EXHIBIT 3

How Much Does the Market Value an Improvement in a Product Attribute?

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A firm contemplating improvements to its product attributes would be interested in the dollar value the market attaches to any potential product modification. In this paper, we derive a measure of market value such that the comparison of the measure against the incremental unit cost of the attribute improvement is key in deciding whether or not the attribute improvement is profitable. Competition from other brands, the potential for market expansion, and heterogeneity in customer preference structures are explicitly modeled using the multinomial logit framework. The analysis yields a closed form expression for the market's value for an attribute improvement (MVAI). A key result we obtain is that customers should be differentially weighted based on their probability of purchasing the firm's product. In particular, customers who exhibit a very high or very low probability of choosing the firm's product should receive less weight in detemining MVAI. Because the probability of choice varies across products, the answer to the question of how much the market values an improvement depends on which firm is asking the question. It is shown that customers whose utilities have a greater random component should be weighted less. Furthermore, the measure developed is robust to the influence of outliers in the sample. An empirical illustration of the MVAI measure in the context of a new product development study is provided. The study illustrates the advantages of the proposed measure over currently used approaches and explores the possibility of competitive price reactions.
(New Product Development; Product Positioning; Multibrand Competition; Conjoint Analysis)

1. Introduction

In many product markets, firms often desire to modify their product attributes. Evolving consumer preferences, advances in technological capabilities, changes in manufacturing costs, and competition from other brands drive firms to consider improving product characteristics. While some companies attempt to develop radically innovative products, new product activity often involves the modification of an existing product. Typically, value adding modifications entail offering more of a desirable attribute or less of an undesirable one.[1] Such product changes have both cost and demand implications, and require reevaluating pricing decisions as well. While,

[1]In reality, there may also be cases where firms wish to accomplish the opposite, i.e., offer less of a desirable attribute or more of an undesirable one (perhaps because of a cost increase). The analysis we present is general enough to handle these cases as well. We have framed the problem in terms of product improvement as it is the most common form of product modification (Griffin 1997).

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in general, firms know their own cost structures, assessing demand sensitivity to product changes can be difficult, especially when the market is comprised of customers heterogeneous in preferences and there are several competing brands. Nonetheless, accurate assessment of the market's response to any such attribute improvement is essential to a firm in the product planning phase, and for effective pricing and forecasting.

To explore this issue in greater detail, we seek to establish a market-level analog to an individual customer's value for an improvement in a product attribute. The latter quantity is usually defined as the increase in price needed to offset an incremental change in an attribute level, so that the customer's overall utility for a particular product remains constant. This calculation is straightforward once the parameters of the utility function for that individual have been estimated by conjoint analysis (Green and Srinivasan 1990). Yet when dealing with a heterogeneous set of customers, all potentially relevant for the firm's market share, it is not obvious *how* to aggregate these individual parameters to form a single market-level valuation index. From a managerial perspective, it is the aggregate measure that is relevant for product planning rather than individual-level measures.

In this paper, we theoretically derive such a market-level valuation measure by looking at the profit change a firm can expect from an incremental improvement in a product attribute when setting its price optimally. We define our measure as the market's value for an attribute improvement (MVAI) and show it has three major advantages over current approaches. First, MVAI has the managerially attractive property that it can be compared to the incremental unit cost of the attribute improvement to determine the profitability of the product modification. Second, it provides a conceptually sound method for calculating the market's value for a product attribute compared to the commonly used method of averaging customer-level willingness-to-pay measures. Third, by deriving an analytic expression in the context of the standard multinomial logit framework, we are able to offer many valuable insights into the factors that affect the market's value for an attribute improvement. Specifically, we find that the market's value for an improvement is *not* obtained as an average of individual-level measures, i.e., by averaging the dollar amount needed to keep each customer's preference constant. Rather, the precise formula involves the ratio of two *separate* and *weighted* sums across customers: one related to the importance of the attribute and the other to the importance of price. It is shown that customers should be differentially weighted based on their probability of purchasing the focal product. A customer with an extreme probability (either approaching zero or one) of purchasing the focal product is relatively insensitive to that product's attribute and/or price modifications and, hence, should be given less weight. Because the choice probabilities vary across products, the market's value for an improvement in a product attribute depends on which competitive product is asking the question. The approach discounts customers whose utilities have a greater error component and are therefore less susceptible to attribute and/or price changes. In addition, the measure is fairly robust to the influence of outliers in the data, making it unnecessary to drop observations or worry about extreme results. In the context of a new product development study, this paper provides an empirical illustration of the advantages of the proposed measure over currently used approaches and explores competitive price reactions.

The rest of the paper is organized as follows: We first derive a general formulation of the market's value for an incremental improvement in a product attribute for a firm assessing the profitability of a product modification. Next, using the standard logit framework to link individual preference parameters to market shares, we calculate an explicit expression for MVAI and highlight the implications for how individual parameters should be weighted and aggregated. An empirical illustration of the proposed measure is then provided that also incorporates competitive price reactions. We conclude with managerial implications of the MVAI measure.

2. Firm Profitability and the Market's Value for an Improvement in a Product Attribute

An important financial criterion for measuring the success of a product development effort is whether it would result in increased profits. For the type of product modification considered in this paper, the relevant question becomes: What determines whether an incremental improvement in a product attribute will result in an increase in profits? We turn to examine this question assuming that, subsequent to any product modification, a firm would adjust its price to achieve maximal profits. As we shall see, answering the above question will allow us to derive a measure of the market's value for an incremental improvement in a product attribute. We begin by analyzing the pricing action of the product modifying firm, assuming that no other firm reacts to its actions (this case is realistic if, in the short run, other firms in the product market are committed to their prices, and it also applies to the monopoly case). Such an analysis is a starting point for determining the profitability of an attribute change. We consider competitive price reactions in §4.3 (and Appendix) and show that our proposed measure is relevant in such contexts as well. In this respect, our work is related to the marketing literature on competitive positioning (e.g., Hauser and Shugan 1983, Ansari et al. 1994). Such papers analyze firm pricing and product attribute decisions in competitive settings and incorporate customer heterogeneity in the form of probabilistic distributions. Our paper contributes to the understanding of how such decisions should be made by analyzing and providing insights on the way individual-level data can be weighted and aggregated so that a single, theoretically meaningful measure of market value for an attribute improvement can be obtained.

