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Financial risk management in the design of products under uncertainty

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ABSTRACT

In this paper we extend a recently presented methodology for product design (Bagajewicz, M. (2007). On the role of macroeconomics multi-scale planning and finances in product design. *AIChE Journal, 53*(12), 3155–3170) to consider uncertainty in the model parameters. We also extend the methodology to the discussion of alternative profitable scenarios and their associated risk. To illustrate the method, we picked wine making. To illustrate the method, we present a simplified consumer preference model, and show how vineyards can guide the selection of wine properties (wine quality), in association with a production rate and a selling price based on their attitude towards financial risk.

1. Introduction

In a recent paper, Bagajewicz (2007) presented a methodology that incorporates microeconomics into product design. The argument is that consumer preferences as well as their reaction to price, both combined, establish demand, which in turn determines profit. As a result, the most profitable product is not always the best product from the consumer preference point of view, a well-known fact that the paper helps quantify. The procedure, however, provides a quantitative means of constructing a meaningful price–demand–quality relationship which can be used to determine the optimal product structure. This was illustrated by Bagajewicz (2007) and by Street, Woody, Ardila, and Bagajewicz (2008). In this paper we illustrate how uncertainty can make one choose a different optimum and how financial risk can be managed. We use wine-making to illustrate the concepts.

The paper is structured as follows: we first overview the product used for the example: wine. Then, we review briefly some of the consumer preference functions. We then compute a net present value as a function of price for different qualities as suggested by Bagajewicz (2007). Finally, we discuss the uncertainty associated to the model and suggest means to deal with uncertainty. Portions of this paper were advanced in a condensed conference article by Whitnack, Ashley, and Bagajewicz (2008).

2. Wine making

Wine has long been considered an art form, where quality was controlled by the producer. However, in the current competitive world wine producers must now consider several other factors, besides quality. In order to identify with the market, the producer must understand the motivations behind the consumer's choice. Currently, after the wine has been bottled, it is outsourced to labs where tests are performed to measure the qualities that the wine possesses. Wine varietals are also sent to tasting competitions, where they are tasted by experts and awarded for overall quality. Experts form their opinions after tasting each individual wine and rank them based on a standard set of criteria, pre-determined by the host of each competition. While these methods are both beneficial and educational to the producer, neither truly addresses the perceptions of the consumers, nor they connect these with the cost to the producer. The producer also has no way of controlling the product at this point. It has been bottled and is simply awaiting distribution. If this knowledge was attainable before the product was complete, the process could, in theory, be modified to attain the overall quality sought by the consumer.

The quality of wine, however, can be known before it is bottled, and that each batch of wine can be engineered to manipulate consumer's preferences in any market, whether it is the highest quality possible or less. After quantification of the consumer's predicted overall satisfaction with the product, the wine can be compared to the quality of any competitor. By comparing its quality to that of the competition, the selling price of the wine can

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be set, optimizing the producer's return on investment. This is the core of the ideas proposed by Bagajewicz (2007).

Consumer preferences are identified, allowing the data generated by market analysis to be related to wine properties. These wine properties are easily measured throughout the winemaking process and can be manipulated by the manufacturer at little cost. Modifiable processes include fermentation, clarification and stabilization, barrel toasting and aging (Cooke & Lapsley, 1988; Eismann, 1999). Finally after the consumer overall preferences are identified, the wine can be compared to the competitor and the selling price of the wine can be set by optimizing the producer's return on investment. Appendix A provides additional background of the manufacturing process.

The wine industry is comprised of several different economic segments. Wines range from economy to premium and ultra-premium to artisan. Economy wines are those costing the consumer less than $7 per 750 mL bottle. These wines dominate 70% of the wine industry (Tinney, 2005) and 27–28% of the industry is made up of premium table wines, which range from approximately $8 to $40 per 750 mL bottle, while only 2–3% of the wine market is owned by the ultra-premium and artisan wines, which are the most expensive of wines available (Bisson, Waterhouse, Ebeler, Walker, & Lapsley, 2002). The premium table wine market segment in the US is the only market segment with stable demand growth (Folwell & Volanti, 2003).

