Measuring Market Efficiency and Welfare Loss

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This study presents a general methodology capable of addressing a number of fundamental questions in consumer policy. Are consumers paying more than the minimum price for a given bundle of attributes? If so, what brands cost more than the consumer needs to pay? What would be the degree of improvement in the consumer’s well being if some intervention sets the price of such inefficient brands at the efficient level? We apply the methodology to data on automobiles and several other goods and analyze the determinants of efficiency.

A brand can be defined as efficient if it provides the highest value per dollar spent for that set of characteristics, or, equivalently, if it is the cheapest brand that can be produced and sold for that set of characteristics. Any brand that fails to satisfy this criterion may be regarded inefficient. Modern economic theory prescribes that brands in a competitive market with perfect (costless) information will all be efficient: they will all be positioned in the characteristics space along an "efficiency frontier" or "consumption possibilities frontier" so that no surviving brand dominates another on all characteristics (Lancaster 1971; Rosen 1974). Nevertheless, as illustrated by the review in the following section, there is empirical evidence in the economic and marketing literatures that inefficient brands may exist in a number of markets.

Several factors may contribute to market inefficiency and to the survival of inefficient brands in the marketplace. First, since the actual product space is not continuous but contains only discrete offerings, and since consumers may not be able to buy mixtures of the product offerings (especially for durable goods), the gaps may give each brand a monopoly over those consumers whose equilibria lie in the vicinity of the brand (Rosen 1974). Second, ignorance of available offerings or of their characteristics may make consumers willing to pay more than the efficient price (Maynes and Assum 1982; Rosen 1974). Finally, consumers' buying strategies may involve a trade-off be-

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between the benefits of finding an efficient brand and the costs involved in this search (Pratt, Wise, and Zeckhauser 1979; Ratchford 1980; Stigler 1961). Overall, since the benefits of searching to find the most efficient brand may fail to exceed the costs of doing so, the optimal decision may be to purchase an inefficient brand—one whose price is above the minimum for its characteristics.

Nevertheless, the elimination of inefficiencies either through direct intervention (e.g., price and quality controls) or by improving consumers’ access to product brand information (Dardis and Gieser 1980; Maynes and Assum 1982) has significant implications for public welfare (Sproles 1986, p. 148):

Complete examination of the problem is needed, and the analysis of efficiency in consumer markets should take a more central position in the consumer literature.

This article presents a methodology for measuring the degree of inefficiency of each brand within a product category. This methodology is adapted from Data Envelopment Analysis (DEA) (Charnes, Cooper, and Rhodes 1978, 1981), which is based on the single input/single output concept of engineering ratio efficiency (Farrell 1957). We apply the methodology to a number of product categories and draw some tentative conclusions about gains to consumers that might result from eliminating inefficient brands. We also use our estimates to test hypotheses about variations of efficiency across product categories; in particular, we find that lower priced categories appear to be more inefficient.

The objectives of our article are similar to those of Hjorth-Andersen (1984), but our approach has at least one important advantage over his: while his de-
terminates only whether any given brand is efficient, ours allows a precise estimate of the degree of inefficiency inherent in the purchase of any given brand. Consequently, our approach makes it possible to make much more detailed statements about the existence of inefficiency and how it might be reduced.

In the sections that follow, we discuss previous studies of product quality and price efficiency and review the DEA methodology that will (1) permit us to measure the extent by which some brands depart from the efficiency frontier, and (2) provide directions to transform these brands into efficient ones. We then present empirical results for two product categories and discuss their implications. Finally, based on summaries of analyses applied to a number of other product categories and the results of tests of hypotheses about the variation of efficiency across product categories, we draw tentative conclusions about the nature of inefficiency across markets and make suggestions about how our methodology might be applied to improve market efficiency.

PRODUCT QUALITY AND PRICE EFFICIENCY

Evidence of Inefficiency

Numerous empirical studies of the price-quality relationship and price dispersion in consumer markets are found in the literature. In general, these studies have found weak price-quality correlations and significant price dispersions, leading to the overall conclusion that market inefficiency is the norm rather than the exception.

Oxfeldt (1950) computed the price differentials between the least and most expensive brands in the same quality grade and found considerable price discrepancies, indicating that some of the brands might have been inefficient.

Morris and Bronson (1969) attempted to measure the market efficiency for a large number (637) of product categories using the price ratio between the most expensive among poor-quality brands and the least expensive among high-quality brands in the same product category. A similar approach was used by Beier (1978). Both studies presented evidence that inefficient brands exist in most markets.

Numerous studies on the price-quality relationship (Curry and Faulds 1986 refer to almost 30 studies on this subject) have failed to find strong evidence of a necessary association, also indicating that "high-quality" brands might not necessarily command the highest prices. Similarly, studies of retail prices have generally found substantial price dispersion, with maximum prices often several times the minimum for items of essentially the same quality (Maynes and Assum 1982; Pratt et al. 1979).

Dating to Stigler (1961), there is a vast literature that explains inefficiency and price dispersion as an outcome of costly information. Although most of this literature is theoretical, Ratchford (1980) uses Consumer Reports data to derive empirical estimates of the magnitude of the trade-off between the gains and costs of information for several consumer durables. Because it provides a possible explanation for observed inefficiencies, the work in Ratchford (1980) is complementary to that presented in this article.

The Measurement of Quality

Much of the work on price-quality relations has been criticized for treating quality as unidimensional when it really is not. Thus, low observed price-quality correlations might simply result from errors in measuring quality.

Perhaps the most forceful statement of this criticism is that of Hjorth-Anderson (1984), who argues that an overall quality rating is valid only under the restrictive condition that all product characteristics are strongly collinear. 1 Otherwise, one would have to assume that all consumers have the same preference function as that represented in the quality rating. Curry and Faulds (1986) defend the unidimensional quality measures on the grounds that price-quality correlations tend to be insensitive to the weights attached to individual attributes. However, their defense of unidimensional quality is not necessarily valid for measures of inefficiency other than price-quality correlations.

The fact that consumers make buying decisions to form bundles of multidimensional characteristics is now widely accepted in the marketing and economics literature (e.g., Hendler 1975; Ladd and Zober 1977; Lancaster 1966, 1971; Lucas 1975; Ratchford 1975; Rosen 1974). Furthermore, individual differences in preference is one of the justifications for the survival of many brands along a consumption-possibilities frontier (Lancaster 1971) or for the existence of multiple market equilibria (Rosen 1974).