2.1. Model

Consider a given product market consisting of J products each offered by a different firm. Let each of the J products be defined by a vector of K product attributes $\vec{x}_j$, with the level of attribute k for alternative j denoted x_{jk}. Denote the market share of firm (product) j as m_j and its unit price as p_j. We allow for the possibility of an outside good with market share m_0, such that $m_0 + \sum_{j=1}^{J} m_j = 1$. Denote by Q the maximum sales potential for the product category, so that the actual sales of the category of J products are $Q(1 - m_0) = Q \sum_{j=1}^{J} m_j$. The outside good permits the market (i.e., sales) for the category of J products to expand or contract depending on the J products' attributes and prices. Furthermore, assume that market shares are differentiable in prices and attribute values. To set up a framework for firm optimizing behavior, let firm j's profit function π_j be

$$\pi_j = Qm_j(p_j - c_j(\vec{x}_j)), \tag{1}$$

where $c_j(\vec{x}_j)$ is firm j's variable cost of producing each unit, which depends on the particular attribute levels offered by product j (for notational convenience, we suppress this dependence and, from here on, denote the variable cost as c_j).[2] Let all market shares satisfy the following standard properties of price competition with differentiated goods: $\partial m_j/\partial p_j < 0$, $\partial m_{j'}/\partial p_j > 0\ \forall j' \neq j$. In particular, $\partial m_0/\partial p_j > 0$, so that aggregate category sales, given by $Q(1 - m_0)$, depend on the firms' prices (the outside good also allows for the special case of a monopoly ($J = 1$) whose sales depend on its product attributes and price.) In §3, we elaborate on how market shares, which satisfy the above properties, can be determined as a function of customer preferences and product attribute levels. We further assume that the profit functions in (1) satisfy $\partial^2\pi_j/\partial p_j^2 < 0$, so that we are guaranteed an interior pricing solution.

Optimizing behavior by firm j means that it sets a price to satisfy

$$\frac{\partial \pi_j}{\partial p_j} = 0. \tag{2}$$

[2] To simplify analysis, we assumed that there are no economies (or diseconomies) of scale so that the variable cost c_j does not depend on the sales level (Qm_j) of product j. For expositional covenience, we also assumed that there are no fixed costs.

Substituting (1) into (2) yields the following first-order condition:

$$m_j + \frac{\partial m_j}{\partial p_j}(p_j - c_j) = 0. \quad (3)$$

We can now examine the total effect on profitability triggered by the change in attribute x_{jk}. This is given by

$$\frac{d\pi_j}{dx_{jk}} = \frac{\partial \pi_j}{\partial x_{jk}} + \frac{\partial \pi_j}{\partial p_j}\frac{dp_j^*}{dx_{jk}}, \quad (4)$$

where p_j^* is the optimal price according to (3). From the first-order condition in (2), we know the second term on the right-hand side of (4) is zero. Thus, (4) can be rewritten as

$$\frac{d\pi_j}{dx_{jk}} = \frac{\partial \pi_j}{\partial x_{jk}} = \frac{Q\partial m_j}{\partial x_{jk}}(p_j - c_j) - Qm_j\frac{\partial c_j}{\partial x_{jk}}.$$

Substituting from (3) we obtain

$$\frac{d\pi_j}{dx_{jk}} = Qm_j\left(-\frac{\partial m_j/\partial x_{jk}}{\partial m_j/\partial p_j} - \frac{\partial c_j}{\partial x_{jk}}\right). \quad (5)$$

We see from (5) that when firm j considers only its actions and sets a price to maximize profits, the condition for the attribute change to be profitable is

$$-\frac{\partial m_j/\partial x_{jk}}{\partial m_j/\partial p_j} > \frac{\partial c_j}{\partial x_j}. \quad (6)$$

The left-hand side of (6) is a ratio of the change in market share the modifying firm can expect from improving a product attribute, divided by the change in market share due to repricing. As this ratio reflects aggregate demand sensitivity for the incremental attribute and price changes, we define it to be the market's value for attribute improvement (MVAI):

$$\text{MVAI} = -\frac{\partial m_j/\partial x_{jk}}{\partial m_j/\partial p_j}. \quad (7)$$

The inequality in (6) has an appealing interpretation; it states that the profitability of each unit sold depends on how much the market value for the proposed improvement exceeds the marginal cost of executing it (aside from any one-time fixed costs). The decision on whether to implement a particular product change takes on an explicit benefit versus cost form. Furthermore, this ''benefit'' to the firm is fundamentally demand driven.

An alternative interpretation of MVAI in (7) comes from the following observation. The total differential of firm j's market share with respect to attribute k and price p_j is

$$dm_j = \frac{\partial m_j}{\partial x_{jk}}dx_{jk} + \frac{\partial m_j}{\partial p_j}dp_j. \quad (8)$$

Suppose we wish to leave firm j's market share unaltered; i.e., we require $dm_j = 0$. It follows from (8) and (7) that

$$\frac{dp_j}{dx_{jk}} = -\frac{\partial m_j/\partial x_{jk}}{\partial m_j/\partial p_j} = \text{MVAI}. \quad (9)$$

Thus, MVAI is also the incremental price the firm would charge per unit improvement in the product attribute (assumed to be infinitesimal) if it were to hold market share (or sales) constant.

