Quality, Class and Competition

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Abstract

The approach of this paper brings together the conceptual view of quality in manufacturing with the multi-attribute product positioning and customer preference models of marketing. In industrial manufacturing applications, "quality" is often defined as conformance to specifications or as meeting expectations regarding the performance of the product. In the marketing and economics literature, "quality" often refers to the performance level or "class" of the product. Here a product is described by a vector of performance attributes, and the population of produced units is assumed to display a distribution on these attributes. The attribute levels (means) are taken to define the class or positioning of the product. Quality in the sense of conformance is then conceptually identified with some measure of the absence of variation of the population around the mean.

It is further assumed that buyers of the product have a cardinal utility function defined on the vector of attributes and price, and that customers maximize expected utility. Product manufacturers are assumed to face a cost of producing a given population distribution. Under specific assumptions regarding costs and utility functions, models of monopoly and perfect competition are formulated. The model clarifies the distinction between class and quality, identifies the sources of quality improvement, and provides an economic framework relating issues of product positioning, process control, quality function deployment (QFD) and customer preference estimation.

Introduction

Economic models dealing with price and quality relationships typically take "quality" to mean performance of the product in terms of a vector of attributes. The description of a product (or service) in these terms is also well accepted in the marketing literature. This definition of quality as *performance quality* is then essentially synonymous with the class or position of the product. This interpretation of the term, while perfectly reasonable, does not coincide with the interpretation that is prevalent in many industrial manufacturing applications. Here the emphasis is typically on *conformance quality* relative to specifications. This variance in terminology makes it difficult to reconcile the approach in the marketing and economics research literature with the discussions of quality that appear in production journals, and in industry magazines. For example the populist phrase "Quality is Free" has a reasonable interpretation in the conformance context: fixed investments in process improvement can reduce variation in output, scrap and rework losses and warranty costs. They can thus eventually result in a positive return or permanent reductions in long term average costs. It is less easy to interpret sensibly in a performance context, since it appears to say that goods with superior performance are cheaper. Given the tremendous emphasis on quality management and the importance placed on the subject by industry, it would seem to be worthwhile to develop a framework for quality management that is consistent with the research literature in economics and marketing, and also adequately represents the sense of the term as used in manufacturing and in the industry press.

Following standard practice, a product is taken to be defined by a vector of attributes. In order to introduce the notion of quality as distinct from class, position or performance, it is assumed that firms produce product units that are drawn from a probability distribution on the vector of product characteristics. In other words, although a firm may set specifications for a product in terms of its characteristics or attribute levels, it may not be able to produce units exactly to specifications due to process variations. Furthermore, customers who buy the product are unaware of the exact performance characteristics of a given unit, but have some knowledge (possibly imperfect) of the distribution for the population of all units of the product. It is assumed that customer preferences for products are given by a cardinal utility function defined on these attributes and price, rather than the value functions implicit in hedonic price models and conjoint analysis. The need for cardinality arises from the uncertainty regarding product attribute levels and the customer's presumed aversion to this risk.

This extension makes it possible to distinguish between product class and product quality, in terms of location and dispersion parameters of the distribution on attributes. Class is identified

with location, and quality with the absence of variation or dispersion. A product may thus be of low class but of high quality, or vice versa. Examples of both abound. If independent Normal distributions are an adequate approximation to the distribution of attributes in the population, then indeed the means and perhaps the inverse of the standard deviations (or variances) might be taken as defining class and quality respectively. However, in general a straightforward association of intuitive concepts and explicit parameters may not be feasible. Also note that in this model, customer perception of quality is not directly represented via a separate quality measure or attribute, but instead is implicit in the utility function, together with preference for class. In particular, risk averse utility functions or ideal point utility functions will both penalize dispersion around the mean. However, a risk neutral or risk seeking utility function would imply indifference to, or even a preference for dispersion of attribute levels.

Consider the descriptive possibilities that this approach affords: Suppose that a firm conducts customer surveys as a basis for product positioning. These surveys are subject to various kinds of sampling error, which could be captured in terms of misestimation of customer utility functions. Once the positioning decision is made, the firm produces an actual population that has some distribution around this position, which may or may not be the mean. The degree of dispersion in the distribution may be controllable through investments in control and improvement of the production process, or through means such as inspection. The benefits of investments in quality control depend on the characteristics of customer preferences for quality (lack of dispersion) as captured in their utility functions. The costs of quality control depend on volume of production as well as issues like rework costs and salvage value. Production costs thus depend on the performance level of the product as well as on the desired lack of dispersion in performance, or the quality level of the product.

