

Economics of total quality management

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Abstract

This paper presents two models of the economics of total quality management. In the first, the concept of quality management is viewed as a technological innovation that requires investment. To reduce cost and improve quality, firms must make investments that are largely sunk. The effect of market competition on quality related technology investments is studied. Several results follow. With new quality technologies, price falls, quality rises and average cost declines. Firms must anticipate rivals' technology choices and the market prices when justifying quality technology investments. When all firms quickly adopt quality technology, returns of such investments are normal, that is, have a zero net present value. However, firms that do not invest in quality related technology are forced from the market. A firm that is faced by competitors that are slow to adopt quality related technology, can earn positive returns by early adoption. The firm invests more in quality related technology, and produces higher quality products, charges a higher price and earns higher profits than competitors. The firm's quality, price and profit advantages persist over time. In the second model, we show that firm value increases when customer satisfaction is used as an objective by aligning incentives. This explains the common use of customer satisfaction measures in TQM programs.

1. Introduction

This paper explores two different aspects of the economics of total quality management. The first deals with the cost of quality improvement programs and the second deals with how customer satisfaction can be used as a performance measure within decentralized firms. These aspects are developed using economic models of quality, which suggest testable hypotheses and normative conclusions.

Total Quality Management (TQM) is a term used to describe programs to improve quality and productivity. Both Garvin (1988) and Kolesar (1993) document the history of quality programs and show that

TQM developed from three earlier movements involving inspection, statistical quality control and quality assurance. Inspection focused on conformance of production to specifications so that products could be assembled with standardized parts. Statistical quality control (SQC), begun by Shewhart (1931) and others at AT&T, developed methods to monitor quality and set standards for large lot manufacturing. SQC provided a method to decide whether a production process met specifications and to detect when it was losing this ability. SQC used statistics to determine if variation in a system was within, or beyond expected parameters. In the latter case intervening action was prescribed. Quality assurance was the next historical stage, focusing on four elements: quantifying the cost of quality, total quality control, reliability engineering and zero defects. The cost of

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quality concept developed by Juran (1951) provided an economic rationale for quality improvement efforts, describing quality costs as avoidable (defect related costs) and unavoidable (prevention related costs). Feigenbaum (1956a) coined the term, *total quality control*. The idea is to expand quality activities beyond the manufacturing floor to the entire firm because “*quality is everybody’s job*” (Feigenbaum, 1956b). Reliability engineering used probability theory to predict and extend the time period over which a product functions according to specifications. The concept of *zero defects*, developed at Martin Company in 1961–1962, emphasized that quality is improved by adopting a standard of no errors, rather than accepting a defect rate defined by SQC. All of these quality ideas were fashioned in the United States. However, the next phase of quality management, called TQM was primarily developed in Japan and first exploited by Japanese companies.

Total quality management is widely perceived as evolving from the earlier movements, but there is no standard definition of TQM. In TQM according to Garvin, quality is defined by the customer, not by manufacturing specifications. Now, (i) customers and users ... judge how well a product fulfills needs and expectations, (ii) satisfaction is related to competing products, (iii) satisfaction is determined by consumption over the product’s useful lifetime, and (iv) customers satisfaction is determined by its multiple attributes (Garvin, 1988, p. 24). Other exponents of quality such as Schoenberger (1990) emphasize the customer orientation of TQM from an internal control perspective. He stresses the organizational integration effects of a common goal of customer satisfaction. Every internal group localizes the goal by recognizing that it has a customer, and the grand goal is continual rapid improvement in customer service. Similarly, Wruck and Jensen (1994) identify TQM as an organizational movement. They state that TQM has the following elements: (1) the use of the scientific method in everyday decision-making by all members of the organization, (2) the effective utilization and creation of specific knowledge at all levels, (3) a decentralized system for allocating decision rights, and (4) the effective use of performance measurement and recognition and rewards. Several of these points are echoed by Kolesar (1993) who identifies the key characteristics of TQM programs:

“(1) a company-wide dedication to ... totally satisfying customer needs and expectations ..., (2) quality concerns are fully integrated and (a) central aspect of ... business planning ..., (3) using factual data to support decision making ..., (4) ... involving all employees ..., (5) ... prevention of quality problems, designing them out of products and the processes that create them and on planning for quality ..., (and) (6) ... a policy of continuous improvement ...”.