Interpreting MVAI as the incremental price change (divided by the attribute change) that leaves market share unaltered suggests a computational method for determining MVAI. First, change the product attribute in the conjoint simulator and then search over the price change that would leave market share unaltered. An efficient way for conducting such a search on price is the method of interval bisection (Wagner 1975, p. 539). As an approximation, one could use this computational method in conjunction with the max-choice rule, in which case the market share for each alternative is obtained by counting all individuals (weighted based on the quantities they purchase in the product category) whose preference for the alternative is highest and dividing by the total number of individuals. The drawback of the computational method is the lack of a closed-form solution for MVAI. In the next section, we provide such a closed-form expression for MVAI in the context of the logit model. The expression also provides valuable insights into the determinants of MVAI.

3. A Logit Model-Based Expression for the Market's Value for an Attribute Improvement

Thus far, we provided a general form for the market's value for a product improvement and established its importance for assessing the profitability of a proposed attribute change. As MVAI is a function of market share, it is obviously related to the change in demand for the modified product. It is not clear, however, what customer-level parameters are required to determine it, how such parameters should be aggregated, and what the dependence on the current set of competing products is. To shed light on these issues, we proceed as follows: We begin by specifying a simple model of customer multiattribute preferences, which is then used to obtain market shares within the standard logit model framework. These, in turn, are used to derive a closed form expression for MVAI. We highlight the analytic insights gained from this proposed measure and discuss its practical benefits.

3.1. Individual Preferences

Since our primary interest is the trade-off between attribute levels and price, as well as the resulting impact on market behavior, it is only natural to operate in the setting of multiattribute preference models (Green and Srinivasan 1990). As such, an individual's deterministic preference for any alternative can be written as a sum of part worths and is given by

$$\upsilon_j^i = \sum_{k=1}^{K+1} f_k^i(x_{jk}), \tag{10}$$

where

υ_j^i = the (deterministic) utility individual i attaches to alternative j;

x_{jk} = level of attribute k for alternative j (there are $K+1$ attributes, including price); and

f_k^i = the part-worth function relating level of attribute k into utility units for individual i.

For expositional ease, we will assume the functions f_k^i conform to the vector (or linear) model; i.e., we can replace them with individual attribute weights w_k^i. As is common with most multiattribute preference models, we treat price as a separable determinant of utility. Consistent with previous notation, we denote the price of alternative j by p_j and its coefficient by $(-w_p^i)$. Equation (10) can now be written

$$\upsilon_j^i = \left(\sum_{k=1}^{K} w_k^i x_{jk}\right) - w_p^i p_j, \tag{11}$$

where $w_p^i > 0$ (note that in (11) price would relate negatively to utility). We assume that the parameters $\{w_k^i\}$, w_p^i and the randomness parameter (see §3.2) are estimated by conjoint analysis (Green and Srinivasan 1978). In the Technical Appendix,[3] we derived some of the major results using the more general formulation, as in (10).

3.2. From Customer Preferences to Market Shares

To obtain market shares from customer preferences, we first link overall utility for an alternative with a choice probability. As we shall see, this approach yields closed form expressions for both market shares and MVAI.

Linking overall preference for an alternative with a choice probability can be achieved by invoking random utility theory (Ben-Akiva and Lerman 1985, pp. 60–66). Thus, we can regard the multiattribute preference model discussed earlier as the deterministic (or systematic) component of utility, to which a random component is added. Thus, the utility individual i assigns alternative j is $u_j^i = \upsilon_j^i + \varepsilon_j^i$, where υ_j^i is the deterministic component and ε_j^i is the random component. The deterministic component is obtained from (11) (or (10) in the more general case). The stochastic components ε_j^i are assumed to be independent across j and distributed Gumbel with cumulative distribution function $F(\varepsilon_j^i) = \exp[-\exp(-\mu_i\varepsilon_j^i)]$, where $\mu_i > 0$ is individual i's scale parameter, which is inversely related to the variance of the random component $\mathrm{Var}(\varepsilon_j^i) = \pi^2/6\mu_i^2$.

[3]The Technical Appendix is available at the INFORMS Marketing Science website at http://www.informs.org.

From this specification of random utility, choice probabilities can easily be derived using the multinomial logit model (McFadden 1974, Ben-Akiva and Lerman 1985, pp. 103–107). Hence, the probability of individual i choosing alternative j, when J alternatives (and an outside good) are available, takes the familiar form

$$\theta_j^i = \frac{\exp(\mu_i \upsilon_j^i)}{\exp(\mu_i \upsilon_0^i) + \sum_{j'=1}^{J} \exp(\mu_i \upsilon_{j'}^i)}, \qquad (12)$$

where υ_0^i is customer i's (deterministic) utility for the substitute outside good. Let q_i denote the (exogenously specified) maximal purchase quantity for customer i. Consistent with previous notation, $Q = \sum_i q_i$ is the maximum product category sales. The expected quantity each individual purchases in the category of J products is thus $q_i(1 - \theta_0^i)$. As the probability of choosing the outside good (or no purchase) is a function of the prices and attributes of all J products in the market, the total sales of the J products in the category generally increase when any firm decreases price or improves its product attributes.

The calculation of market shares is now straightforward. For each alternative, add the individual probabilities of choosing it, weighted by the appropriate purchase quantities

$$\begin{aligned} m_j &= \frac{1}{Q} \sum_i q_i \theta_j^i \\ &= \frac{1}{Q} \sum_i \frac{q_i \exp(\mu_i \upsilon_j^i)}{\exp(\mu_i \upsilon_0^i) + \sum_{j'} \exp(\mu_i \upsilon_{j'}^i)}. \end{aligned} \qquad (13)$$

It is straightforward to establish that market shares thus defined satisfy all the properties required in §2 (namely, $\partial m_j / \partial p_j < 0$, $\partial m_{j'} / \partial p_j > 0 \ \forall j' \neq j$, and $\partial m_0 / \partial p_j > 0$).

