DESIGNING GOOD PRODUCTS VS. DESIGNING PROFITABLE PRODUCTS: UNEXPLORED ISSUES IN THE INTERFACE OF ENGINEERING WITH MARKETING/MICROECONOMICS

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Abstract. Products are usually designed by establishing technical goals first. Then, once the product is designed, marketing worries about pricing, market choices, advertising, etc. In doing so, many times, the "best" product is targeted. Such "best" product is obtained many times by investigating consumer preferences. In this paper pricing theory (from microeconomics) is used to show that the "best" product is not always the most profitable one.

Keywords: First Keyword, Second Keyword and Third Keyword.

1. Introduction

Product design has been advocated to be one of the new frontiers opened for chemical engineers (Westerberg and Subramanian 2000; Cussler and Moggridge, 2001). It is claimed that we are moving from a commodity based to a high value added and product performance-based chemical industry. Some call it a shift in interest (Hill, 2004), with obvious impact in research and education (Seider et al., 2004; Cussler and Moggridge, 2001), while others advocate that this is just an expansion of the competency that will include the commodity supply chain, but will also incorporate the new performance based constraints corresponding to a product (Stephanopoulos, 2003,

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Cussler 2003; Cussler and Moggridge, 2004). Bagajewicz (2005a) claims that this expansion goes farther than defining product performance and that the definition of a venture associated to a particular product goes all the way from its molecular design, which settles its properties, to all the finance aspects (commercialization, pricing, etc), going through the definition of the manufacturing process and the associated supply chain. In this line of thought, Bagajewicz et al. (2005) claimed that product design has to be merged with microeconomics, process design and supply chain design. More specifically, it is suggested that pricing theory has to be used to determine profitability of potential new products. These ideas have been presented in a plenary lecture in the recent Enpromer (Bagajewicz, 2005b).

A product is defined by its composition and structure as well as its functionality. These, in turn define the product effectiveness or in general, its quality. For example a liquid soap has fixed structure (liquid) and defined functionality (cleaning). Its composition determines its effectiveness. A soap bar's effectiveness is defined by its composition and its structure because it is usually a multiphase system as Hill (2004) has pointed put.

In turn, a coffee maker, for example is a device that can make different types of coffees (cappuccinos, latte, espresso, etc) and therefore can have multiple functionalities. Its structure is driven by its functionality. Another example of multifunctional product is a liquid soap that also prevents wrinkles forming in the clothes.

Products appeal to customers for two reasons: quality/effectiveness/taste, etc., in addition to price. The field of microeconomics has studied in extent the relationship between price and demand. One of its biggest assumptions is the constant elasticity of substitution, which has been somehow substantiated by observations. Using such assumptions, and some information of the market type the product is immersed on (free competition, oligopoly, monopoly, etc), it is possible to determine the demand of a certain product in the market as a function of its price. This is also known in Marketing as product positioning. We assume here for the moment that the behavior of the competition is not modeled and is therefore static (prices and qualities of competitor's products don’t change for a certain period of time) to make the explanation simple enough. This functional relationship contains parameters that depend on the quality/effectiveness/taste etc. Thus, one can alter demand by altering price, or changing the product. THIS IS WHERE ENGINEERING MEETS MICROECONOMICS AND MARKETING.

The profit, however, is yet to be determined. For example, a certain product for which a large demand (achieved by lowering the price) is advisable may not be achievable because the company is constrained by resources, especially when one discusses multi-product lines in the same company. This problem has been discussed recently by the author and others (Guillén et al., 2005). Another case is the substitution of ingredients for cheaper ones. Reduction in quality/effectiveness/taste may actually increase profits. Finally, one has to realize that one can perform different types of pricing and discounts to retailers as well as geographic segmentations. The problem of determining the right product composition and structure as well as picking the optimal functionality is tied to all these microeconomic functions.

In summary, one needs to determine manufacturing and distribution costs (supply chain issues) as well as price demand relations in different market segments as a function of product composition and structure and functionality before one can optimize the product.

The major difficulty of this stems from determining consumer preference models, which are those that determine the perception of quality/effectiveness, etc. For example a skin humidifying lotion, is judged by the consumer not only by its effectiveness, but also by its smoothness, its thickness, its spreadability, its greasiness/oiliness (these are usually emulsions) among other properties, and to a lesser but not unimportant degree, its fragrance and color. A wine is judged by its bouquet, its acidity, its sweetness, its aftertaste, etc. Thus an assessment is needed of the consumer response to each of these variables or subset of variables in terms. Then there is a need to connect these properties to physicochemical properties and ultimately to composition and structure. In addition functionalities have to be added and subtracted to determine consumer preference. Note that this preference is, in principle, INDEPENDENT of price. In addition, there is the issue of consumer awareness of the product, which needs to be assessed.