Therefore, it seems clear that any study of market efficiency should be based on the multiple characteristics possessed by the various offerings rather than on a single, arbitrarily defined quality rating.

Hjorth-Anderson's Study

Because of its close relationship to this study, we examine Hjorth-Anderson 1984 in more detail. The Hjorth-Anderson study is important, because it takes a first step toward developing a procedure for effi-

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1 Although the methodology used to support this argument empirically has been both criticized (Curry and Faulds 1986) and well defended (Hjorth-Anderson 1986), the controversy has no bearing on the validity of the argument.
ciency measurement that overcomes the limitations of unidimensional quality ratings. The present study can be seen as a refinement of the Hjorth-Andersen study capable of producing more precise information about the nature of inefficiencies.

Hjorth-Andersen defined an efficient brand as any brand not dominated by another brand on all characteristics, including price. Based on this definition, he showed that across 127 product categories, more than half of all brands analyzed were inefficient.

Hjorth-Andersen’s definition (but not the measurement) of efficiency is directly related to Lancaster’s (1966) concept of efficiency frontier. However, Hjorth-Andersen provides only the identity of the brands on the efficiency frontier, giving no indication of how inefficient the other brands are. As a consequence, Hjorth-Andersen must measure inefficiency at the market level and must employ some strong assumptions about how consumer expenditures would be reallocated if the inefficient brands were eliminated.

The efficiency measure developed in Hjorth-Andersen’s study is defined in the “product space” (using Lancaster’s terminology) without explicitly considering the trade-offs between price and characteristics made by consumers. The efficiency frontier as per Lancaster (1966) or Rosen (1974) is not explicitly defined.

Because our measure of price efficiency discussed in the following section is defined in the “characteristics-space,” it allows comparison of the price of each brand with the best possible price under the technology available at its particular combination of characteristics. The methodology used here allows us to measure the price efficiency for each individual brand, to identify the set of efficient brands used as the standard of comparison, and to provide some directions to take to make a brand price-efficient. Consequently, we are able to get more precise answers to the questions posed by Hjorth-Andersen.

Although the DEA methodology presented in this article has certain advantages over alternatives, it still can measure efficiency only for a given set of characteristics. In applying the methodology, it is always assumed that this is the set that is salient to consumers. The identity of this set must be determined by other means. Some problems in applying DEA that might result from difficulties in identifying salient characteristics are discussed later.

AN APPROACH TO MEASURING PRICE EFFICIENCY

Examples

As stated earlier, a brand can be defined as efficient if it provides the highest value per dollar spent for that set of characteristics, or, equivalently, if it is the cheapest brand that can be produced and sold for that set of characteristics. The DEA approach, which is a set of linear programming procedures for measuring the efficiency of any process characterized by multiple inputs and outputs (Banker, Charnes, and Cooper 1984; Banker and Morey 1986; Charnes et al. 1978, 1981; Fare and Grosskopf 1983), can be applied to measuring the efficiency of any brand, where the brand may be defined as yielding several characteristics for a given expenditure.

Although our later empirical applications will generally involve multiple characteristics, some simplified examples for goods yielding only one characteristic will demonstrate the intuition behind the technique.

Example 1: Continuous Characteristics. Consider the problem of measuring the efficiency of side-by-side refrigerator/freezers. Let the only salient characteristic of these be their capacity, measured in cubic feet. Prices and capacities of five brands are listed below:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>$950</td>
<td>$1,000</td>
<td>$1,080</td>
<td>$1,100</td>
<td>$1,300</td>
</tr>
<tr>
<td>Capacity (cu.ft.)</td>
<td>14</td>
<td>15</td>
<td>15.5</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Price/cu.ft.</td>
<td>$67.85</td>
<td>$66.67</td>
<td>$69.66</td>
<td>$68.75</td>
<td>$76.47</td>
</tr>
</tbody>
</table>

Which brands are efficient? If one could somehow divide refrigerators (purchase refrigerators in fractional units), Brand B would clearly be the most efficient: it has the lowest price per cubic foot. Alternatively, if there were constant returns to scale in the production of refrigerators, it should be possible to sell any refrigerator at $66.67/cu. ft., e.g., to produce and sell Brand A at $66.67 × 14 = $933.38, and so on. In this case, only Brand B would be efficient. All other brands would sell at above their minimum price for that set of characteristics.

However, for durable goods such as refrigerators, the assumption of constant returns would be too strong; they cannot be purchased in fractional units, and there might be economies of scale in production at certain levels of characteristics. On the other hand, it would seem reasonable to assume that the general structure of production is convex, and that there are constant returns within adjacent segments of the production function at which similar levels of characteristics are produced. This convexity postulate is critical to applications of DEA for continuous characteristics (Banker et al. 1984).²

Given this assumption, Brand C is inefficient: it should be possible to produce and sell a 15.5 cu. ft. brand for $1,050, since $1,050 would lie on a linear function relating price to cu. ft. in the range between

²Banker et al. (1984) present a detailed discussion of this convexity assumption and other axioms upon which DEA rests.
15 and 16 cu. ft. (this function is \( P = -500 + 100 \times \text{cu. ft.} \)). If the price of Brand C were multiplied by \(1050/1080 = 0.9722\), it would become efficient. We can therefore say that the \textit{price efficiency} of Brand C is 0.9722, where an efficient brand would be assigned a value of 1 on a price efficiency scale. Alternatively, if the cu. ft. of C were improved to 15.8, it would become efficient; we could therefore say that its \textit{attribute efficiency} is 15.5/15.8 = 0.9810.

However, in contrast to the case where there were constant returns to scale, all other brands must now be regarded as efficient; since Brand B cannot be produced in fractional units, there is no clear evidence that brands A, D, or E could be produced for a lower price per cubic foot. Thus, since they are not dominated by any linear combination of adjacent brands, A, D, and E must be regarded as efficient if there are nonconstant returns to scale: at that scale, there is no cheaper substitute. If there were constant returns, these brands would no longer be efficient.

This example presents the essence of the DEA model as it is applied to continuously scaled attributes. Brands within a facet of the convex production possibilities set are compared with a "virtual brand" that is formed as a linear combination of the efficient brands that define the boundaries of the facet. These brands are price inefficient if their price exceeds that of a "virtual brand" containing the same set of attributes. Although it is also possible to determine attribute inefficiency, as in this example, our empirical estimates will focus on price inefficiency, which will generally have a much more straightforward interpretation.