The customer has a perceived distribution for a product which may be modified through advertising or through learning about the product via search or experience mechanisms. Customers may be heterogenous not only in terms of the relative value they place on attributes, but also in their degree of risk aversion which here becomes preference for quality. Analogously, firms may differ in their ability to provide class (performance) as well as quality (conformance).

The sources of mismatch between product performance and customer expectations may be due to misestimation of customer preferences by the firm, or dispersion in the population produced, as well as the misinformation of consumers through advertising. As discussed by Karmarkar (1991), it is often thus conceptually useful to separate *process quality* or conformance to internal specifications, with *product quality* or mismatch with customer expectation. It is

conceivable that a firm may achieve high levels of one kind of quality and not the other. It is also possible that a firm may have high product quality levels but customer perceptions of either the class or quality of the product might be erroneous, as captured by the mismatch between actual and perceived distributions of product performance.

Representing customer preferences by cardinal utility functions is well suited to consumer goods markets, where either ideal point or non-decreasing utility functions could apply. In the case of industrial markets, it may be preferable to model customer preferences by determining the cost or loss to the buyer due to deviations from expectations. This conforms to the concept of a loss function for variation on specifications as used in traditional process control and in modern methods such as the Taguchi approach.

In the next section we briefly survey the literature in economics, marketing and operations dealing with various aspects of modeling class, quality, and competition. Next, a formal model of class and quality competition is formulated and analyzed in monopolistic, and perfect competition settings. Subsequently, extensions and variations of the basic model are discussed. The qualitative implications of the models are in some ways different from existing results in product positioning.

Literature Survey

As mentioned above, in the research literature in economics and marketing, the term "quality" is often associated with what we have termed "class" or performance quality. In addition to the paper by Mussa and Rosen (1978), other examples include the papers by Stiglitz (1987), Tellis and Wernerfelt (1987), Bajic (1988), Deaton (1988), Moorthy (1988), Ratchford and Gupta (1990), Bagwell and Riordan (1991) and Horsky and Nelson (1992).

Another approach to modeling quality has been to treat it as an additional attribute of the product. For example, Economides (1989) analyzes a Hotelling type of location model with an additional quality attribute. In this model, the addition of the quality attribute leads to maximal differentiation in the location (or variety) in products, in contrast to the usual result of minimal differentiation. Chander and Leruth (1989) develop a model of product differentiation in which congestion is taken as a measure of the lack of quality, though congestion mechanisms are not modeled explicitly. Devany (1976) and Devany and Saving (1983) develop models in which quality is identified with waiting time and congestion effects are modeled explicitly via queueing

mechanisms. Bennet and Boyer (1990) consider flight frequency as a measure of quality in a model of the airline industry.

Several papers associate quality with reliability and dependability. Lutz (1989) investigates prices and warranties as signals of quality, when quality in conjunction with maintenance determines reliability. White and Truly (1989) address warranty evaluation and risk aversion. Tapiero et al. (1987) present a model that considers tradeoffs between pricing, reliability, and quality in the sense of process control. Hegde and Karmarkar (1989) capture the costs of product failure to customers via a renewal model, and develop models of the market for product support.

The literature in the economics of information (Stigler, 1961; Spence, 1974; Arrow, 1974; Phillips, 1988) deals with market models where there are information asymmetries and poorly informed customers. The focus is on issues such as price searching and signalling. A particularly relevant paper is the examination of the market for used cars by Akerlof (1970). This paper, while also defining quality in terms of performance or class, explicitly addresses variability in performance quality. The emphasis is on asymmetric information in the market, in which customers are poorly informed about quality levels. The conclusion of the paper is that only poor quality cars are brought to market, since poorly informed buyers are not willing to pay higher prices for the better cars. Although we have not done so in the following, this type of analysis could be overlaid on ours, with the further refinement that used cars from different manufacturers will have different distributions of performance attributes, and customers may well be able to distinguish between these distributions, if not within them.

Fine (1986,1988) presents a model of quality in the manufacturing sense of process control and improvement, considering learning effects and cost effects. Fine and Porteous (1989) discuss a dynamic model of process quality improvement and setup reduction via small improvements over time. There is a large literature on process control and industrial quality programs that we do not attempt to review. However the books by Feigenbaum (1991), Juran (1988), Crosby (1979) and Deming (1990) are representative works by individuals considered to be pioneers of the modern practice of quality management.

There do not appear to be models in the literature that address both the performance and conformance dimensions of quality in a manner consistent with marketing and manufacturing usage of these concepts. In particular, we address the issue of the control of quality defined as lack of variation and the supply of quality, as well as the preference for quality or equivalently aversion to performance variation.