Summarizing, while designing the best product to maximize consumer preference might be still profitable (but sometimes not), it might be that smaller consumer preference combined with proper pricing might be more profitable. We claim that this is very often the case.

2. Pricing

We assume first that there is an established market for the new product and that what we are looking is for substitutes. The question is what price will be the right one to attract the optimal number of customers and the new demand associated to it. We begin with posing the consumer optimization problem. In classical microeconomics, this is posed as follows. Consider two products, with demands d_1 (for the new product) and d_2 (for the existing products). Then the consumer maximizes his utility (satisfaction) $u(d_1, d_2)$ subject to a budget limitation, that is:

$$\left.\begin{array}{l} \underset{d_1,d_2}{Max}\ u(d_1,d_2) \\ s.t. \\ p_1 d_1 + p_2 d_2 \le Y \end{array}\right\} \tag{1}$$

where p_1 is the new product's selling price, and p_2 the competitor's product price and Y is the available budget of the consumer set. Sometimes a demand constraint $d_1 + d_2 \le D$ is added. A typical utility function is concave. One such function is given by the following:

$$u(d_1, d_2) = \left(x_1^{\rho} + x_2^{\rho}\right)^{1/\rho} \tag{2}$$

where $\rho < 1$ and $x_i = x_i(d_i)$ is a function of the demand reflecting the satisfaction the consumer gets from consuming d_i units of product. This utility exhibits "constant elasticity of substitution" with respect to x_1 and x_2. Elasticity of substitution is a term coined to describe the shift from one product to another under price shifts and has been proven to reflect real consumer behavior (Varian, 1992). For $x_i(d_i)$ (and two products) we propose the following:

$$x_1 = d_1 \tag{3}$$

$$x_2 = \frac{\beta}{\alpha} d_2 \tag{4}$$

In these expressions, β is a measure of how much more the consumer prefers product 2 over product 1; it compares the "wants and needs". In turn, α represents how much the consumer is aware of the superiority of the product. This idea comes from Hedonic theory (Rosen, 1974, Epple, 1987, Kahn and Lang, 1988).

To illustrate the role of β, we consider α =1, that is, consumer's perfect knowledge of both products. Then consuming k units of product 1, gives the same utility (satisfaction) as consuming k/β units of product 2. For $\beta = 0.5$ one needs twice as much units to achieve the same utility level. Conversely, if the two products exhibit the same preference to the consumer (β, we consider α =1, half of the people know about this difference, then the same utility is achieved by using Under these conditions, the solution to consumer utility maximization is given by the following implicit equation for d_1

$$\Phi(d_1) = p_1 d_1 - \left(\frac{\alpha}{\beta}\right)^{\rho} p_2 \left[\frac{Y - p_1 d_1}{p_2}\right]^{1-\rho} d_1^{\rho} = 0 \tag{5}$$

The above function has several properties. Among others: a) It predicts d_1=d_2 when the prices are equal and when , b) It predicts a monotone decreasing value of d_1 with p_1, which makes sense, and most important c) It predicts a monotone decreasing value of d_1 with β (the larger β is the worse product 1 compares).

The last property establishes the connection with product design, because changing the product allows modifying β and therefore influence in sales. The task remains to obtain the optimal value of β and p_1, the two decision variables available so far (there are others).

3. Consumer preference

It has been suggested (Bagajewicz, 2005b) that the consumer preference coefficient β is given by the ratio the competition preference function (H_2) to the new product preference function (H_1):

$$\beta = H_2 / H_1 \tag{6}$$

Thus, if the preference for product 2 is half of that for product 1, β =0.5. In turn the consumer preference function is proposed to be constructed as follows:

$$H_i = \sum_j \omega_{i,j} y_{i,j} \tag{7}$$

In this expression the property scores $y_{i,j}$ of characteristics are the contribution of property j to the preference function of product i (like for example effectiveness, durability, feel, form, scent, and toxicity of an insect repellent, which is our example, see below). These scale from zero to one. In turn, $\omega_{i,j}$ are weights, satisfying $\sum_j \omega_{i,j} = 1$, which determine the importance of each product attribute and is determined solely by surveys.