\textit{Example 2: Ordinal and Nominal Attributes}. In many cases, attributes are defined only on ordinal or nominal scales. In these cases the convexity assumption outlined above has no clear meaning (Banker and Morey 1986). To illustrate the concept and measurement of efficiency in this case, consider the problem of measuring the efficiency of toasters, where the only salient attribute is assumed to be "toasting performance," which is measured on a rating scale "fair" to "excellent." Prices and ratings for four brands are as follows:

<table>
<thead>
<tr>
<th>Brand</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>$75</td>
<td>$32</td>
<td>$27</td>
<td>$18</td>
</tr>
<tr>
<td>Performance</td>
<td>Excellent</td>
<td>Good</td>
<td>Fair</td>
<td>Fair</td>
</tr>
</tbody>
</table>

Now, because the ratings form only an ordinal scale, one cannot clearly judge whether Brand B lies on a facet between Brands A and D. Since it is not dominated, one must therefore regard Brand B as efficient. However, Brand C is clearly inefficient because one can get the same level of performance from Brand D at \(\frac{1}{3}\) the price: we can say that the \textit{price efficiency} of Brand C is \(\frac{1}{3}\). Thus, in the case of nominal attributes, one can make efficiency comparisons, but only when brands are dominated.

It is worth pointing out that these ordinal comparisons coincide with Hjorth-Andersen's definition of attributes and efficiency; the convexity postulate for continuous attributes outlined earlier therefore makes a somewhat stronger assumption about production possibilities than invoked by Hjorth-Andersen. Nevertheless, we believe that this assumption is reasonable and consistent with not only other applications of DEA, but production models in economics as well (see Footnote 2). Thus, whenever attributes are continuous, we employ the approach outlined in Example 1. When they are ordinal or nominal, we employ that outlined in Example 2. When attributes are mixed, we use a mixture of these approaches. Programming procedures for determining efficiency are outlined later. First, however, we need to establish a formal link between efficiency measurement and an underlying model of consumer behavior.

\textbf{An Underlying Model of Consumer Behavior}

As should be evident from these definitions and examples, the set of efficient brands traces out the alternative bundles or characteristics that are the maximum that can be achieved at alternative expenditure levels. As such, it can be thought of as the solution to the first stage of the consumer's choice problem, which can be conceived as producing characteristics from goods available on the market (Deaton and Muellbauer 1980; Lancaster 1966, 1971). Inefficiencies may arise at this stage from the choice of goods that do not yield maximum characteristics per dollar at that level of expenditure; these goods do not yield maximum production efficiency.

The second stage of the consumer's choice problem involves the choice of a utility-maximizing bundle of characteristics and level of expenditure from the set of efficient bundles (Deaton and Muellbauer 1980). Inefficiencies may also arise at this stage from choices of some bundle of efficiently produced characteristics other than one that maximizes utility.

In this study, however, we focus on inefficiencies arising at the first stage: we wish to measure the extent to which there are brands on the market that provide less than the maximum possible characteristics for a given expenditure. One reason for doing this is that one can measure brands yielding less than maximum characteristics per expenditure without knowledge of the preferences of any individual consumer. A policy maker, or other information provider such as \textit{Consumer Reports}, might therefore calculate which
brands were inefficient, or publish the maximum efficient price for each brand, without recourse to detailed information about consumer preferences. This information would be equally relevant to all consumers, and thus could be disseminated on a mass basis along with other product information. Although we concentrate on inefficiencies due to brands that yield less than maximum characteristics per expenditure, the possibility remains that non-utility-maximizing choices from among efficient brands may also be an important source of consumer losses. This possibility is left for further study.

Application of the DEA model to brands involves a number of implicit assumptions about the nature of the household production problem—the first stage of the consumer's choice problem. The underlying model of household production is most similar to that of Lancaster (1966, 1971) or Rosen (1974), in which the characteristics embodied in brands are assumed to produce utility directly. In applying DEA to the brands in a product class, it is implicitly assumed that brands in the class yield only the measured set of characteristics, and that no good outside this class produces this set of characteristics (Lancaster 1966). In empirical work, the first of these assumptions can be problematic for goods that possess a large number of characteristics, or characteristics that are hard to measure, such as style or aesthetic qualities; perhaps DEA is most readily applied to goods that are primarily functional in nature, such as refrigerators or toasters. A final assumption, which results from the second stage of the consumer's choice problem, is that the dimensions of the consumer's utility function are defined in terms of the measured characteristics; in particular, all of the measured characteristics must be relevant to at least some consumers.

Applying the DEA Method to Measure Price Efficiency

Having presented the intuition behind the DEA technique, and having discussed how the measurement of efficiency fits into an overall model of consumer behavior, we are now ready to present a formal outline of the DEA methodology.

Our objective is to measure the extent to which any particular brand (denoted by the subscript “o”) is efficient according to the definitions presented, given the presence of all other brands on the market. Efficiency is measured as the ratio between the "efficient" price and the actual price paid, \( P_o \). Mathematically, efficiency can be determined by solving the following problem:

\[
\text{Max } f_o = \frac{(V^T X_o + U_o)}{P_o}
\]

subject to: \( \frac{(V^T X_j + U_o)}{P_j} \leq 1 \quad j = 1, 2, \ldots, n \)

\( V > 0 \)

(1)

where \( X_o \) is an \( m \) element vector of characteristics of Brand \( o \); \( X_j \) is a similar vector for all \( n \) brands, including \( o \); \( V \) is an \( m \) element vector of weights attached to each characteristic; \( U_o \) is an intercept, defined for Brand \( o \), that allows for varying returns to scale (Banker et al. 1984); \( P \) is price. Intuitively, the objective of Equation 1 is to find the most favorable set of weights \( V \) and \( U_o \) for Brand \( o \) subject to the constraint that maximum efficiency is set at one. If Brand \( o \) is efficient, \( f_o \) will achieve its maximum value of one; if not, \( f_o \) will measure the ratio of the price of the corresponding efficient brand (the virtual brand) to the actual price of \( o \); multiplying the \( P_o \) by this amount will make Brand \( o \) efficient.

From Equation 1, \( U_o + V^T X_o \) provides the shadow price of Brand \( o \) if it has characteristics \( X_o \); in general, \( U_o + V^T X_o \) determines the shadow price function for any brand \( j \) in the region of \( o \). In the sense that it can be interpreted as defining the opportunity set in terms of prices and characteristics available to consumers, the solution to Equation 1 for all brands in the market defines a hedonic price function at the efficiency frontier. However, the interpretation of the functional relationship between prices and characteristics obtained from Equation 1 differs somewhat from the relationships between prices and characteristics discussed in the hedonic price literature in economics (Rosen 1974). The latter are regression relationships that seek to explain actual prices by pricing out a product's characteristics. In contrast, the above piecewise linear function measures the lowest shadow prices for such characteristics observed in a market, at different scale sizes.