Class and Quality Competition

In this section we formalize some of the ideas discussed in the introduction. A specific example is discussed in detail. Define

- x : a vector of attributes describing a product type
- p : price
- $u(x,p,\alpha)$: A cardinal utility function defined on the vector of product attributes x , and price p , with parameter set α .
- $f(x,\theta)$: The probability density function describing the distribution of output from the production process, with parameter set θ .
- $c(\theta)$: A production cost function giving unit production cost as a function of the distribution parameters θ .
- $g(x,\phi)$: A probability density function representing customer perception of the distribution of product units, with parameter set ϕ .

Suppose that customers are homogenous and the parameter set α is known. Furthermore, suppose that customers know the true distribution of product performance, so that g is identical to f . Customers will buy the product if $E_{x|\theta}u(x,p,\alpha)$ is greater than some minimal level $\underline{u}$, which could be zero. A monopolist's pricing and product positioning decision can be stated as

$$\begin{array}{ll} \text{Max} & p - c(\theta) \\ & p, \theta \\ \text{subject to:} & E_{x|\theta}u(x,p,\alpha) \geq \underline{u} \end{array}$$

Defining $U(\theta,p) = E_{x|\theta}u(x,p,\alpha)$, the first order conditions for the monopolist's problem can be stated as

$$1 = \lambda \partial U / \partial p$$

$$\nabla_{\theta} c = \lambda \nabla_{\theta} U$$

$$\lambda(U - \underline{u})^+ = 0; \lambda \geq 0$$

where λ is a Lagrange multiplier. Since price will be set at the highest level acceptable to customers, the constraint will typically be binding. When $\lambda > 0$, it can be eliminated from the first two equations to yield

$$(\partial U / \partial p) \nabla_{\theta} c = \nabla_{\theta} U$$

For the case of perfect competition, assume that the number of customers is much larger than the number of firms in the market. Competition will induce firms to produce products with the highest expected utility to consumers, subject to profits being non-negative. Hence, the firm's pricing and product positioning decision can be stated as

$$\begin{array}{ll} \text{Max} & U(\theta, p) \\ p, \theta & \\ \text{subject to:} & p - c(\theta) \geq 0 \end{array}$$

This model tacitly assumes that a more attractive choice of θ from the customer's viewpoint, also costs the firm more to produce; i.e., quality is not free and neither is class. The constraint will therefore be binding, and may be eliminated by substitution for p . The first order conditions for the problem can be written as

$$\nabla_{\theta} U - (\partial U / \partial p) \nabla_{\theta} c = 0$$

Thus the form of the first order conditions for the vector θ are identical for the cases of monopoly and perfect competition, although they are typically evaluated at different values of p (higher for the monopoly case). When $\underline{u}=0$, or when $\nabla_{\theta} U$ is independent of p , as it is in all of the examples we explore, θ is the same for monopoly and perfect competition.

Example: Assume that a product can be described by a single attribute, x , and that the distribution of x in the population produced is given by a Normal distribution with mean μ and standard deviation σ . Here we might interpret μ as product class or product position, and say $1/\sigma^2$ as a measure of product quality. The costs of production are given by $c(\mu, \sigma) = c\mu^2 + d/\sigma^2$. Furthermore, customer preferences for price and performance can be represented by the expected utility expression $U(p, \mu, \sigma) = a\mu - b\sigma^2 - p$. These expressions are chosen primarily for simplicity in exposition. However, the expression can be interpreted as a heuristic mean-variance model where risk aversion with respect to x is captured by the variance term.

The monopolistic model, assuming $\mu = 0$ and substituting for p , simplifies to

$$\text{Max}_{\mu, \sigma} \quad a\mu - b\sigma^2 - (c\mu^2 + d/\sigma^2)$$

which gives $\mu = a/2c$, $\sigma^2 = (d/b)^{1/2}$, and $p = a\mu - b\sigma^2 = a^2/2c - (bd)^{1/2}$. The perfect competition case, on substitution for p , results in exactly the same solution for μ and σ . However, price is now driven to cost, i.e. $p = c\mu^2 + d/\sigma^2 = a^2/4c + (bd)^{1/2}$. ||

Example: For the same cost and output models as in the preceding example, suppose that customer preferences are represented by an ideal point utility function of the type $u(x,p) = a - b(x - z)^2 - p$. Then simplifying and dropping constants, $U(p,\mu,\sigma) = a + b(\mu - z)^2 - b\sigma^2 - p$. Using the same technique as above, we arrive at class $\mu = bz/(b+c)$ and quality stays at $1/\sigma^2 = (b/d)^{1/2}$. Note that if the cost of positioning were $c=0$, then class would be set at z . ||

Market Uncertainty

In this section, we inquire about the impact of parameter uncertainty, as well as the costly acquisition of information to reduce such uncertainty. This will give us some indication of the robustness not only of the general approach outlined above, but also of the conclusions drawn from the simple model. It will also lead into some discussion of the relationship of marketing and manufacturing in the context of product quality.