Each score is a function of consumer related or "marketing" properties. These are properties that a regular consumer or surveyor can relate to. The task of engineers is to connect these properties to physical properties or functionalities and ultimately to product composition or functionality or structure. This connection is the essence of our theory of product design. We now illustrate this briefly through an example.

4. Example

Consider an insect repellent to compete with an emerging competitor of the current market leader, a DEET-based repellent. It was decided that the basic active ingredient would be Picaridin, the same as the emerging competitor. Four ingredients were chosen to contribute to these characteristics: Picaridin, ethanol, aloe, and fragrance. Six important characteristics of a repellent were chosen: effectiveness, durability, stickiness, form, scent, and toxicity (Ashley and Doman, 2006). We now show how to relate those to concentration.

Effectiveness: A common experiment performed on repellents is the "mosquitoes in a box" test. In this test, a known mosquito population is placed inside a long rectangular box. One side of the box is treated with the repellent of interest and at the end of a certain amount of time, the number of mosquitoes on the repellent side of the box is counted. Fifty percent of the mosquito population on the repellent side would prove the repellent was ineffective and would correspond to a utility of zero. Zero mosquitoes on the repellent side would prove the repellent was completely effective and would correspond to a utility of 100. The experiment was not done, so we assume a certain set of results. We now present one possible result of such experiment (Figure 1). This figure shows a first graph, which relates the consumer preference score of effectiveness to the common person/consumer measurable property (% of mosquitoes). The first graph comes from observation (abscissa) and survey of consumers (ordinate). The second graph relates the measured quantity of mosquitoes to % picaridin. This second graph is also experimental in this case. The third graph provides the relationship sought. All data presented comes from informal surveys of small number of persons, performed only to advance the concept and should not to be used to make conclusions.