For estimation, the fractional programming problem in Equation 1 may be replaced by a more tractable linear programming equivalent (Banker et al. 1984), which is described in the Appendix as the Price Reduction Model (see the Appendix, Equation A1). To determine the efficiency of each brand in a market, Equation 1 or its equivalent is solved in turn for each brand.

As an example, consider the calculation of Equation 1 for Brand \( o = \) Brand C in the refrigerator example presented earlier. For Brand \( o = \) Brand C, \( U_o = -500 \), \( V = 100 \), the hedonic price function for the corresponding facet is \( P = -500 + 100 X \), and \( f_o \) for \( X_o = 15.5 \) is equal to 1050/1080 = 0.9722. As stated earlier, multiplying \( P_o \) by 0.9722 gives the price of an efficient 15.5 cu. in. unit.

In summary, by solving the problem in Equation 1 or its equivalent linear programming problem in Equation A1 using transaction prices and objective measurements of the characteristics for each brand in...
a product category, one can obtain the following diagnostic information:

- Determine whether or not the brand is efficient, and measure its efficiency ratio $f_o = z_o$.

- Identify the efficient brands that directly compete with Brand $o$ and form the efficient facet corresponding to $o$.

- Indicate how much (if anything) the price of $o$ should be reduced to make the brand efficient (and also whether changes in its characteristics are needed in addition to the price cut—see the Appendix).

As stated earlier, the price efficiency model outlined here and in Equation A1 must be modified to accommodate ordinal or nominal characteristics. This extension is briefly outlined in the Appendix; a detailed description of this modification can be found in Banker and Morey (1986). Whenever our empirical data involved ordinal or nominal characteristics, this extension was incorporated into our analyses.

### EMPIRICAL ILLUSTRATIONS

We present illustrations in this section to show in detail how the DEA model may be applied and to demonstrate how diagnostic information obtained from the model may be used to draw conclusions about market efficiency. In these illustrations, we apply the methodology discussed earlier to price and attribute ratings for two product classes—C-size batteries and automobiles—published by Consumer Reports. Later, we will present summary results for 20 products and present analyses of the determinants of inefficiency.

The product categories discussed here represent different types of purchase situations. C-size batteries are a low-value, frequently purchased item of a type unlikely to generate extensive search prior to purchase. They are rated by consumers as medium to low in involvement (Ratchford 1987). Moreover, they are described by a few readily measureable characteristics. Although there is some evidence that they may also generate surprisingly little search (Newman 1977; Newman and Staelin 1972), automobiles are a high-value, infrequently purchased item viewed by consumers as very high in involvement (Ratchford 1987). Moreover, they possess many more dimensions of performance than do batteries.

C-size Batteries

*Consumer Reports* rates this product category on the following attributes: Lowest market price, Average Life under continuous usage (in hours), Average Life under intermittent usage (hours), Performance under continuous usage (five-point scale), and Performance under intermittent usage (five-point scale). The 16 brands are rated in Table 1. Although these brands are classified in three categories (Alkaline, Heavy Duty, and Regular), this classification was not considered in the model, since it is already embedded in the other ratings.

Application of the model described in Equation A2 (see the Appendix) to these data led to the results displayed in Table 1. Out of the 16 brands, eight were identified as efficient. These brands are highlighted with asterisks in Table 1. The efficiency ratio for the other brands ranges from 0.60 (Radio Shack Alkaline) to 0.93 (Ray-O-Vac Regular). Ray-O-Vac Alkaline is rated as inefficient because a linear combination of Eveready Alkaline (with a weight of 0.96) and Ray-O-Vac Alkaline (0.04) results in the same intermittent life and 0.2 more hours of continuous life at 60 percent of its price.

Rather than assuming that the consumer could form this “virtual” brand by combining the purchases of the efficient brands at the 0.96/0.04 ratio, we interpret this “virtual” brand as a feasible offering, given the technology available at that particular mix of attributes. Therefore, consumers who buy the inefficient brand should be paying a “fair” price 60 percent below the current market price, and still get 0.2 more hours of continuous battery life.

By the same token, assuming that all relevant attributes have been considered and that the market prices reported by *Consumer Reports* are accurate, consumers who purchase Ray-O-Vac Regular could be purchasing another brand (K-Mart Regular) at 93 percent of the price they pay, with 0.3 more hours of continuous battery life and 0.2 hours of intermittent life. The efficiency ratios measure the extent to which the inefficient brands are overpriced for the amount of attributes they offer. The slacks listed in Table 1 show how much more of the attributes should be offered by the inefficient brands, in addition to the price reduction, to make the brand efficient, considering the technology available to produce that particular mix of attributes.

Assuming that preferences are monotonically increasing for all of the attributes considered, and that budget is not a binding constraint for this low-priced product, any consumer, regardless of his/her utility function, should consider only the eight efficient brands, since these brands define the boundaries of the efficiency frontier. Given the attributes considered in this study, consumers who buy the inefficient brands are incurring a loss of between (100 - 93 =) 7

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4Although the number of makes considered or number of dealers visited may be low, total time spent searching for cars may be substantial. In a study in progress by one of the authors, a sample of 394 recent car buyers reported spending an average of 21 hours searching prior to their purchase. More information is available on request.
percent and \((100 - 60 = \) 40 percent relative to the minimum price for that set of characteristics, depending on the brand purchased. Moreover, as indicated by the slacks listed in Table 1, purchasers of the inefficient brands are incurring additional losses because the attribute levels of the inefficient brands would also have to be increased to make these brands efficient. The “best” choice among the efficient brands will depend on the trade-offs each consumer is willing to make among the attributes and price. The dual solution of the mixed integer-linear programming problem in Equation A2 can be used to build a piecewise linear efficient price function, which can be used by consumers to determine the “fair” price, given the mix of attributes offered by a brand.

The coefficients of this price function, which can be interpreted as the marginal costs of each attribute to the consumer, are presented in Table 2 for each facet of the efficiency frontier. Each price function listed in Table 2 is defined within the boundaries formed by the brands in the respective facet of the efficiency frontier. The coefficients of this price function are not sample estimates, but exact descriptions of the marginal prices of the attributes at the efficiency frontier observed among the 16 brands considered in the study. Therefore, statistical inference is not applicable in this case.