We focus on two aspects of TQM programs. First, the quality management movement is viewed as technological innovation that requires *investments* to implement. Investments include purchase of equipment, costs of restructuring organizations and the expense of training workers. These investments reduce production cost and help to increase product quality. Second, total quality management has caused changes in organization. This is reflected in the use of *customer satisfaction* as an integrating objective and performance measure. In the quality paradigm, workers and managers define their customers, and are evaluated on how well they satisfy their customer. This motivates workers to provide better service to internal customers (that lowers their cost) and products to external customers (that increase their utility).

Quality improvement programs have costs and benefits. Major resources are expended to train workers and reorganize. Most quality proponents ignore this aspect. Many companies devote considerable time to team related meetings and activities. At the beginning of its quality program Xerox provided each of its one hundred thousand employees six days of training, amounting to 1644 man years of worker time, (Kearns and Nadler, 1992, p. 262). Corning devotes 5% of worker time to training amounting to 1.5 million worker hours per year and First Chicago provides every employee at least 40 hours of training that soon will be raised to 80 hours (Hiam, 1992, p. 248). New bureaucracies arise dealing with the management of quality teams, approval of objectives and ratification of solutions. In an infamous case, Florida Power and Light, winner of the Deming Quality Award, fired its chairman and scaled back its quality program because of its bureaucratic growth (Wood, 1991). There is only limited evidence of the net benefits of quality management on productivity and

financial performance. The Government Accounting Office (1991) survey study of 22 Baldrige Award finalists shows favorable results of quality programs: market share, sales per employee, return on assets and return on sales were positively impacted by quality programs. On the other hand, the International Quality Study conducted by American Quality Foundation and Ernst and Young surveyed 586 firms. The study finds that “many businesses waste millions of dollars a year on quality-related improvement strategies . . .” (Wall Street Journal, 1 October 1992, p. B7). Another study by Jarrell and Easton (1993) presents favorable, but not statistically significant evidence that TQM programs increase firm value as measured by stock price. Hendricks and Singhal (1994) study the impact of winning a quality award on the market value of firms and find evidence of statistically significant positive abnormal returns. TQM practitioners and consultants contend that “quality and productivity are not antithetical, that higher quality results in lower costs” (Kolesar, 1993, p. 704). However there is only weak evidence of this association.

This paper presents two related theoretical models of quality, that suggest hypotheses that can be tested against empirical data. In the first, we consider firms’ technology and quality decisions. We view quality management as a technological innovation that allows lower cost, and reduces the cost of increasing quality. To implement TQM and thereby reduce cost and potentially improve quality, firms must make investments that are largely sunk. The effect of market competition on the quality investment decision is studied. The purpose is to study the effect of the investment decision on firm cost, quality and profits. Several testable results follow, as well as normative conclusions. With new quality technologies, price falls, quality rises and average cost falls. Firms must anticipate rivals’ technology choices and market prices when justifying investments. When all firms quickly adopt quality technology, returns of such investments are normal, that is, have a zero net present value. However, a firm that is faced by competitors that are slow to adopt quality related technology, can earn positive profits and above normal returns. A firm that adopts new quality technologies faster than competitors invests more in their quality programs and has higher quality products.

Firms that do not adopt quality related technology are forced from the market. In the second, we show the economic rationale of using customer satisfaction as a performance measure in decentralized firms. Use of this measure increases firm value by aligning incentives.

1.1. Literature review

A fundamental issue that divides the literature is the definition of quality. Karmarkar and Pitbladdo (1992) point out that economics and marketing literatures often take quality to mean performance of the product in terms of a vector of attributes (performance quality), while the traditional quality management literature emphasizes conformance quality relative to manufacturing specifications. Recent marketing literature combines these by defining quality as conformance to customers’ expectations; see for example, Zeithaml et al. (1990). Karmarkar (1990) formalizes the difference between these two types of conformance quality by defining *product quality* as conformance to customers’ expectations and *process quality* as conformance to manufacturing specifications. Quality problems can arise because the product does not have the bundle of attributes that the customer wants (product quality), or there is a problem of reliable production of the product (process quality), or both.

Many marketing and economics papers study quality in terms of performance quality. Mussa and Rosen (1978) study positioning and pricing of goods by a monopolist. Devany and Saving (1983) present a quality model where quality is delay time that is endogenously defined using queuing models. Moorthy (1988) presents a model of competitive product performance choice. Moorthy and Png (1992) study sequential quality decisions by a firm offering products with different performance levels. Banker and Khosla (1992) study how quality choice is influenced by competitive intensity. Economides (1989) uses a Hotelling model to study positioning in a quality dimension. Several economics papers focus on the problem of information asymmetry: customers may not be fully informed about product quality. A seminal contribution in this area is (Akerlof, 1970). Tellis and Wernerfelt (1987) examine information asymmetry in an empirical study of the correlation

between product quality and price as a function of consumer information.