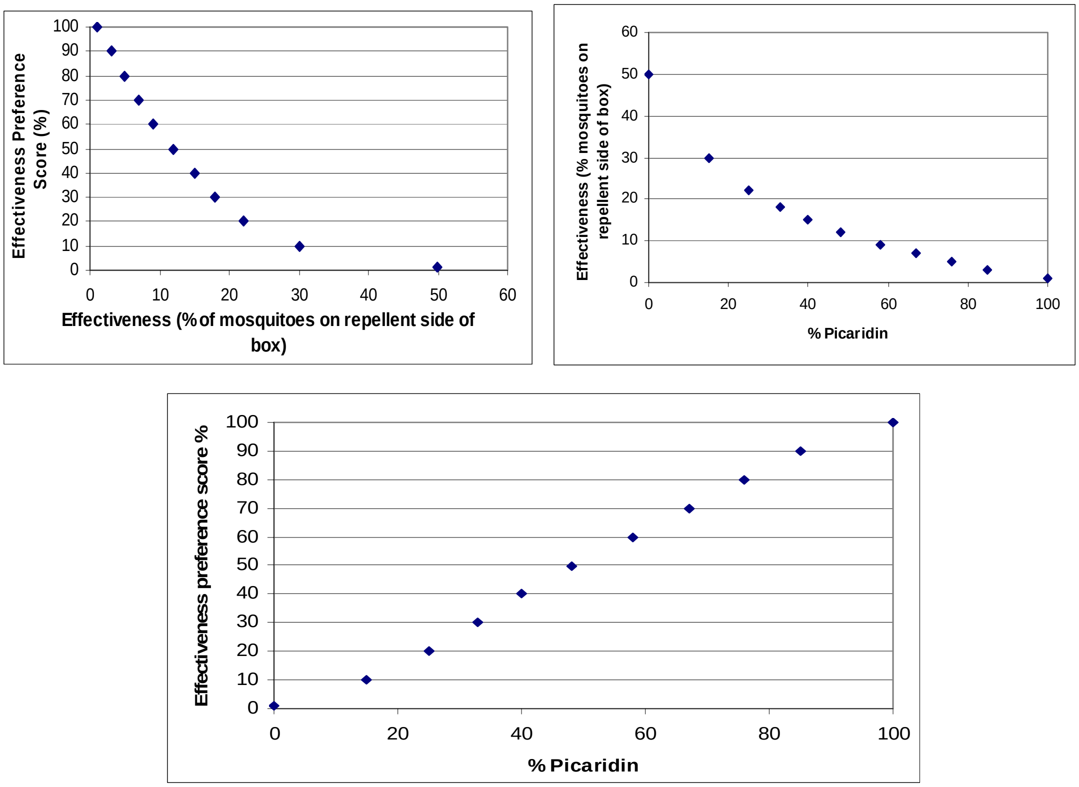

Figure 1: Effectiveness score vs. % picaridin

Durability: Durability is defined as the length of time that one dose of repellent remains effective. We assume that a great repellent, one that would have a score of 100%, would last 12 hours or more, and would be best explained by a linear relationship with slope 100/12 (%/hr). Next, the repellent durability (time) needs to be related to some physical property of the repellent. This physical property is the composition of the overall liquid mixture. For simplicity, we chose to model the situation like follows: a) There is a vapor layer of composition c_{is} immediately close to the liquid that is in equilibrium with the liquid composition, that is, $c_{is} = p_{is} / RT = x_i P_i^0 (T) \gamma_i / PRT$, b) The rate of removal of the mixture from the layer is assumed to be given by a natural convection mass transfer coefficient (although a more elaborate diffusion model can be constructed), that is: $N = h \sum_i c_{is}$, and c) replenishment of the vapor phase to reach equilibrium is considered instantaneous.

Therefore one can write $\frac{dm_i}{dt} = -AN_i = -Ac_{is}N$, and $M = \sum_i m_i$; so after substitution one obtains a differential equation for the mass of each component in the liquid as a function of composition, which can be integrated numerically using $m_i = m_i^0$ at t=0. For the mass transfer coefficient we have used a correlation for forced convection turbulent mass transfer on a flat plate ($k_\rho^* = 0.0365 N_{\mathrm{Re},L}^{0.8} \frac{D}{L}$). We understand this model can be enhanced substantially, but we chose to keep it simple and only for the purpose of being able to advance the conceptual approach we are presenting. Results, which illustrate the concept, are shown in Figure 2 together with the final durability score