These price functions can be used to determine the “fair” price for a new brand (not included in the previous analysis), given the amount of attributes it offers. For example, a new brand offering top performance at intermittent and continuous usage—13.3 hours of continuous life and 100 hours of intermittent life (within the boundary formed by Ray-O-
### TABLE 3
1984 CAR RATINGS AND EFFICIENCY ANALYSIS

<table>
<thead>
<tr>
<th>Transaction price</th>
<th>Rear leg room</th>
<th>Acceleration</th>
<th>Passing speed</th>
<th>Length</th>
<th>Width</th>
<th>MPG</th>
<th>Ride Handling</th>
<th>Repair</th>
<th>Luxury</th>
<th>Efficiency Facet</th>
<th>Ratio</th>
<th>Brand name</th>
</tr>
</thead>
<tbody>
<tr>
<td>8600</td>
<td>29.0</td>
<td>3.6</td>
<td>1.9</td>
<td>206</td>
<td>74</td>
<td>17.6</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td></td>
<td>Dodge Diplomat</td>
</tr>
<tr>
<td>13050</td>
<td>29.0</td>
<td>3.6</td>
<td>1.9</td>
<td>206</td>
<td>74</td>
<td>17.6</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td></td>
<td>Chrysler 5th Avenue</td>
</tr>
<tr>
<td>6875</td>
<td>28.0</td>
<td>3.9</td>
<td>2.0</td>
<td>176</td>
<td>68</td>
<td>28.0</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>76</td>
<td>Ford Tempo</td>
</tr>
<tr>
<td>7275</td>
<td>28.0</td>
<td>3.9</td>
<td>2.0</td>
<td>176</td>
<td>68</td>
<td>28.0</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>76</td>
<td>Mercury Topaz</td>
</tr>
<tr>
<td>7300</td>
<td>25.0</td>
<td>3.8</td>
<td>2.0</td>
<td>179</td>
<td>69</td>
<td>27.0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>88</td>
<td>Ford Mustang</td>
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<td>7700</td>
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<td>3.8</td>
<td>2.0</td>
<td>179</td>
<td>69</td>
<td>27.0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>68</td>
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</tr>
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<td>22-75</td>
<td>Pontiac 2000</td>
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<td>3.5</td>
<td>1.7</td>
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<td>65</td>
<td>27.0</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>22-75</td>
<td>Olds Firenza</td>
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<td>1.8</td>
<td>188</td>
<td>69</td>
<td>28.0</td>
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<td>2</td>
<td>4</td>
<td>0</td>
<td>22</td>
<td>Celebrity</td>
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<td>3.8</td>
<td>1.8</td>
<td>188</td>
<td>70</td>
<td>28.0</td>
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<td>4</td>
<td>2</td>
<td>0</td>
<td>22</td>
<td>Cutlass Ciera</td>
</tr>
</tbody>
</table>

NOTE: Boldface indicates efficient brands.

Vac Alkaline and Eveready Alkaline)—should be priced at no more than 74 cents (0.0071 × 13.3 + 0.1642 + 0.2286 + 0.2544). A new brand offering these same attributes at a price lower than 74 cents would be efficient and would define new facets in the efficiency frontier. New brand offering attribute values beyond the boundaries defined in Table 2 can be evaluated only by rerunning model A2 with the inclusion of the new brand.

One may argue that some consumers have a long-term demand for this particular product class to be satisfied through repeated purchases. This may be the case, for example, for a teenager maintaining his/her personal stereo. Here, one would be interested in the best prices per attribute over the whole attribute range, rather than in the efficient offerings at a particular scale level. In other words, rather than assuming varying returns to scale, one would be interested in identifying the lowest overall cost per unit of the attributes. Consumers could then satisfy their demand for the attributes, at the lowest cost, through repeated purchases of the price-efficient brand.

The situation just described requires a model with constant returns to scale (Charnes et al. 1978) that is similar to model A2, with the exclusion of the unit constraint on the $h_i$ weights ($2, h_i = 1$) in Equation A2. Application of this model to our data led to a few changes in Table 1. Under constant returns to scale, only live brands are price-efficient (Eveready Alkaline, Ray-O-Vac Alkaline, Radio Shack Heavy Duty, Eveready Heavy Duty, and Panasonic Regular). Sears Alkaline is now inefficient with a ratio of 0.70 relative to Eveready Alkaline. K-Mart Regular and Radio Shack Regular are also inefficient relative to Panasonic Regular, with ratios 0.73 and 0.55. Therefore, consumers interested in high performance under con-

---

1Here we assume that the marginal costs of shopping (time costs, transportation, and so on) are negligible, since this purchase would be part of a regular grocery shopping trip.
tinuous and intermittent usage will attain the lowest long-term cost per hour of use by choosing either Eveready Alkaline or Ray-O-Vac Alkaline. The choice between these two brands would depend on whether consumers will use the batteries continuously or intermittently. Consumers choosing among low (rated D or E) continuous or average (rated C) intermittent performance should select Panasonic Regular for the lowest cost per average life in the long run.

Automobiles

We now apply the methodology to a more complex product class involving a larger number of continuous and ordinal attributes and a larger number of brands. Our data include Consumer Reports ratings of 74 and 82 domestic and imported car models in 1978 and 1984, respectively. The attributes considered in this study were the ones listed by Consumer Reports:

- Rear leg room (inches)
- Acceleration from 0 to 60 mph (miles per square minutes)
- Passing speed (miles per square minutes)
- Length (inches)
- Width (inches)
- Miles per gallon
- Ride (3-point ordinal scale)
- Handling (5-point ordinal scale)
- Repair frequency (5-point ordinal scale)
- Luxury or sport (1 if sport or luxury)

Since a considerable amount of dealing appears to take place in the market for cars, list prices are probably not indicative of the real price paid by consumers. To get a better estimate of transaction prices, we used NADA Blue Book prices for October of the corresponding model year. Although the Blue Book lists prices for used cars, it should reflect the new car prices for these models as well as the original available data.

Application of model A2 to the 1984 data showed that 18 out of 82 cars for which we had data were price-inefficient. These models are listed in Table 3, along with the efficient ones to which they are compared. Overall, one notices that the efficiency ratios are reasonably high (mostly over 0.93). Most of the inefficient models are being compared with their corporate twins (e.g., Ford Escort/Ford Mercury Lynx, Dodge Daytona/Chrysler Laser, and so on)—a surprising result, given that they are offered by the same seller. It is possible that there are some attributes beyond the objective attributes considered in our model that distinguish these pairs, such as fancy trim, attractive interiors, or better dealer service. Although our data are able to distinguish between general attributes that may create large amounts of efficiency/inefficiency, they may not be comprehensive enough to account for those attributes that lead to small price differences between otherwise similar models. As noted earlier, this might be a general problem in applying DEA to complex products with dimensions that are difficult to describe objectively.