3.3. Calculating Market Value for an Attribute Improvement

Having established how market shares are formed from individual preferences, we are now ready to apply this framework to derive an explicit expression for MVAI. Using (11)–(13), (7) can be shown to be

$$\begin{aligned} \text{MVAI} &= -\frac{\partial m_j / \partial x_{jk}}{\partial m_j / \partial p_j} \\ &= \frac{\sum_i q_i \mu_i \theta_j^i (1 - \theta_j^i) w_k^i}{\sum_i q_i \mu_i \theta_j^i (1 - \theta_j^i) w_p^i} = \frac{\sum_i a_j^i w_k^i}{\sum_i a_j^i w_p^i}, \end{aligned} \qquad (14)$$

where a_j^i represent customer weights for the jth product and are given by

$$a_j^i = q_i \mu_i \theta_j^i (1 - \theta_j^i). \qquad (15)$$

3.4. Properties of the MVAI Expression

This section highlights the major insights from the previous analysis, in particular, the properties of Equations (14)–(15).

3.4.1. The Aggregation of Individual Influences. Let us reconsider the basic question we intended to answer: What value does the market attach to an improvement in a product attribute? If there is only one relevant customer, say individual i, then the answer to the above question is

$$\frac{w_k^i}{w_p^i}. \qquad (16)$$

This follows immediately from (14) with only one customer.[4] Thus, at a conceptual level, w_k^i and w_p^i are core parameters that should be part of any solution to the original question. Yet, in a fully heterogeneous model, where potentially all individuals are relevant for market performance, how individual parameters should be weighted and aggregated is of primary interest.

A common practice in conjoint analysis for obtaining a single market value measure is to take a weighted average of the individual ratios in (16) (Wyner 1997). Following this approach with a sample of N individuals we obtain

[4]The same answer is obtained in conjoint analysis by considering only Equation (11) and posing the condition that individual i's deterministic utility for alternative j stays unchanged. This can be verified by dividing i's preference for alternative j throughout by the weight of price w_p^i, as suggested by Srinivasan (1979). Thus, utility is measured on a dollar-metric scale, and the coefficient for attribute k becomes w_k^i / w_p^i.

$$\frac{1}{Q}\sum_{i=1}^{N} q_i \left(\frac{w_k^i}{w_p^i}\right). \tag{17}$$

There are several important differences between the expression in (17) and our MVAI measure (14). While in (17), the summation is over individual ratios (w_k^i/w_p^i), in (14), we have a ratio of two summations. The numerator of (14) is an aggregate measure of sensitivity to the level of attribute k, while the denominator is an aggregate measure of sensitivity to price. From a methodological perspective, the formulation in (14) is more robust and less affected by outliers with extreme parameter values. Individuals with a very low price weight (relative to their weight for attribute k) would impact the overall measure suggested in (17) far more than is called for. Such outliers will cause the change in attribute k to be overevaluated. In particular, $w_p^i = 0$ for any one customer would make (17) practically useless (unless this observation is dropped). This problem is automatically avoided in our MVAI formulation by separating the summations of customer attribute and price weights before dividing.

While it is possible to reduce the outlier problem by computing the (weighted) median of the set $\{w_k^i/w_p^i\}_{i=1}^N$ instead of the weighted mean as in (17) (Orme 2001), both approaches would incorporate only individual specific parameters (attribute and price weights and individual quantity of purchase). In contrast, an important aspect of the MVAI expression is that individual attribute and price weights are multiplied by customer specific weights a_j^i (see (14)–(15)) prior to summation. In particular, two additional quantities, the probability of purchase θ_j^i and the logit scale parameter μ_i, now play a role in determining how much each customer's attribute and price weights should contribute to the aggregate measure. We discuss the significance of these factors in turn.

3.4.2. The Impact of Probability of Purchase. The setting for our analysis is that of a product category in which each existing alternative has a specified multiattribute location and price. The infinitesimal changes we explore are taken about the current attribute values of the focal product. From Equation (12), this implies that prior to any change, each individual has well-defined choice probabilities for the J available alternatives. While these probabilities are irrelevant when only one customer is analyzed (see (16)), when the entire market is taken into account, they are, in fact, important. Specifically, in (15), the weight given to customer i has a probability-related factor given by $\theta_j^i(1 - \theta_j^i)$. This factor, arising in other applications of the multinomial logit (e.g., Bucklin et al. 1998), is a concave function of θ_j^i that attains its maximum at $\theta_j^i = 0.5$ and approaches zero as $\theta_j^i \to 0$ or 1. What this means is that individuals who either have a very low or a very high initial probability of choosing alternative j will bear far less on the overall measure of market value than those with a probability closer to 0.5. The intuition behind this result is that the more extreme the probability of purchase (either toward 0 or 1), the less likely a change in product location or price will cause a shift in choice probability or induce switching to or from the focal product. For such individuals, the original preference for the focal product is either very low or very high, making them far less likely to change their purchase probability. Thus, from the perspective of impact on market share, we should focus on those customers whose choice probabilities exhibit maximal sensitivity. In the context of our present model, these are the customers indifferent between our product and the composition of all others. Such customers are not too inclined or disinclined to choose the product so that their relative impact is most relevant.[5] It is noteworthy that even when the number of products is $J > 2$, it is still true that the most relevant customers to the firm making

[5]We thank Professor Donald Lehmann for pointing out that our result is analogous to political candidates exerting maximum effort on undecided voters, and direct marketers offering deals to customers "on the fence." The significance of marginal consumers, for which a price increase in their consumed commodity induces switching to another commodity, has also been pointed out by Novshek and Sonnenshein (1979).

the changes are those with $\theta_j^i \to 0.5$, i.e., not those with equal choice probabilities for all brands.[6]

As the term $\theta_j^i(1 - \theta_j^i)$ is a function of all the alternatives in the market studied, the competitive structure of the product market is, in a sense, reflected. In contrast, (17) depends only on the individual specific parameters. Because θ_j^i depends on j, we emphasize that with MVAI, the market's value for the same increment in a product attribute will differ, in general, for each of the J products. MVAI would also be different for the same focal product if we changed the set of competing alternatives. In particular, we discuss the implications of increasing the number of competitors in connection with the empirical application in §4.3.