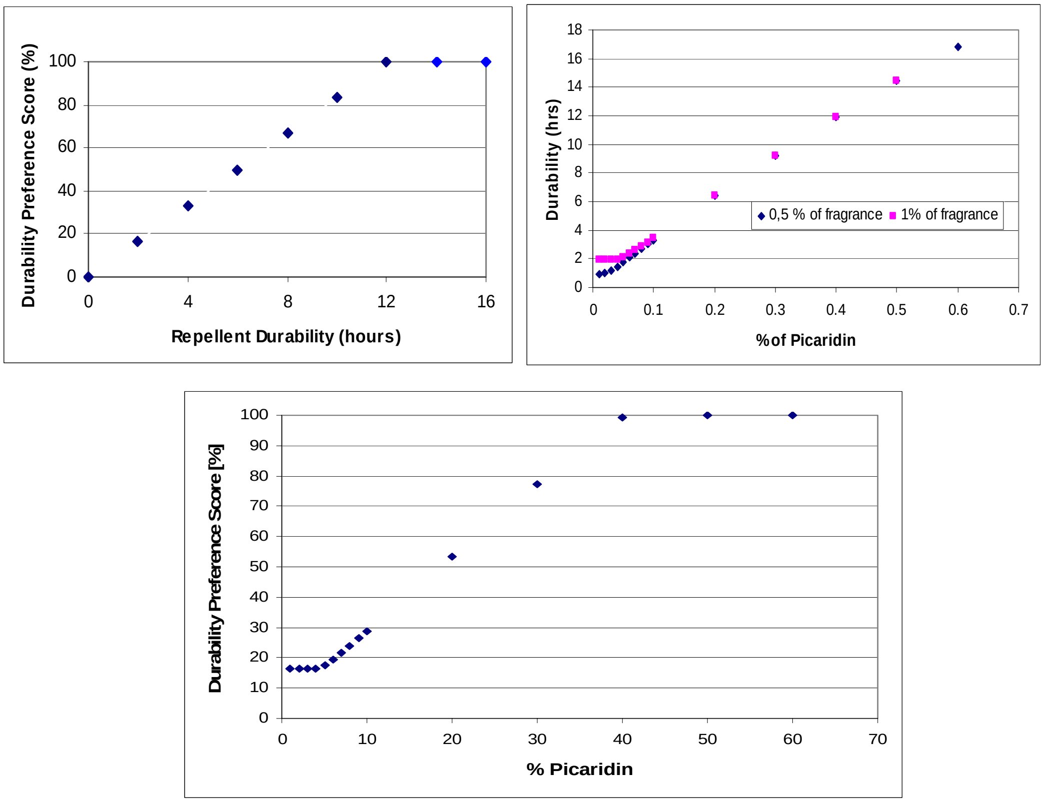

Figure 2: Durability score vs. % picaridin

Stickiness: The first step in relating utility to stickiness was assigning qualitative descriptions to levels of stickiness preference (first graph of figure 3), which comes directly from consumer surveys. Then we relate these levels of stickiness to some measurable physical property through a “Paper Test” (second graph of Figure 3). To perform this test, a person applies repellent of a specific formulation to the underside of his arm and places a two-inch-by-two-inch piece of paper on the applied area. The thickest piece of paper that sticks to the applied area and does not fall off determines the stickiness of the repellent. Thickness of paper, or basis weight, is measured by the weight of 500 sheets of that type of paper. For example, a full sheet of 50-pound paper would weigh 1/500 of 50 pounds, or one tenth of a pound.

The next step is to relate this consumer test to a physical property of the repellent formula. Ethanol and Picaridin are non-sticky, so only aloe can be related to the feel consumer test. For simplicity, we assumed each contributes independently of the other. Results are shown in Figure 3.

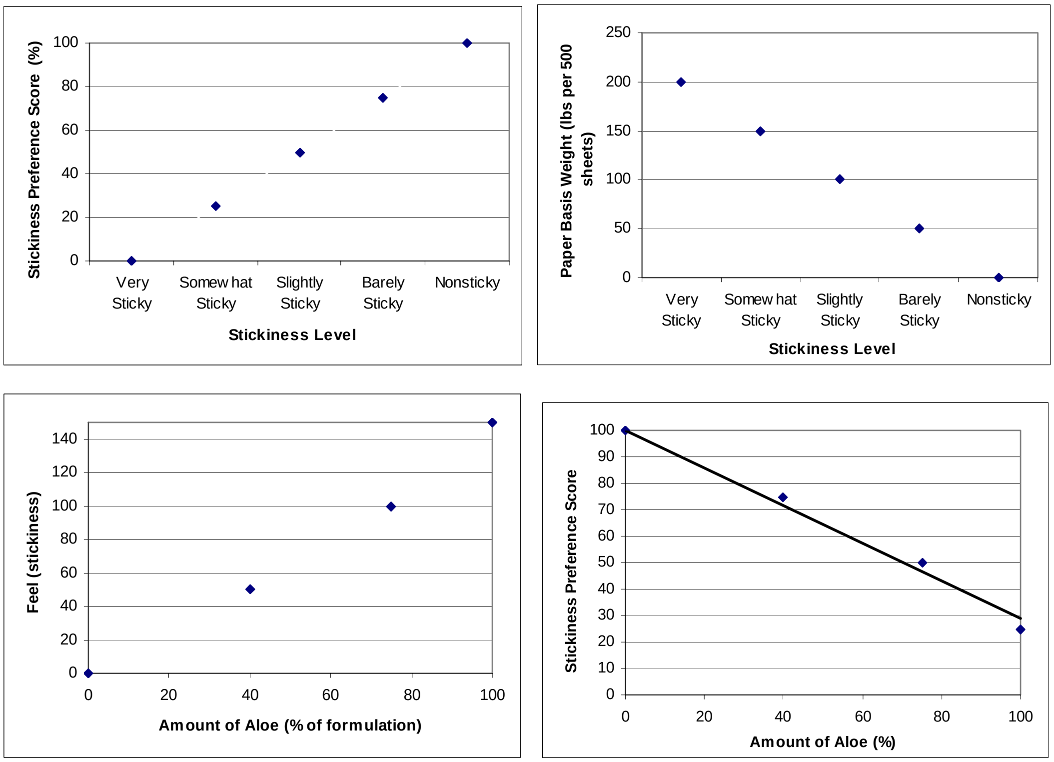

Figure 3: Stickiness score vs. Aloe concentration

Scent: To construct the scent utility function, the consumer determines how satisfying each fragrance scent strength would be to them. In addition, alcohol also contributes to scent but negatively. Thus, for we compute the total scent score using the weighted average of two preference scores:

$$y_{i,scent} = \frac{y_{i,ethanol}x_{i,ethanol} + y_{i,fragrance}x_{i,fragrance}}{x_{i,ethanol} + x_{i,fragrance}} \tag{8}$$

Figure 4 shows the results: The first two figures show the scores for fragrance and ethanol as a function of consumer perception. The most preferred point is where the repellent has only a trace scent, and it decreases for any change in strength. Ethanol, in turn has a increasing negative effect for the whole range. A linear relationship between concentration and scent power is used for both species (100% corresponding to overpowering and 0% to none).