Classics of the traditional quality management literature are the books of Juran (1951), Feigenbaum (1956a), Crosby (1979) and Deming (1990). A survey and assessment of this literature are found in (Kolesar, 1993).

There have been several management science models of process improvement that are related to this paper. Fine (1986), Tapiero (1987), and Fine (1988) study quality improvement as a learning process involving detection and correction. These papers show that by optimally exploiting learning effects, a firm's quality rises and cost falls. As in this paper, Fine and Porteus (1989) study the firm's problem of deciding how much to invest in quality improvement activities. Their model studies this investment problem when quality improvement is gradual.

2. A competitive model of quality choice

This section suggests a model of firm cost and market demand, and studies the competitive quality and technology choice consequences. The assumption is that total quality management is a technological innovation that allows lower cost, and reduces the cost of increasing quality, but at some investment.

First, we consider the customers. Assume that customers desire to purchase a good. Customers enjoy higher utility from higher quality goods. Quality is measured by the scalar variable q , where $1 \geq q \geq 0$ and $q = 0$ is a customer's most desired quality level. Thus, low values of q correspond to high quality and improving quality corresponds to reducing variable q . There are a host of interpretations that support this model. Variable q can represent *product quality* in terms of an attribute whose ideal point is zero. *Process quality* can be modeled by assuming risk averse consumers and interpreting q as a measure of output variability. One example that supports the latter is interpreting q as the defect rate. For simplicity, the customer's cost of poor quality is a linear function of q : λq . It is assumed that customers know a product's quality. If a firm charges p for the good, the customer's full price is just $P = p + \lambda q$. Customers purchase from the firm offering the least full price. Total customer demand

is a linear downward sloping function of its full price, P , $d(P) = \alpha - \beta P = \alpha - \beta(p + \lambda q)$.

Next, we consider the firms, their objectives, decisions and cost structure. For simplicity we assume that firms are full price takers, where the market's full price is P . Firms are considered to be small, and a firm's decisions have negligible effect on the market's full price. Each firm i chooses its production level Q_i , and quality level q_i to maximize its profit. Firm i 's price for the good is therefore, $P - \lambda q_i$.

In the model, firms choose quality, quantity and quality related technology. Technology enables a firm to lower production cost and improve quality. "Technology" is interpreted broadly and includes equipment, organizational changes, and worker training. Technology requires an investment that may be wholly or partially sunk. Technology is parameterized by a scalar.

Initially all firms have access to a "status-quo" technology $T_0 > 0$. This technology does not require any investment. However, due to technological innovation, firms have access to more advanced quality technology that allows firms to reduce cost and improve quality at lower cost. An increment to technology by a firm is parameterized by a scalar ΔT , $\Delta T \geq 0$. The required investment in technology is a positive, monotone increasing function of ΔT that depends on the scale of production. Firms with larger output require larger investment, for example for training more workers. For simplicity, assume that the investment is a scalar multiple of the increment: $g(\Delta T) = fQ\Delta T$, with $f > 0$.

In the model, quality is considered to be a performance level or conformance level attribute of output. For any technology selected, products of quality, q , can be produced. However, variable production cost rises with quality. Investment in technology reduces the cost of producing output at a fixed quality level.

Variable production cost is a function of output, quality and technology selected. Variable production cost includes all costs associated with actual production: labor, materials, power, supplies, supervision, support, etc. Suppose that variable production cost demonstrates the following properties: *ceteris paribus*,

– better quality levels imply higher total variable production cost;

- higher output levels imply higher total variable production cost;
- larger investment in technology implies lower total variable production cost; and
- larger investment in technology implies lower incremental cost of quality improvement.

$C(Q, q, \Delta T)$ is a firm's variable production cost to produce output Q with quality q with additional investment in quality technology ΔT . The firm's variable production cost is assumed to be of the form $C(Q, q, \Delta T) = VQ^2 / ((\Delta T + T_0)q)$, with $V > 0$. This function obeys the properties hypothesized for variable cost. Although this is a specific cost function, it captures reasonable properties of variable production cost when quality matters. Fig. 1 reports total variable cost C as a function of quality for two different values of technology investment and shows that as investment increases, variable cost declines at any fixed quality level.