3.4.3. The Role of the Logit Scale Parameters. In addition to the $\theta_j^i(1 - \theta_j^i)$ factor, the customer weights a_j^i are also affected by μ_i. This term originates from the random utility component of the multinomial logit model. A very small μ_i (relative to the weights w_k^i) indicates that the variance of the random component is large, implying that the deterministic utility function has less impact on choices. In fact, if $\mu_i \to 0$, $\mathrm{Var}(\varepsilon^i) \to \infty$ and, consequently, $\theta_j^i \to 1/(J + 1)$ for $j = 0, 1, 2, \ldots, J$. That is, the deterministic utility function (and, hence, any attribute change) has no effect on choice probabilities. On the other hand, a very large value of μ_i would mean that customer i's probability of choosing the product with the highest υ_j^i approaches one. Therefore, the presence of μ_i allows for each customer's contribution to the aggregate measure to be scaled to reflect the relevance of the deterministic component of utility in establishing his or her choice probability.

[6]Obviously, individual choice probabilities (θ_j^i) tend to decrease as the number of alternatives J increase. However, as this is true both in the numerator and denominator of (14), even as J becomes very large, MVAI and the average of individual ratios approach (17) are generally expected to yield distinctly different values. See also empirical results presented in §4.3.1.

4. Empirical Illustration

We now illustrate how the proposed MVAI measure can be estimated in the context of a new product development study. We discuss the advantages of our proposed measure over alternative approaches and allow for competitive price reactions.

4.1. Estimation of Multiattribute Preferences

The product category used in this particular study was portable camera mounts. This represents a durable product category in which a typical customer requires, at most, only one item, i.e., $q_i = 1$, $\forall i$. The data are from 302 respondents who were contacted as part of a graduate-level course in new product design at Stanford University and who expressed interest in purchasing a product in the category.[7] On the basis of qualitative customer and retailer research, a set of five product attributes, in addition to price, were predetermined as the most important drivers of customer choice in the product category. Participants were asked to rank, in order of likelihood of purchase, 18 full profile cards with all attributes having three possible values, thus avoiding any number-of-attribute-levels effects (Wittink et al. 1990). (The "outside good" was not considered in this application.) Using exploded logit (Ben-Akiva et al. 1992, Chapman and Staelin 1982, Hausman and Ruud 1987) we estimated the product of attribute weights and logit scale parameters ($\mu_i w_k^i$) for each attribute (including price) and for each individual.[8]

4.2. Calculating Market Value for an Attribute Improvement

To simulate a product market with competing alternatives, we used two existing commercial products (UltraPod and Q-Pod) and a third designed by the students (GorillaPod). See Table 1 for a description of these three products (the Camera Critter and Half Dome products are discussed in §4.3.1). Given the

[7]See Srinivasan et al. (1997) for more details regarding the course entitled "Integrated Design for Marketability and Manufacturing" (IDMM).

[8]In the exploded logit model, it is not possible to estimate μ_i and w_k^i separately; only their product can be estimated.

Table 1 Attribute Levels of Portable Camera Mount Products

Product	Weight (oz.)	Size[a]	Set Up Time (min.)	Stability[b]	Flexibility[c]
UltraPod	2.0	0.98	0.98	1.8	1.96
Q-Pod	3.5	0.84	0.84	2.5	2.17
GorillaPod	4.6	1.27	0.50	2.3	2.84
Camera Critter	1.7	0.80	0.62	2.5	1.8
Half Dome	5.7	1.2	0.42	3.0	2.33

[a] Where 1 represents a camera mount that can fit in a standard pocket, and 3 only in a standard book bag.
[b] Where 1 means a camera mount stable enough under light-medium wind conditions for a small camera with a built-in lens, and 3 for a full-size camera with a large lens.
[c] Where 1 means that the Positioning Flexibility of a camera mount is low, and 3 is high. Positioning Flexibility is the degree to which the product can be adapted to various terrains (flat-uneven) and be adjusted for height (inches-feet) and angle (fixed-complete rotational freedom).

Table 2 Comparing Methods for Calculating Market Value for an Attribute Improvement[a]

Attribute (cost)[e]	MVAI[b] UltraPod	Q-Pod	GorillaPod	Ave. Ratios[c]	Med. Ratios[d]
Weight (0.49)	1.59	1.66	1.58	2.87	0.60
Size (0.23)	1.12	1.26	1.15	2.06	0.03
Set Up Time (1.41)	0.95	0.99	1.00	2.06	0.68
Stability (0.31)	1.10	1.35	1.26	2.58	0.63
Flexibility (0.26)	0.74	0.86	0.89	1.93	$\sim$0
RMSE[f]				1.14	0.84
MAD[g]				1.13	0.78
MAPD[h]				101.4%	68%