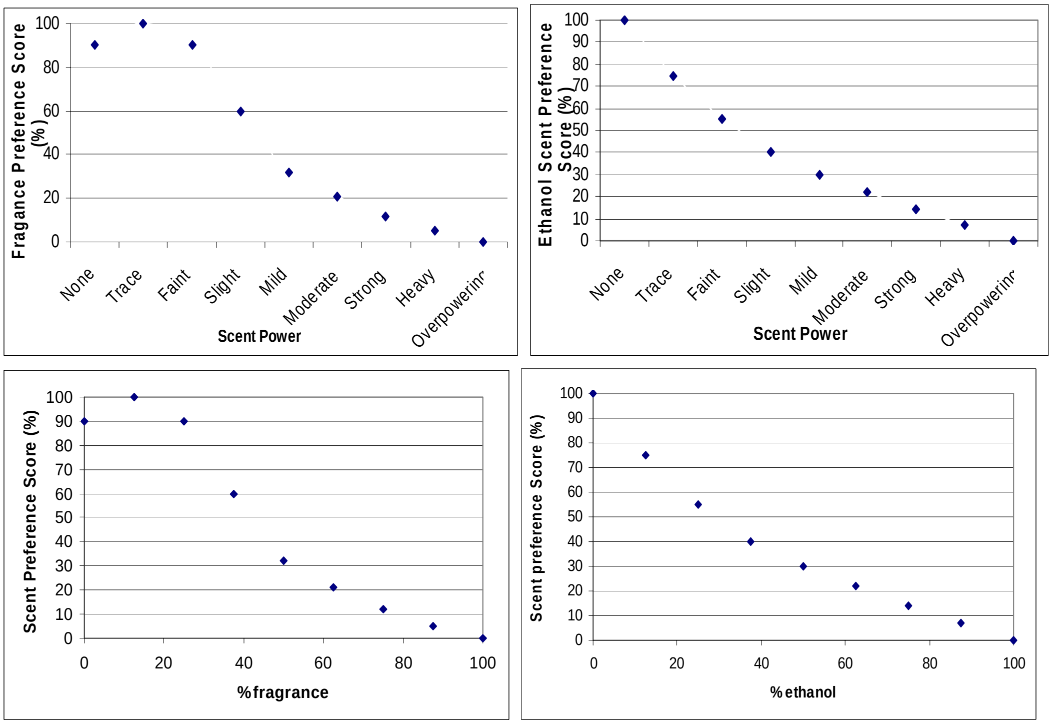

Figure 4: Scent preference score from fragrance and ethanol

Form: There are two forms of repellent available to consumers—lotion or spray. The most important physical property to ascertain this form is the mixture viscosity (surface tension would address droplet size) because it determines if the product will be flowing free enough to be a spray. If it is too thick, it will be a gel or lotion. Liquids with a kinematic viscosity over 75 centistokes will be too thick to be sprayed by a finger pump, a typical packaging for insect repellent. The values for dynamic viscosity are known or estimated for each of the materials. For any mixture, the resulting dynamic mixture viscosity is calculated with the Grunberg and Nissan method (Reid et al., 1987) and converted to kinematic viscosity.

The form score is derived from consumer preferences. For example, if z% of consumers prefer spray repellent over the lotion form, a repellent in spray form would have '100% score' to z% of consumers, but smaller, 50% in our case, to the other (1-z)%. Thus, a spray repellent would have an overall consumer preference score of z_{cs}=z + 0.5*(1-z). Conversely, a repellent in lotion form would have a score of z_{cl}=(1-z)+ 0.5z. Finally, the relationship between viscosity and utility can be expressed with an 'If… then….' statement giving the utility for any mixture viscosity, i.e. 'If kinematic viscosity is less than 75 centistokes, utility is z_{cs} %; if kinematic viscosity is more than 75 centistokes, utility is z_{cl}' For brevity we omit including a figure.

Toxicity: The major benefit of a Picaridin-based repellent is the decreased health risk compared to DEET-based repellents. A consumer preference score should be based on the danger to health that is associated with each component. As the risk increases, consumer happiness will decrease; this is modeled as a linear relationship. The risk associated with each component is derived from the National Fire Protection Association (NFPA) Health Hazard rating, often found on Material Safety Data Sheets (MSDS). The NFPA ratings are as follows for each material: DEET—2; Picaridin—1; ethanol—1. Results are shown in Figure 5. A linear relationship is used to describe the NFPA toxicity score as the concentration of each component increases to 100% composition, where it reaches its NFPA rating.