Consider the last example of the ideal point utility function, $u(x,p) = a - b(x - z)^2 - p$. Suppose the ideal point z , shared by each customer (the heterogeneous case will be considered later), is not known with certainty by a monopolistic firm by the time the process which generates (μ,σ) must be committed to (assume a single process; multiple processes will be considered later). Let the firm's prior distribution on Z be normal with mean M and variance S^2 .

The firm can observe a signal of Z : $Y = z + e$, where e is independent and normally distributed with zero mean and variance $1/\tau$. The firm can choose the precision of the signal, τ , at a cost which is linear in precision, $k\tau$, where k is the cost of precision (linearity in precision is an analog of the case of discrete sampling with a constant cost per independent sample). In contrast to production costs, information costs are independent of sales.

The price that the market will bear is $a - bE_X(X-Z)^2 = a - b\sigma^2 - b(\mu-Z)^2$. Given $Y=y$, Z is distributed normally with posterior mean

$$M' = \frac{M/S^2 + \tau y}{1/S^2 + \tau}$$

and variance $S'^2 = (1/S^2 + \tau)^{-1}$.

The objective for setting class and quality μ, σ , given the signal y , is

$$a - b\sigma^2 - bE[(\mu-Z)^2|y] - (c\mu^2 + d/\sigma^2) = a - b\sigma^2 - b(\mu-M')^2 - bS'^2 - (c\mu^2 + d/\sigma^2)$$

which is maximized by setting

$$\mu = bM'/(b+c) = \frac{b}{(b+c)} \frac{M/S^2 + \tau y}{1/S^2 + \tau}$$

$$\sigma^2 = \sqrt{\frac{d}{b}}$$

Let Q denote the size of the market (number of customers). Expected profit prior to the sampling is:

$$[a - b\sigma^2 - bE(\mu-M')^2 - b/t - (c\mu^2 + d/\sigma^2)]Q + kS^2 - kt$$

where $t = 1/S^2 + \tau$.

By setting the derivative with respect to t to zero, and invoking the envelope theorem to justify ignoring the dependence of μ on t , maximization is accomplished by setting $t = (bQ/k)^{1/2}$.

The optimal production quality level $1/\sigma^2 = (b/d)^{1/2}$ is unchanged from the previous analysis, and estimation precision t , an index of the quality of marketing information, has the same form, with production quality unit cost d replaced by information cost per customer k/Q .

Heterogeneous Customers

Consider again the ideal point utility function, $u(x,p) = a - b(x - z)^2 - p$, but now assume z differs among the customers. Suppose that there are many customers and that the distribution of the customers' ideal points can be approximated by an absolutely continuous function H with density h . $H(z)$ represents the number of customers whose ideal point is less than z .

A customer's net utility is $U(p,\mu,\sigma) = a - b(\mu - z)^2 - b\sigma^2 - p$. In general, it is no longer optimal for a monopolist to serve the entire customer population. In setting price, there is now a tradeoff between profit margin and sales. Only those customers with positive net utility will buy. But given sales $q < Q$, the firm's profit is:

$$[p - (c\mu^2 + d/\sigma^2)] q$$

A decrease in σ^2 increases unit costs at a rate of $d/(\sigma^2)^2$. If price is reduced at a rate b (per unit decrease in σ^2), then no customer's net utility is changed. Correspondingly, sales will not change. A first order condition for profit maximization is thus $b = d/(\sigma^2)^2$ or $\sigma^2 = (d/b)^{1/2}$ once again.

Determining the optimal class μ is not as simple, since z and μ are not separable in the expression for consumer utility U , as are z and σ . Changes in μ can have a different impact on different customers, whereas changes in σ^2 affects all customers the same. As such, neutralizing the effect of a change in class has on sales by adjusting p is not straightforward, and requires additional development.