[a] All values in the table are positive to reflect value of attribute improvement (in tens of dollars).
[b] $\mathrm{MVAI}_{jk} = \sum_i \theta_j^i(1-\theta_j^i)(\mu_i w_k^i)/\Sigma_i\, \theta_j^i(1-\theta_j^i)(\mu_i w_p^i)$.
[c] Average of individual ratios $= (1/N)\,\Sigma_i\,(w_k^i/w_p^i)$, $N = 302$.
[d] Median of individual ratios from the set $\{w_k^i/w_p^i\}_{i=1}^N$.
[e] Number in parentheses denotes the marginal cost of improving the attribute (in tens of dollars).
[f] Root mean squared deviation from MVAI (based on the 15 different items, i.e., 3 products $\times$ 5 attributes, for which the deviation from MVAI can be computed).
[g] Mean absolute deviation from MVAI.
[h] Mean of absolute percent deviation from MVAI.

product market, it is straightforward to use the approach described in §3.3 to calculate a dollar MVAI for each attribute. This is done with respect to all five attributes and for each of the three products. The resulting values are given in columns 2–4 of Table 2. To highlight the benefits of our proposed measure compared to other commonly used methods, we computed the following two additional measures based on the value each individual, when analyzed separately, attaches to the attribute change (see (16)). The average and median of these individual ratios are reported in columns 5 and 6 of Table 2, respectively. It is clear from the table that both alternative measures yield very different results compared to those arising from the MVAI measure. In particular, the values generated by the averaging approach differ by 101.4% from the MVAI measure (averaged across all five attributes and all three products), and are always higher (in some cases, by as much as 161% for the UltraPod product with respect to Flexibility). This is an indication of the upward bias resulting from averaging individual measures because of outliers (i.e., very small price weights) in the data as discussed in §3.4.1.[9] Also note that while Size and Set Up Time have equal values with the averaging approach, this is not the case with MVAI.

The values generated by selecting the median of individual ratios differ from MVAI by 68%. While the outlier problem is avoided with this approach, the values are biased downward for all attributes.[10] In addition, Set Up Time is the most highly valued attribute with this approach, while it is only the fourth highly valued attribute in terms of MVAI. The difference between MVAI and the median is most pronounced for Flexibility, with a near zero median value. We also note that, while MVAI gener-

[9] This was true even after constraining individual price weights so that each individual had at least some minimal level of price sensitivity according to $(|(\mu_i w_p^i)\Delta_p|)/(\sum_{K+1}|(\mu_i w_k^i)\Delta_k|) \geqslant 1/t(K+1)$, $t = 2$, and $\Delta_{k,p}$ the feasible range of attribute k or price, respectively. We also set $t = 1$, $t = 4$, and obtained qualitatively similar results.

[10] The distribution of w_k^i/w_p^i is positively skewed due to the division by w_p^i; hence, the median is expected to be lower than the mean. Note that in our empirical application, the median values are not only lower than in the averaging approach but are also lower than the corresponding MVAI values.

Table 3 UltraPod Profitability from an Attribute Change When Incorporating Competitive Price Reactions

Attribute Changed[d]	MVAI-Based[a]	Competitive-Reaction Scenario[b]	
		No Reaction	Price Reaction[c]
Weight	108.5	109.9	67.3
Size	87.8	89.2	69.8
Set Up Time	−45.4	−44.9	−67.0
Stability	77.9	79.7	40.5
Flexibility	47.3	48.2	21.3

[a]Based on (5), we report Qm_j (MVAI − MC), where MVAI and MC (the marginal cost of improving the attribute) are as given in Table 2, $Q = N = 302$, and $m_{\text{UltraPod}} = 32.65\%$ based on the initial product market attribute levels (Table 1).
[b]To be on a comparable scale to the MVAI-based values, we report $\Delta\pi_j/\Delta x_{jk}$ where $\Delta\pi_j$ is the difference in UltraPod profits before and after the attribute change, and Δx_{jk} is the amount by which the attribute was improved.
[c]Given the attribute change by UltraPod, all firms simultaneously adjusted prices so that the market was in a Nash price equilibrium.
[d]Each attribute was changed by 5% of its range of values.

ally produces different values for each of the alternative products, the average and median of individual ratios do not depend on the product considered (see (17)). For example, MVAI gives UltraPod a higher market value for Size than Stability, while the reverse is true for Q-Pod and GorillaPod.

The derivation of MVAI in (3)–(5) shows that it is meaningful to compare MVAI with the marginal cost of improving each attribute. From prototypes of several products the students actually built, we obtained through multiple regression analysis, an approximate marginal cost associated with each attribute improvement ($\partial c/\partial x_k$). These marginal costs are given in parentheses in column 1 of Table 2. Several interesting conclusions emerge. When subtracting the marginal cost increase associated with attribute improvement from MVAI, Set Up Time is clearly not profitable for any of the products. However, comparing this cost of improvement with the value given by the averaging approach predicts that Set Up Time is a profitable attribute to improve.

4.3. Incorporating Competitive Price Reactions

Our MVAI measure (and the corresponding comparison of it with marginal cost of attribute improvement (5)–(6)) was developed under the assumption that competitors do not react to the attribute and price changes made by the repositioning firm. In many cases, it is more realistic to assume that competitors will, in fact, react by adjusting their own prices. To explore this possibility, we allowed one firm, UltraPod, to improve each of its five attributes (one at a time by 5% of the range of allowable attribute values).[11] Two possible scenarios were considered. In the No-Reaction Scenario, only UltraPod modified a product attribute and then changed its price to achieve maximal profits. In the Price-Reaction Scenario, we let all firms simultaneously change prices subsequent to the attribute change by UltraPod and required that the market be in a Nash price equilibrium (just as it was in such an equilibrium prior to the UltraPod move).

The results of exploring the two scenarios are provided in Table 3. Column 2 of Table 3 gives the MVAI-based criterion (5) for evaluating profitability (using the marginal costs of improving attributes given in parentheses in column 1 of Table 2). Columns 3–4 of Table 3 give UltraPod profitability under the two Competitive-Reaction Scenarios described above on a per unit attribute changed, thus allowing direct comparison with the MVAI-based criterion. As expected, UltraPod profitability levels for all attribute improvements decrease as one moves from column 3 to 4.