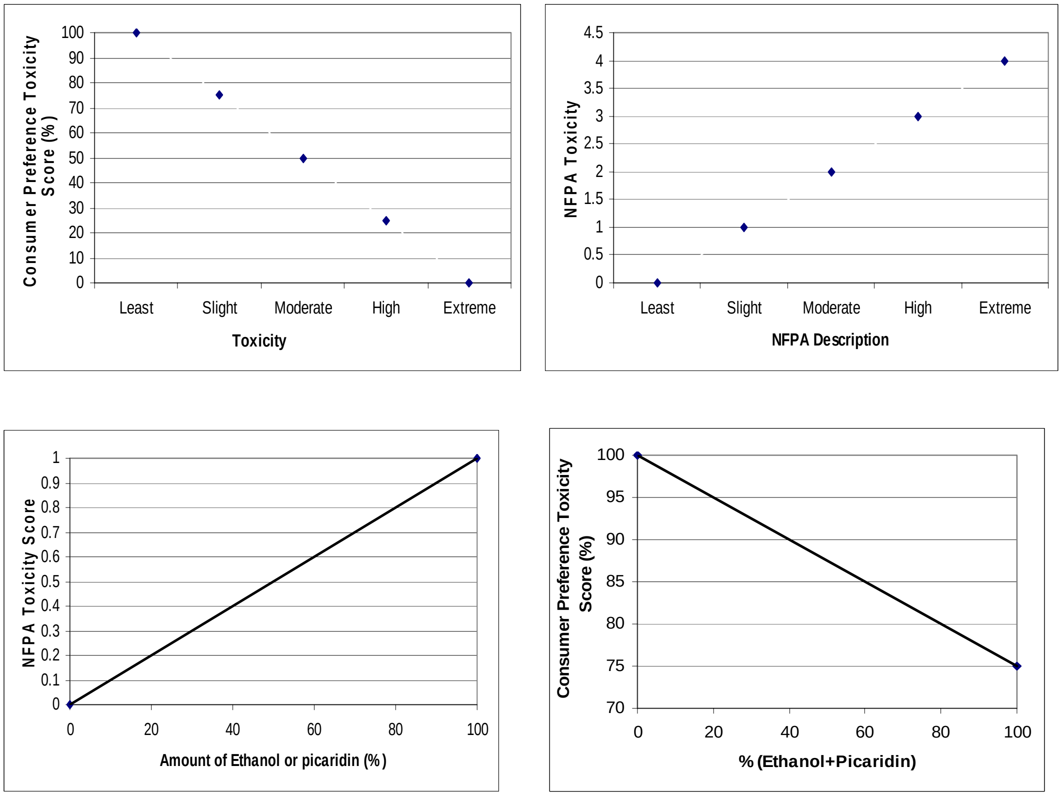

Figure 5: Toxicity score vs. ethanol and picaridin concentration

Weights: These are given in Table 1 and were again obtained using an informal survey of a small number of people.

Table 1: Weights of the preference function.

Characteristic	**Weight**
Effectiveness	0.29
Durability	0.24
Feel	0.19
Form	0.14
Toxicity	0.09
Scent	0.05

When consumer preference (H_1) was maximized, which is equivalent to seeking the minimum of β (because H_2 is fixed), the result suggested a product that is 98.21% Picaridin 1.79% ethanol, 0% aloe and 0% fragrance with a beta value of 0.524. This makes sense because of the weights used. Such a product is not profitable as it will be shown in the next section.

5. Multiscale Profit model

Then we want to choose the product composition and the optimal price to maximize the Profit (Bagajewicz, 2005b) for which we use a net present value. The level of demand that the model chooses determines the associated FCI. In a simplified manner, for just one product a deterministic model is as follows: Let z be the composition of the product and p its price. Then,

$$
\begin{aligned}
&\underset{z,p}{\mathit{Max}}\quad \mathit{NPV(z)}\\
\mathit{s.t.}\quad &\mathit{Demand} = \mathit{Demand}\ (z, p)\\
&\mathit{Fixed\ Capital\ Investment} = \mathit{Fixed\ Capital\ Investment\ (Sales)}\\
&\mathit{Manufacturing\ Costs} = \mathit{Manufacturing\ Costs\ (Sales,\ z)}\\
&\mathit{Transportation\ Costs} = \mathit{Transportation\ Costs\ (Sales)}
\end{aligned}
$$

The demand function is given by Equation (5) above. The others are standard. We omit other complications like many markets, different products and process for these markets, etc.