Apart from these corporate twins, only the Cutlass Supreme, Regal Supreme, Pontiac 2000, and Oldsmobile Firenza were identified as price-inefficient in comparison to nonrelated models. According to the results in Table 3, buyers of Cutlass Supreme could get 0.5 inches more of leg room, 1.2 miles per square minute more of acceleration, 0.3 miles per square minute more of passing speed, 12 inches more of length, 3 inches more of width, a better ride, and better handling and repair frequency at a price 0.5 percent lower by purchasing an Impala Caprice.

Assuming that we have considered all relevant attributes, the welfare loss among buyers of the Cutlass Supreme, Regal Supreme, Pontiac 2000, and Oldsmobile Firenza due to the fact that these brands are purchased above the efficient price amounts to:

<table>
<thead>
<tr>
<th>Car model</th>
<th>1984 Sales</th>
<th>Welfare loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>($1,000)</td>
<td>($1,000)</td>
</tr>
<tr>
<td>Cutlass Supreme</td>
<td>300,973</td>
<td>.005</td>
</tr>
<tr>
<td>Regal Supreme</td>
<td>182,814</td>
<td>.005</td>
</tr>
<tr>
<td>Pontiac 2000</td>
<td>124,123</td>
<td>.036</td>
</tr>
<tr>
<td>Olds Firenza</td>
<td>60,633</td>
<td>.069</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Therefore, the welfare losses due to the purchase of a price-inefficient brand represented less than 0.1 percent ($11.1 million) out of the total sales of $8.9 billion for all 82 brands considered in our analysis. Notice that these losses are computed as the expenditures above the efficient price rather than as the total expenditures on the inefficient brands. Welfare losses are measured as that amount consumers paid over the minimum feasible price for that set of attributes. This approach is also distinct from the one used by Hjorth-Andersen, who measures welfare loss as the expected gain if all inefficient brands were eliminated, assuming that their sales would be distributed to the efficient ones in direct proportion to their original shares.

The results for 1984, then, show a relatively efficient market in which most brands are not dominated by others when the relevant attributes are taken into account, and where there is a relatively small welfare loss due to price-inefficiency. This efficiency may be due to the fact that the purchase decision for automobiles is important to most consumers, who are therefore willing to invest enough time in information gathering and processing to make an efficient choice.

Rather than measure price-efficiency and welfare loss for 1978 as well, we will use the methodology to identify and measure possible changes in efficiency between 1978 and 1984. Were there any improvements in the price/attributes between these years?

To answer this question, we inflate 1978 prices to 1984 dollars and build an overall model as in Equa-
tion A2, considering both 1978 and 1984 cars. In addition to the attributes listed before, we add a binary variable (0 for 1978, 1 for 1984), which allows the comparison of each 1978 brand with an efficient facet formed by either 1978 or 1984 brands. A 1978 brand inefficient in comparison to 1984 offerings would indicate a reduction in the costs per unit of the attributes for the consumer, at that particular scale size. Therefore, quality improvements could be measured as the reduction in marginal costs per unit of the attributes rather than in terms of the amount of attributes being offered.

The results from this longitudinal analysis detected only two inefficient brands from 1978 being compared with an efficient facet formed by 1984 brands. The 1978 Honda Accord was found to be inefficient relative to the 1984 Nissan Sentra, and the 1978 Audi Fox was inefficient relative to the 1984 Ford Tempo. This result indicates that, in general, the efficiency frontier has not moved downward toward lower real prices for a given set of characteristics between these years. This leads to the conclusion that no major quality improvements were attained in 1984 in comparison to 1978.

The next logical question is whether quality (attributes per dollar) has decreased during the (1978–1984) period. An answer to this question can be found by repeating the analysis described previously, but reversing the definition of the binary indicator of time. The results of this analysis showed only two (out of 82) 1984 brands as inefficient relative to a facet formed by 1978 brands. Therefore, the overall conclusion is that no major changes in the efficient prices (per unit of the attributes) were found in the industry between these years. This illustrates how DEA might be used to make inferences about changes in efficiency over time.

**VARIATION IN EFFICIENCY ACROSS PRODUCTS**

To provide a more general analysis of the level of efficiency across categories and to test hypotheses about the correlates of efficiency, we applied our price efficiency analysis to *Consumer Reports* data for 20 product categories. The major criteria for choosing categories were data availability and ability to measure prices and attributes unambiguously. We also tried to cover a range of prices, durability, numbers of brands, and salient attributes. Because the analysis is a bit cumbersome (one must run a separate linear programming problem for each brand), it had to be limited to 20 categories. A summary of the results and of the descriptors of each product category is presented in Table 4.

In Table 4, the mean inefficiency column provides an approximate measure of the average proportionate reduction in price needed to make all brands efficient, under an assumption of equal market shares. Mean inefficiency ranges from 0.478 for bath soaps (an average price reduction of 47.8 percent would be needed to make all brands efficient) to 0.058 for microwaves and humidifiers. Mean inefficiency is between 0.05 and 0.10 in seven cases, 0.10 and 0.15 in five cases, 0.15 and 0.20 in three cases, and greater than 0.20 in five cases. Though our measure of inefficiency is somewhat different than that of Hjorh-Andersen, these estimates seem broadly consistent with his 1984 estimates of consumer benefits from the elimination of inefficient variants. Since informed consumers might reasonably be expected to buy efficient brands, one might expect these to have larger than average shares. Consequently, the inefficiency estimates in Table 4 represent the upper bound that would result if information were so poor that all purchases were made at random.