The results demonstrate the relevance of MVAI. First, note that the MVAI-based profitability measure is closely related to the profitability values in the No-Reaction Scenario.[12] This corroborates the theoretical derivation of MVAI for small changes taken about the existing product. Second, the attribute changes for which MVAI is positive (negative) continue to be positive (negative) after taking competitive price reactions into account and are generally the same rank order. The only exception is that Size becomes slightly more profitable than Weight in the

[11]We also explored 1% and 2.5% improvements and obtained similar results.
[12]The MVAI result in column 2 of Table 3 is based on an infinitesimal change in attribute value, while column 3 is based on a 5% change in attribute value.

Price-Reaction Scenario. This intuitively occurs because Weight is the most highly valued attribute for all three competing products, as can be gleaned from the MVAI values in Table 2. Hence, an UltraPod change in that attribute triggers a stronger pricing response than Size does. In the Appendix, we provide a theoretic explanation for why comparison of MVAI to the incremental cost of attribute improvement continues to be important when other firms react through price to the focal product's attribute change, as well as how profitability generally decreases as competitors react with price changes.

4.3.1. Sensitivity of MVAI to Expanding the Competitive Set. As noted in §3.4.2, the presence of the term $\theta_j^i(1 - \theta_j^i)$ in both the numerator and denominator of (14) renders MVAI values for each product sensitive to the set of competing alternatives. In particular, the introduction of additional alternatives can change the MVAI values of existing products.[13] The sign of these changes depends on how the relative attractiveness of each product's attribute levels and equilibrium price are affected by additional products in the set. Table 4 presents MVAI values when the set of alternatives is increased from three to four and then to five products (a description of the additional alternatives is given in the last two rows of Table 1). As can be seen, when the existing three alternatives are joined by Camera Critter, all MVAI values for UltraPod decrease. This is because the price charged for UltraPod decreases considerably; hence, it tends to attract (on a probabilistic basis) individuals who are relatively price sensitive (with high w_p^i). Given that the presence of Camera Critter also tends to reduce the relative appeal of UltraPod product attributes,[14] the denominator of (14) (reflecting price sensitivity) tends to increase relative to the numerator, resulting in lower MVAI values for all attributes. For Q-Pod, the situation is reversed. It is the highest-priced alternative (with the margin of difference to the second- most expensive product having increased); hence, it tends to attract individuals who are less price sensitive. The denominator thus decreases relative to the numerator, offsetting the fact that Camera Critter is more attractive on some attributes. For GorillaPod, the situation is mixed. Its price is in a middle range; hence, on the attributes on which it dominates (Set Up Time and Flexibility), MVAI values tend to increase, while for attributes the new alternative is more attractive on, they tend to decrease. Similar considerations help explain MVAI changes between the four- and five-product scenarios. It is noteworthy that because the fifth alternative (Half Dome) is relatively highly priced, it now tends to attract the price-insensitive individuals and, consequently, MVAI values for Q-Pod all decrease.

Table 4 MVAI as a Function of the Number of Competing Products[a]

Products in Competitive Set[c]	MVAI[b] Weight	Size	Setup Time	Stability	Flexibility
1. UltraPod (8.84)	1.59	1.12	0.95	1.10	0.74
2. Q-Pod (9.89)	1.66	1.26	0.99	1.35	0.86
3. GorillaPod (9.53)	1.58	1.15	1.00	1.26	0.89
1. UltraPod (7.72)	1.54	1.09	0.92	1.04	0.73
2. Q-Pod (9.22)	1.72	1.33	1.01	1.44	0.94
3. GorillaPod (8.50)	1.55	1.14	1.01	1.26	0.95
4. Camera Critter (8.22)	1.63	1.20	0.99	1.25	0.76
1. Ultra Pod (7.15)	1.52	1.06	0.90	0.98	0.70
2. Q-Pod (8.53)	1.69	1.30	0.99	1.37	0.90
3. GorillaPod (7.75)	1.50	1.10	0.99	1.18	0.92
4. Camera Critter (7.49)	1.59	1.17	0.97	1.19	0.72
5. Half Dome (10.39)	1.93	1.44	1.19	1.85	1.17

[a]A description of the products is given in Table 1. All values in the table are positive to reflect value of attribute improvement (in tens of dollars).
[b]$\text{MVAI}_{jk} = \sum_i \theta_j^i(1 - \theta_j^i)(\mu_i w_k^i)/\sum_i \theta_j^i(1 - \theta_j^i)(\mu_i w_p^i)$.
[c]Number in parenthesis is the equilibrium price (in tens of dollars).

5. Conclusion

This paper intended to theoretically derive a measure of the MVAI (in dollar terms). We achieved this

[13]We stress that individual attribute weights are estimated through a conjoint study (rank ordering 18 hypothetical product profiles) independently from the set of alternatives in the simulated product market.
[14]The only exception is Flexibility, that is slightly higher for UltraPod (see Table 1) and, consequently, MVAI decreases the least for this attribute (from 0.74 to 0.73).

goal by examining the change in demand for the firm's product as a result of an incremental improvement in a particular attribute, with its price being adjusted optimally. We obtained a closed form expression for MVAI by using the multinomial logit framework, which has been extensively used to model marketing phenomena. The expression for MVAI reveals that the market's valuation is not a simple average of the individual customers' valuations for an improvement in a product attribute. While the trade-off between price and attribute level needs to be captured by the corresponding price and attribute weights, there are other factors to be considered. We find that individual-level parameters should be differentially weighted according to probability of purchase of the firm's product. "Extreme" customers, i.e., those with very high or very low probability of purchasing the focal product, are far less relevant in determining the market value of an attribute change because their probabilities are not as sensitive to the proposed changes. How much the market values an improvement in a particular attribute depends on which competitive product is asking the question. The measure developed scales individual weights by a factor related to the inverse of the variance of the random component of utility. It should also be noted that attribute and price weights are summed separately. This kind of formulation, as opposed to averaging the ratio of these individual weights, is less susceptible to the influence of outliers.