6. Example – Continued

The demand function is given by Equation (5) above. The others are standard. We omit other complications like many markets, different products and process for these markets, etc. The competitor sales price is 90$ and has a formulation of 7% picaridin, 30% ethanol and the rest water. Figure 6 shows NPV curves as a function of the proposed price for the new product. We see that the optimal value of beta for this market with the aforementioned weights is $\beta = 0.67$, which gives an NPV of almost 12,000,000. This value of beta corresponds to a concentration of 40% picaridin, 58% ethanol 1% aloe and 1% fragrance (these last two having reached their imposed lower limit). Interestingly, the curve for $\beta = 0.76$ shows a peak at 90 dollars (same price as the competition) with an NPV of around 10,700,000 (the corresponding concentration is

30% picaridin, 63% ethanol, 3.3 % aloe and 3.3% fragrance. Lower values of β (0.61 and 0.59) show remarkable lower profit. For values of β lower than 0.59, the NPV is smaller and does not achieve a maximum in the range of prices chosen, showing increasing monotonicity and crossing from negative to positive NPV's at larger prices. We consider large prices unrealistic. We expect the above consumer model to break down when prices are so different. This will be object of future work. Larger values of β result also in a lower profit.

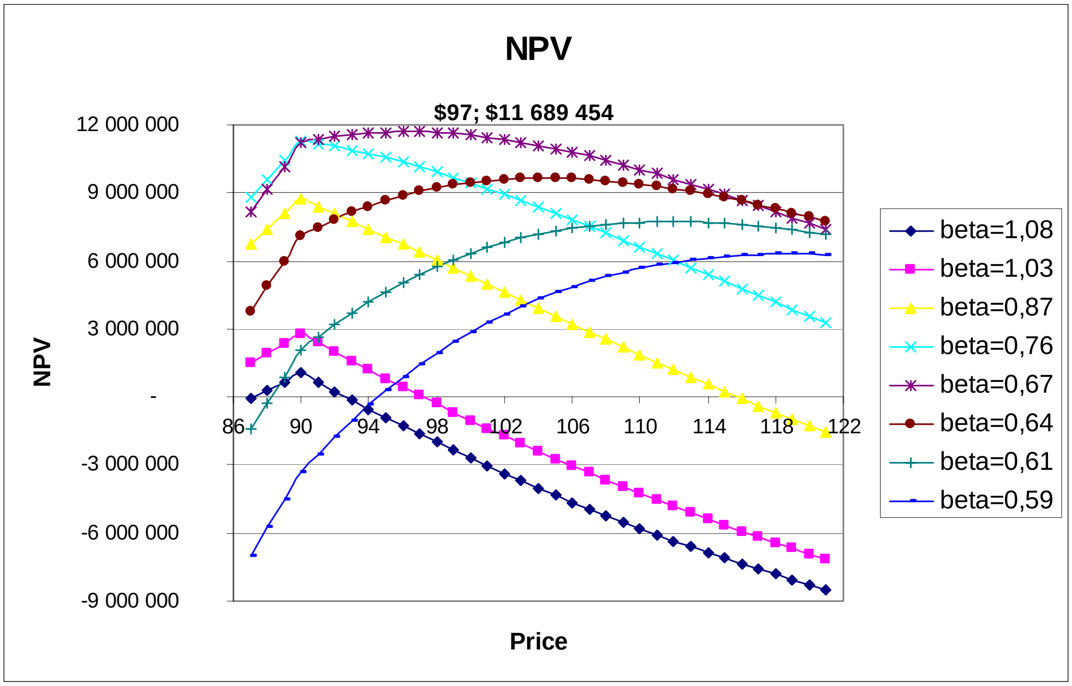

Figure 6: Profit as a function of quality and price.

Conclusions

The basic message that this paper conveys is that pricing and microeconomics are needed when one wants to design new products. We have resorted to hedonic theory to develop a framework in which all the elements of new product commercialization, namely, the product composition/structure, the manufacturing investment and costs, the associated supply chain and the consumer behavior with respect to price product and price are taken into account in a multi-scale model that determines all the parameters of the subsystems involved, form the product structure to the choice of markets and the price of the product in each market. This framework will be advanced in upcoming work for which this paper is a small advance.

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