In our particular case we are concentrating on Pinot noir to demonstrate our methodology. Pinot noir is the softest of the reds and is considered to be the red wine choice of the white wine drinker. It is described as being "soft" and "supple" on the palate and is generally not high in tannins.

Adapting a certain existing manufacturing facility (winery in this case) to produce a new (or even a slightly different) product is a subset of the bigger problem posed by Bagajewicz (2007) for product design. Indeed, although manufacturing and supply chain architecture and operation modality are not subject to change, the major and most important ingredients of the approach, namely the connections between consumer preferences, price and choices of wine properties, remain and are used to determine the properties of a product. We would still call this "product design", although others might prefer a different name.

3. Pricing and consumer preference models

We use the same constant elasticity of substitution model as Bagajewicz (2007). This model is a small modification of the constant elasticity of substitution models found in literature (Hirshleifer & Hirshleifer, 1998; Varian, 1992) where hedonic theory is incorporated. This was extended to multiple competitors by Street et al. (2008). The final expression relating demand of new product to price is

$$d_1 = \left(\frac{\alpha}{\beta}\right)^{\rho} \frac{p_2}{p_1} \left(\frac{Y - p_1 d_1}{p_2}\right)^{1-\rho} d_1^{\rho} \tag{1}$$

where d_1 is the demand of the new product, p_1 its proposed price, p_2 the average price of competitor wines, ρ a predetermined constant, α a zero to one measure of the amount of knowledge the consumer has for the product of interest and, Y is the consumer budget, which satisfies

$$Y \geq p_1 d_1 + p_2 d_2 \tag{2}$$

Finally, β is a positive coefficient that relates how much more appealing the consumer will find the product of interest in comparison to the competing product. It is defined as the ratio of the consumer preference functions $\beta = H_2/H_1$. In turn, the consumer preference functions are related to product attribute scores (y_i; in our case, taste, bitterness, sweetness, etc.) as follows:

$$H_i = \sum_i w_i y_i \tag{3}$$

Each attribute is weighted based on the rank of importance (w_i) to the consumer. Thus, the scores, or values of y_i, can be manipulated by altering the production process as well as the raw materials used, including their quality.

Each of these characteristics is evaluated individually by the consumer's level of preference attained. This level of preference will be normalized on a scale ranging from 0 (minimum of 0% preference) to 1 (maximum of 100% preference). A curve is formed that describes the individual's preferences as a function of the characteristic identified and the consumer descriptions ("as tasty as", "as sweet as", "as acid as", etc.) used to evaluate each characteristic. These descriptions can then be related to physical, measurable qualities. For example, if one says, "as acid as pure kitchen vinegar", then one can relate this description to a particular pH, that of kitchen table vinegar. By identifying the correlation of the consumer's words to these qualities, the qualities can then be related to the consumer's preferences.

We now describe each wine characteristic separately.

4. Preference functions

Consumer preferences for each attribute (y_i) and the weights (w_i) can be identified through market research. The most important and commonly judged characteristics of wine that we will use to build our example are as follows:

- Acidity
- Sweetness
- Bitterness
- Clarity
- Color
- Brightness
- Bouquet
- Body/texture
- Finish/aftertaste

These are only a small fraction of the large list of characteristics (The Wine Pages, 2006). One should also consider other factors like brand strength, or others, etc. in the preference function. Although this is in principle (but arguably) a constant term in (3) that can be easily added, we ignore it in this paper. Although many of these characteristics interfere with each other sometimes, one masking the effects of others, we treat them here independently. Our objective is to address the nonlinear versions of Eq. (3), multivariable relations between y_i and physical properties in future work and effect of advertisement in brand strength and product loyalty. Because our purpose is to highlight the methodology we rely on informal surveys on small population samples (around 45 persons).

4.1. Weights

Informal surveys were made and the weights given in Table 1 were obtained.

4.2. Acidity

This characteristic is the result of the balance or lack of balance between the acidity level, alcohol content, and body. Acidity can be broken down into different levels based on consumer descriptions (Pandell, 1999). If the acidity is too high, it begins to taste tart,