Correctly assessing the market value for a product attribute change has important implications for firms engaging in product modifications. By comparing the market value with the marginal cost of providing that change, the firm can determine whether an attribute improvement would be profitable. Taking this comparison a step further, MVAI allows the firm to establish, given the current market structure, which product characteristics are most worthwhile to modify and where to direct R&D efforts.

The customer weights in (14)–(15) suggest an approach for segmenting customers following the attribute change. In particular, the focal firm would want to target customers for whom both the customer weight a_j^i and the individual value (w_k^i / w_p^i) are high.[15]

While the main purpose of this paper was to derive a theory-based measure for the market-level valuation of an attribute improvement, we also provided an empirical application demonstrating how the proposed measure can be estimated in practice. The results clearly highlight the benefit of the MVAI measure in mitigating the effects of data outliers. They also reveal the potential misleading implications of using alternative approaches (average or median of individual values), which do not incorporate the relative appeal to customers of competing products, in determining the market's value for an improvement (Orme 2001). The empirical analysis also explored the possibility of competitive reactions in prices by rivals. Even under this scenario, the MVAI-based criterion for evaluating profitability was found to be useful in providing directional insights to a firm considering product modifications.

There are several limitations in our study. First, our measure is only applicable to attributes that are differentiable in the neighborhood being analyzed; thus, we are unable to treat discontinuous product features, e.g., a car manufacturer contemplating the addition of a side-impact air bag. However, such discontinuous features can be analyzed by the conceptual framework of §2. Second, although the multinomial logit is widely accepted for modeling marketing phenomena, our result (14) may not hold precisely under other probabilistic choice models. Third, in the competitive reaction analysis (§4.3 and Appendix) we considered only price reactions. Suppose the focal firm improves attribute x_k by y%. If competitors match the focal firm's attribute change, and all firms optimally adjust prices, it can be shown (under certain assumptions) that all equilibrium profits will remain the same as prior to the attribute change. However, competitors may react by changing multiple attributes by amounts that may be different from y%. Recognizing this, the focal firm

[15]For another customer segmentation approach that uses statistical significance between differences in probability of purchase in an industrial marketing context, see Gensch (1984).

may also change multiple attributes by differing amounts. The equilibrium analysis under product and pricing changes is a worthwhile subject for future research. Finally, our empirical study used real data gathered from individuals interested in making a purchase in the camera mount category, and involved product design and development by students. It would be useful for future research to validate the desirable properties of our MVAI measure (compared to the alternative approaches) in other categories and using firm-level sales data prior and subsequent to a product improvement.

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Appendix

Competitive Price Reactions

We now examine the case where all J firms reoptimize their prices following an attribute change by a single firm and require that the market be in a pricing equilibrium.[16] In an interior solution, all J firms must be simultaneously solving

$$\frac{\partial \pi_{j'}}{\partial p_{j'}} = 0, \quad \text{for } j' = 1, 2, \ldots, J. \tag{A1}$$

Once again, we examine the total effect on the profitability of the focal brand j arising from an infinitesimal change dx_{jk}

$$\frac{d\pi_j}{dx_{jk}} = \frac{\partial \pi_j}{\partial x_{jk}} + \frac{\partial \pi_j}{\partial p_j}\frac{dp_j^*}{dx_{jk}} + \sum_{j' \neq j} \frac{\partial \pi_j}{\partial p_{j'}}\frac{dp_{j'}^*}{dx_{jk}}. \tag{A2}$$

From (5), (A1), and (A2), we obtain

$$\frac{d\pi_j}{dx_{jk}} = Qm_j\left(-\frac{\partial m_j/\partial x_{jk}}{\partial m_j/\partial p_j} - \frac{\partial c_j}{\partial x_{jk}}\right) + \sum_{j' \neq j} \frac{\partial \pi_j}{\partial p_{j'}}\frac{dp_{j'}^*}{dx_{jk}}. \tag{A3}$$

The first term on the right-hand side of (A3) is known as the "direct effect" while the second term represents a "strategic effect" (see Tirole 1988, pp. 326 and 327). The direct effect reflects the impact of firm j's own actions on its profits and is essentially the same as that in Equation (5), clarifying that MVAI plays a crucial role in assessing the profitability of attribute modifications even when we require the market to be in a pricing equilibrium. The strategic effect arises from the simultaneous reaction of all other firms to the improvement firm j is administering. In the multinomial logit market share model, products compete as substitutes (in prices), i.e.,
$\partial \pi_j / \partial p_{j'} > 0$ ($j \neq j'$); hence, the sign of the strategic effect is largely determined by the equilibrium price adjustments of the rival firms. If the direct effect is positive and outweighs the strategic effect, the sign of the profit change will be positive. See the Technical Appendix for such an example.[17]

[16] In many industry settings, price is typically a variable that firms can change relatively quickly while other changes are harder to administer in the short run due to production constraints. This assumption is common in empirical studies of differentiated products (e.g., Berry 1994). It is also similar to the one used by Horsky and Nelson (1992) and Choi and DeSarbo (1994). While both studies use a conjoint type method for establishing demand, they do not provide general analytical insights as to how changes in a particular attribute level affect equilibrium profits and how these effects depend on individual-level parameters. Choi et al. (1990) provide some analytic comparative statics around the Nash price equilibrium for the duopoly case but assume that customers are homogeneous in both their sensitivity to price and quality.

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[17] The Technical Appendix is available at the INFORMS *Marketing Science* website at http://www.informs.org.

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