. The research presented in this paper builds on Yayla-Kullu et al. (2013) and Yayla-Kullu et al. (2011) to consider the impact of uncertainty regarding consumers’ purchasing behavior, which is represented by the distribution of willingness-to-pay for quality, on a firm’s product line decisions, in a setting with limited capacity and product-dependent resource consumption.

While the existing literature has studied product line decisions considering heterogeneity in consumer preferences, for the most part this literature has not considered the impact of uncertainty regarding consumers’ purchasing behavior, i.e., uncertainty regarding the distribution of willingness-to-pay for quality, in the context of a vertically differentiated product line. However, there is a line of research that considers the effects of uncertainty regarding product quality. For example, Bester (1998) studies when consumers are uncertain regarding product quality and how it affects the firm’s incentives for horizontal differentiation. Cavaliere (2005) also considers a model in which the consumers’ have uncertainty regarding product quality and studies how firms can use price as a signal of quality. There is also literature that considers uncertainty regarding consumer tastes in the context of horizontal differentiation, i.e., using the Hotelling model. For example, Casado-Izaga (2000) and Meagher and Zauner (2005) demonstrate that uncertainty regarding consumer tastes increases the degree of product differentiation.

In the context of a vertically differentiated product line, Saak (2008) considers a setting in which consumers themselves lack precise knowledge of their willingness-to-pay for quality. The research most closely related to the current paper, Johnson and Myatt (2006b), studies
how a shift in consumers’ purchasing behavior will change the (vertically differentiated) product line choices of a firm. However, the authors study the implications of advertising on consumers’ purchasing behavior and they assume that the shift in purchasing behavior is deliberate and known to the firm. In contrast, our paper studies the impact of the economic environment on consumer behavior and models the shift in purchasing behavior as a random variable.

The current paper also contributes to the body of literature that considers marketing-manufacturing interface, including a line of research that has studied the impact of operational issues on a firm’s product line decisions. For example, Kim and Chhajed (2000) and Heese and Swaminathan (2006) study the effects of component commonality on the product line design. Netessine and Taylor (2007) characterize the effects of production technology. Chayet et al. (2009) consider a shared resource used for offering a product line in a monopoly setting. Monroe and Zoltners (1979) study the pricing of a product line taking into account resource scarcity and consider how a firm should allocate a common resource among its products, under the assumption that product demands are independent. Krajewski et al. (2010) demonstrate how a firm’s product mix depends on its capacity through the margin per unit of resource required to produce one unit of that product. However, they take prices and product demands as exogenously specified. Dobson and Yano (2002) consider a shared resource used for the production of a product line. However, their model also assumes the products have independent demands and thus cannibalization is not a factor.

CONTRIBUTIONS AND MANAGERIAL INSIGHTS

In this paper, we add to the existing literature by studying the impact of uncertainty regarding consumers’ purchasing behavior (in particular, the distribution of willingness-to-pay for quality) on a capacity-constrained firm’s product line decisions, given that different products consume different amounts of the limited resource. We do so in a two-period model, which captures the dynamic nature of the firm’s product line decisions. We model the uncertainty regarding the distribution of the willingness-to-pay by specifying a probability distribution on the maximum willingness-to-pay, i.e., the upper bound on the distribution of willingness-to-pay.

We first solve the second period problem to find the production quantities for each product type, taking the capacity allocations and maximum willingness-to-pay as fixed. In contrast to the conventional wisdom from the economics literature, we find that when the capacity allocated the low quality product is sufficiently low (below a certain threshold) and the cost to quality ratio favors the low quality product, the production quantity decision also favors the low quality product. If the maximum willingness-to-pay is low, then the firm only produces (and sells) a limited amount of the low quality product (i.e., less than the allocated capacity) in order to keep its price high. If the maximum willingness-top-pay is moderate, the firm will use all of the available production capacity for the low quality product. In some cases, the firm will produce only the low quality product (using all of its allocated capacity) even if capacity has been allocated to the high quality product. Only when the maximum willingness-to-pay is sufficiently high (above a certain threshold) will the firm start producing the high quality product.

Given the optimal production quantities in the second period, we next solve the first period problem to find the optimal capacity allocations. When the model parameters are such that the capacity constraint is not binding and the cost to quality ratio favors the low quality product, we find that the optimal strategy is to differentiate and offer both products in the market, as is the case when there is no uncertainty. However, there is one important difference: the capacity allocated to the high quality product increases with the level of uncertainty while the capacity allocated to the low quality product remains constant.
When the capacity constraint is binding, we use numerical examples to study the impact of uncertainty on the product mix decisions. When the cost to quality ratio favors the high quality product, but the resource consumptions favor the low quality product, we find that the capacity allocated to the low quality product increases with the level of uncertainty when the available capacity is below a certain threshold. However, since the capacity constraint is binding at this level, this additional capacity allocation to the low quality product is achieved by decreasing the capacity allocation to the high quality product. This result is in contrast to the unlimited-resource case. Moreover, we find that, for moderate levels of capacity, uncertainty may cause an increase in the number of products offered on the market. Thus, in contrast to common wisdom, we find that the capacity allocated to the low quality product and the product variety may increase as uncertainty increases when resources are limited, even when the cost to quality ratio favors the high quality product.

Full details of the model, propositions, proofs, results, and discussions can be found in the full length paper (Yayla-Kullu et al., 2014).

REFERENCES

References available upon request.