Because dollar losses for a given level of inefficiency increase with price (inefficiency of 0.10 on a $1 item implies a loss of 10 cents; inefficiency of 0.10 on a $100 item implies a loss of $10), one might expect more search, and consequently less inefficiency, for high-priced items. To test this hypothesis, the following regression was run on the data in Table 4. The results are:

\[
E = 0.2944 - 0.0362 \ln P
\]

\[R^2 = 0.40,\]

where \(E\) is mean inefficiency, \(\ln P\) is the natural log of mean list price, and \(N = 20\). This is significant beyond the 0.01 level, and confirms our hypothesis that effi-

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6To see this, note that \(1 - Z_i\) for any brand "o" is an approximate measure of the proportionate price reduction needed to make that brand efficient. Thus the total price reduction across all brands \(i\) can be written as

\[
\sum_i P_i Q_i (1 - Z_i) = PQ [Z (1 - Z) S_i]
\]

where \(PQ\) is total revenue, and \(S_i = P_i Q_i / PQ\) is market share of \(i\) in dollars sold. Under constant share \(P_i Q_i / PQ = i/n\), where \(n\) is number of brands. The term in brackets is then the mean of \(1 - Z_i\), which is the mean inefficiency in Table 4. If we had data on actual brand shares, we could substitute these into the equation just written and come up with a much more precise measure of average efficiency. Unfortunately, we have been unable to locate share data for the categories listed in Table 4.

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7To correct for changes in the value of the dollar, we inflated by the overall Consumer Price Index (CPI): to inflate, 1978 prices were multiplied by \(CPI_{1984}/CPI_{1978}\). It might be pointed out that the comparison between years still can be made if every brand improves: if, for example, every 1984 brand improved over 1978, each 1978 brand would show up as inefficient in the analysis. In this case, one could say unambiguously that the real price of cars declined between 1978 and 1984.
TABLE 4
DEA RESULTS AND OTHER DESCRIPTORS FOR 20 PRODUCTS

<table>
<thead>
<tr>
<th>Product</th>
<th>Consumer Reports Issue</th>
<th>No. brands</th>
<th>No. attributes</th>
<th>No. inefficient brands</th>
<th>Mean inefficiency</th>
<th>Mean list price ($)</th>
<th>Std. dev. list price ($)</th>
<th>Price-quality correlation</th>
<th>Annual expenditure (MM*) ($)</th>
<th>Annual expenditure per household ($)</th>
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<td>7</td>
<td>.034</td>
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<td>6</td>
<td>6</td>
<td>.058</td>
<td>104.44</td>
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<td>5</td>
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<td>.48</td>
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<td>175</td>
<td>65.89</td>
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<td>25</td>
<td>5</td>
<td>15</td>
<td>.156</td>
<td>2.53</td>
<td>.75</td>
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<td>301</td>
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<td>Printing calculators</td>
<td>10/79</td>
<td>22</td>
<td>6</td>
<td>11</td>
<td>.117</td>
<td>111.73</td>
<td>31.66</td>
<td>NA</td>
<td>NA</td>
<td>111.73</td>
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<td>Hair conditioners</td>
<td>1/86</td>
<td>47</td>
<td>2</td>
<td>40</td>
<td>.287</td>
<td>2.42</td>
<td>.80</td>
<td>-.10</td>
<td>2,197</td>
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<td>Bar hand &amp; bath soaps</td>
<td>1/85</td>
<td>44</td>
<td>3</td>
<td>38</td>
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<td>1.10</td>
<td>1.74</td>
<td>NA</td>
<td>2,940</td>
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<td>11/86</td>
<td>23</td>
<td>6</td>
<td>9</td>
<td>.058</td>
<td>228.74</td>
<td>55.85</td>
<td>.00</td>
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<td>5/87</td>
<td>28</td>
<td>8</td>
<td>8</td>
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<td>335.30</td>
<td>114.45</td>
<td>.03</td>
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<td>F.S.U.P.*</td>
<td>5/86</td>
<td>21</td>
<td>10</td>
<td>.175</td>
<td>228.86</td>
<td>131.20</td>
<td>.14</td>
<td>675</td>
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<td>Blow dryers</td>
<td>8/80</td>
<td>24</td>
<td>4</td>
<td>12</td>
<td>.183</td>
<td>20.29</td>
<td>6.56</td>
<td>.28</td>
<td>–</td>
<td>20.29</td>
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<td>Dishwashers</td>
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<td>25</td>
<td>10</td>
<td>11</td>
<td>.089</td>
<td>446.44</td>
<td>103.29</td>
<td>.28</td>
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<td>8</td>
<td>5</td>
<td>.074</td>
<td>128.05</td>
<td>72.86</td>
<td>.17</td>
<td>–</td>
<td>128.05</td>
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</table>

\[ ^{a} \text{Mean value of } 1 - Z_{2} \text{ in Equation A2.} \]
\[ ^{b} \text{Correlation between list price } CP \text{ and } CR \text{'s quality ranking (the latter is unavailable for certain product categories).} \]
\[ ^{c} \text{From } Predicsats \text{ Basebook, 1985. MM = million.} \]
\[ ^{d} \text{For nondurables, the annual expenditure per using household was computed by multiplying the number of households using the product (85.7 billion) by penetration obtained from } Simons \text{ of Progressive Grocer. For durables, this figure is equal to the price of the good (assuming one purchase per household).} \]
\[ ^{e} \text{Free-standing, upright unit.} \]

Efficiency is higher for higher priced items. The regression indicates that inefficiency declines with \( P \) at a rate of 3.62 percent of \( P \).\[ ^{g} \]

Based on our theory, market functioning should be inversely related to mean inefficiency. An alternative measure of market functioning that has been used often in the literature is the price-quality correlation. Convergent validity would require that the two measures be inversely related. To test this, we first calculated the Spearman correlation coefficient between the Consumer Reports quality ranking and price within the 14 product categories for which the quality ranking was available. The resulting correlations appear in the price-quality correlation column in Table 4. It is evident that there is no clear relationship between mean inefficiency and the price-quality correlation for the corresponding category. For example, the highest price-quality correlation is for videotapes, which also exhibit high inefficiency, a contradictory result; conversely, the second highest price-quality correlation is for paper towels, which also exhibit low inefficiency, a convergent result.

To get a more general test of the relationship between inefficiency and price-quality correlations, we correlated these numbers across the 14 categories for which data were available (see Table 4); since the mean inefficiencies and price-quality correlations both represent continuous scales, a Pearson correla-
tion coefficient was computed in this test. The resulting correlation was 0.38, which is positive, contrary to expectation; the relation was significant at only the 0.18 level. Apparently, as we conjectured earlier, mean inefficiency and price-quality correlation are measuring different dimensions of market performance.

In sum, we have found that inefficiency as measured by DEA varies considerably across product categories, and that much of this variation can be explained by price. As expected, high-priced items tend to exhibit less inefficiency.