The set of customers constituting sales to the firm are those for which $z_- < z < z_+$, where z_- and z_+ are the respective roots of the equation $a - b(\mu - z)^2 - b\sigma^2 - p = 0$. We have

$$z_+ = \mu + (a - p - b\sigma^2)^{1/2}$$

$$z_- = \mu - (a - p - b\sigma^2)^{1/2}$$

Sales are $q = F(z_+) - F(z_-)$, whereby $dq/d\mu = f(z_+) - f(z_-)$, and $dq/dp = -(1/2)(a - p - b\sigma^2)^{-1/2} [f(z_+) + f(z_-)]$. An increase in μ increases unit costs at a rate of $2c\mu$. If price is also increased at a rate of

$$(1/2)(a-p-b\sigma^2)^{1/2}[f(z_+) - f(z_-)]/[f(z_+) + f(z_-)] ,$$

then there is no change in sales. Equating the two opposite impacts on profit margin, a first order condition for profit maximization is that

$$\mu = \frac{(a-p-b\sigma^2)^{1/2} [f(z_+)-f(z_-)]}{4c [f(z_+)+f(z_-)]}$$

While this is not a closed form expression for μ (due to the dependence of the z 's on μ), there are some insights that can be extracted. The expression clearly highlights the importance of the marginal customers, on both sides of μ . This was hidden when all customers were the same, and hence were all marginal. High μ , and hence high marginal cost, can be justified only when there are more customers in the vicinity of the upper margin than the lower margin. And, obviously, high cost of class results in lower choice of class level.

Quality Function Deployment (QFD)

To put it somewhat simplistically, Quality function deployment (QFD) is a technique for relating engineering specifications for a product to the preference attributes by which the product can be described. For example, an automobile may be described by a market model with attributes such as comfort, gas mileage, and acceleration. From the manufacturing viewpoint, these attributes need to be converted to specifications regarding the product that can be tested at the process level. For example, acceleration may relate to a host of issues ranging from those necessary to produce the acceleration (engine torque, horsepower, gear ratios) to related supporting issues (suspension, seatbelt design). Going back another stage, torque may have to do with valve, piston and fuel delivery system design and tolerances.

QFD as described by Akao (1990) or Hauser and Clausing (1988) is a pragmatic technique for determining these relationships stage by stage. Moskowitz et al. (1990, 1991) have formalized these relationships as mappings between sets of attributes. They propose using "fuzzy regression" to estimate these maps as affine functions.

The QFD concept can be incorporated in the model of this paper by introducing a vector of attributes y , on which customer preferences are defined. The product is still defined in terms of attribute vector x , which is now taken to represent measurements that can be made at the process or plant level. The vector x may include design characteristics, physical engineering specifications

(e.g., part tolerances) as well as more general tests (for example dynamometer tests of engine performance).

The modifications to be made in the basic model are straightforward if the mapping from x to y is known with no uncertainties. For example, the monopolist's problem becomes

$$\begin{array}{ll} \text{Max} & p - c(\theta) \\ p, \theta & \\ \text{subject to:} & E_{x|\theta} u(y(x), p, \alpha) \geq \underline{u} \end{array}$$

where $y(x)$ is the map relating x to y . If on the other hand the mapping is noisy, as is likely to be the case, the uncertainty creates yet another reason for a mismatch between product position and customer expectations, which can be an issue even when (internal) process quality is very good.

From an intuitive viewpoint, uncertainty in this mapping may be intrinsic to the product. For example, it might be hard to relate design specifications to the "feel" of a product. On the other hand, it may be possible to reduce uncertainty in the design by investing effort in determining the nature of the relationship, leading to a resource allocation decision analogous to that of estimating customer preferences more accurately.

Fit and Finish: Signals of Quality

In addition to performance, conformance and reliability, quality is also sometimes identified with details of cosmetics and appearance. Certainly, fit and finish can be regarded as a product attribute in which variation or mismatch with expectations is undesirable. However, it also seems plausible that poor finish is taken as a signal of poor product quality generally. One way of incorporating this into our model is to assume that customers perceive that, attribute levels are correlated. That is to say, poor performance on one attribute suggests poor performance on others. Thus, if there are attributes that are not easily examined or experienced, the effect of perceivable problems with finish may lead to underestimation of performance on other attributes. For example, loose fittings may lead to concerns regarding reliability.

To flesh this out a little further, suppose that g represents a customer's prior distribution about the attribute levels of a product. Examining the product with respect to its finish, provides information with which the prior is updated. The sampling distribution is informative with respect

to finish but not with respect to other attributes. However if the prior is that attributes are correlated, the distribution of all attributes will be affected by the new information.

Summary and Future Research

This paper has presented a first cut at a formal economic framework for quality management, that brings together quality concepts from marketing and manufacturing. One direction for future research is to examine the issue of investing in quality improvements. For example, it seems plausible that fixed cost investments in process quality will only be worthwhile if the volume of production is large, or if quality is a major determinant of product purchase. It also seems as though process improvements involving fixed costs would create barriers to entry, or differentiation in the market place. These effects appear to be worth examining. Finally, future work will examine quality management in service industries, which have several characteristics which are very different from manufacturing.

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