CONCLUSIONS

The methodology discussed and illustrated in this article represents an alternative that has some advantages over Hjorth-Andersen's approach to measuring market efficiency. First, it measures efficiency at the brand level, indicating the extent to which a brand is overpriced relative to its close competitors. Second, it provides a diagnostic on how inefficient the brand is. Moreover, despite its focus on brand-level efficiency analysis, this methodology also can be applied to the aggregate measurement of welfare loss, if sales data are available for each brand in the market.

Evidently, any conclusion derived from either our approach or that of Hjorth-Andersen is conditional on the assumption that all (and only) relevant attributes have been considered. The inclusion of a large number of discriminating but irrelevant attributes would tend to show all brands as efficient, since they would not be dominated on all attributes. The exclusion of a relevant attribute, in contrast, will result in an efficiency ratio that in part reflects the cost of this missing attribute to consumers.

Given that the analysis captures salient attributes, the procedure outlined in this article could be a device for developing valuable consumer information. For example, in addition to its quality rankings, Consumer Reports could run DEA on its test products for each category and publish the resulting efficiency ratios. This would provide information on which brands are inefficient and which should consequently be avoided unless their price is reduced enough to make them efficient. Since this information is independent of consumer preferences, it is equally valid for all consumers.

We have illustrated how the methodology can be used to determine the efficient price for a new offering, based on the hedonic price function defined at each facet of the efficiency frontier. We have also shown that the application of this methodology to longitudinal data will detect any changes in "quality," measured in terms of the unit cost per attribute.

In addition to the obvious implications for public policy making, the DEA methodology can also be helpful to marketing managers, who may use it to re-


define the pricing strategy for their price-inefficient brands or use the shadow prices at the efficient frontier to determine the "fair" competitive price for a new brand, given the bundle of characteristics it offers.

Finally, it must be acknowledged that in this study we have focused on only one source of consumer welfare loss—that is, the loss due to consumers buying brands that seem overpriced relative to prices of close competitors. Consumers may still lose welfare if they choose a price-efficient brand that is suboptimal relative to their utility function. Measuring this loss will require knowledge of each consumer's utility function or, at least, of the density function of these utilities. This endeavor is left to future research.

APPENDIX

The Price Reduction Model

The fractional programming problem in Equation 1 may be replaced by a more tractable linear programming equivalent (Banker et al. 1984),

$\text{Min } Z_o + e(s^+ + \sum s^-_i)$ \hspace{1cm} (A1)

subject to:

$-P_o z_o + \sum_{j} p_j h_j + s^+ = 0$

$\sum_{j} x_i h_j - s^-_i = X_o \hspace{1cm} (i = 1, 2, \ldots m)$

$\sum_{j} h_j = 1$

$h_j, s^+, s^-_i \geq 0 \hspace{1cm} (j = 1, 2, \ldots n)$

$(i = 1, 2, \ldots m)$

where $z_o$ is the efficiency ratio for the brand under consideration; $e$ is an infinitesimal archimedean (usually a very small constant); and $s^+$ and $s^-_i$ are slack variables.

The objective in Equation A1 is to find the best linear combination $(h_j)$ of the brands in the market, offering the highest amount possible of each characteristic $X_i$ (and no less than offered by Brand $b_o$) at the lowest price (no higher than $P_o$). This linear combination defines the efficient facet (in the characteristics space) to which Brand $b_o$ is compared. The vertices of this efficient facet are the brands $j$ such that $h_j > 0$.

The efficiency ratio $Z_o$ and slack variable $s^+$ indicate how much the price of the Brand $b_o$ must be reduced to make it efficient. The efficient price is given by:

$P'_o = P_o z_o - s^+$

If any of the characteristics slacks $(s^-_i)$ is positive, the brand under analysis can be made efficient only if
the characteristic \( i \) is also increased by the amount \( s_j^- \) (along with the price reduction).

Including Ordinal and Nominal Characteristics

In this section, we briefly outline the procedure developed by Banker and Morey (1986) for incorporating ordinal and nominal characteristics into DEA. First, the discrete variable \( i \) (say, in \( K_i \) levels) is transformed into a set of \( K_i - 1 \) "dummy" variables so that the lowest original level is represented by zeros, the next level by a unit value on the first dummy, and so on. Let

\[
Z_o, X_o, P_j, s^+, s_i^-, h_j \text{ be as previously defined.}
\]

\( d_{\omega_i}^{(k)} \) = dummy variable assigned to the discrete \( i \)th attribute of Brand \( j \), so that it will be equal to one if the attribute is at the level higher than \( k \) or zero otherwise,

\( t_{ik} = \text{integer (0/1) slack associated to the level } k \text{ of the discrete attribute } i. \)

Then, following Banker and Morey (1986, pp. 1615–1624), the price-reduction model in Equation A1 can be rewritten as a mixed Linear Integer Programming problem:

\[
\text{Min } Z_o + \epsilon [s^+ + \sum_i s_i^- + \sum_k (\sum_j t_{ik})] \quad (A2)
\]

subject to:

\[
-P_o z_o + \sum_j h_j p_j + s^+ = 0
\]

\[
\sum_j h_j x_{ij} - s_i^- = x_{i0} \quad (i = 1, 2, \ldots, m)
\]

\[
\sum_j h_j = 1
\]

\[
\sum_j h_j d_{\omega_i}^{(k)} - t_{ik} = d_{\omega_i}^{(k)} \quad (i = m + 1, \ldots, M; \quad k = 1, \ldots, K - 1)
\]

\[
t_{ik-1} - t_{ik} \geq d_{\omega_i}^{(k)} - d_{\omega_i}^{(k-1)} \quad (i = m + 1, \ldots, M; \quad k = 2, \ldots, K - 1)
\]

\[
t_{ik} = (0/1) \quad (i = m + 1, \ldots, M; \quad k = 1, \ldots, K - 1)
\]

\[
h_j, s^+, s_i^- \geq 0 \quad (i = 1, 2, \ldots, m)
\]

\[
(j = 1, 2, \ldots, n)
\]

The interpretation of this model’s results is similar to that of model A1 except that now one can also determine the shift in the ordinal attributes necessary to make the brand under analysis efficient. The efficient level for an ordinal attribute \( i \) is found by:

\[
d_{\omega_i}^{(k)} = d_{\omega_i}^{(k)} + t_{ik} \quad (i = m, \ldots, M; \quad k = 1, \ldots, K - 1).
\]

Nominal (rather than ordinal) discrete characteristics can also be accommodated by Equation A2. This is done by adding constraints as in the ordinal case, but not allowing for any slack \( t_{ik} \).

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REFERENCES