With fixed technology, the firm can improve quality but with the penalty of increased variable production cost. For example let q be interpreted as the defect rate. Defects can always be sorted out and quality can be raised at the cost of increased variable production cost. However, by upgrading technology, variable production cost can be reduced, and quality improved at lower variable cost, that is $\partial C / (\partial \Delta T) < 0$ and $\partial^2 C / (\partial \Delta T \partial q) > 0$ (by increasing ΔT , the

marginal effect of q on C decreases, so that quality can be improved at a smaller penalty).

The firm has other fixed cost, F , that is independent of production volume and technology such as sales and administrative expense.

Next, we explain how competition is modeled. Free entry of firms is allowed and we study competition by characterizing a competitive equilibrium. A competitive equilibrium is a full price for the good along with firms' decisions about quality, quantity and quality related technology so that (i) firms make profit maximizing decisions, (ii) full prices equate aggregate supply to customer demand, and (iii) no firm can profitably enter the market. This competitive model is a variation of that first proposed by Devany and Saving (1983). The following sections analyze properties of the equilibrium.

In the following sections, analytic results that lead to testable hypotheses are proposed. These results are stated in statements called "Propositions".

2.1. One-period problem of competitive price, production, quality and technology choice

Initially, we consider a one period problem. Firms exist for one period and sell their output. All firms have access to an existing, status quo production technology. There has been innovation, and a new

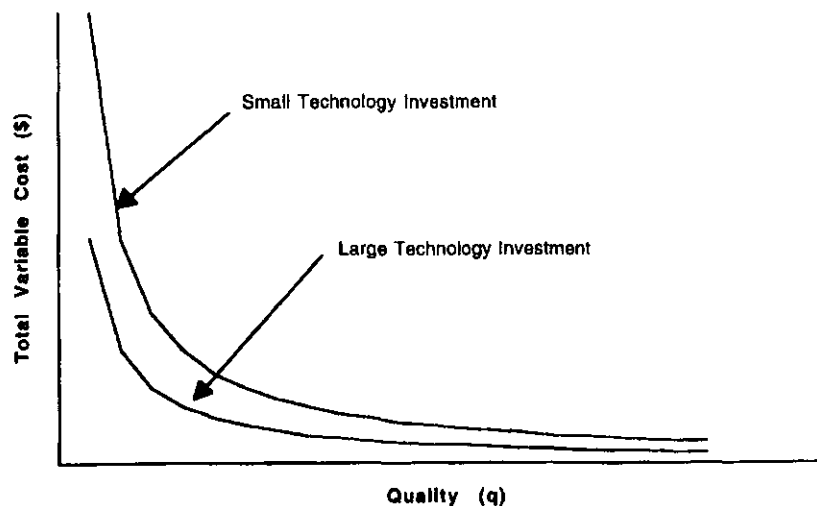


Fig. 1. Total variable cost as a function of quality (q) with fixed output level. Here, total variable cost is compared for two different levels of technology investment. As technology investment increases, total variable cost falls at any quality level.

class of quality related technologies are discovered that require investment to implement. Each firm chooses its technology at the beginning of the period, and sells to customers during the period. To simplify and avoid discounting, assume that all cash flows take place at the end of the period.

Consider the problem of a single profit maximizing, price-taking firm competing against several similar firms. The firm chooses its production technology, quality and production quantity to maximize its profits. A firm's problem is to

$$\begin{aligned} \text{Max}_{\Delta T, q, Q} \quad \pi &= (P - \lambda q)Q - F - Qf\Delta T \\ &\quad - \frac{VQ^2}{(\Delta T + T_0)q}. \end{aligned}$$

From the first order conditions associated with above equation, we easily find that optimal quality levels are

$$q(\Delta T, P) = \frac{P - f\Delta T}{3\lambda}, \tag{1}$$

and optimal production levels are

$$Q(\Delta T, P) = \frac{(\Delta T + T_0)(P - f\Delta T)^2}{9V\lambda}. \tag{2}$$

From these results we can conclude the following.

Proposition 1. *Variable q is a decreasing function of quality technology investments and an increasing function of full price. Thus quality improves if technology investment rises or full price falls. If f is small enough, quantity is a strictly increasing function of technology investment.*

At quality/production levels given by (1) and (2), firm profits are

$$\Pi(\Delta T, P) = \frac{(\Delta T + T_0)(P - f\Delta T)^3}{27\lambda V} - F. \tag{3}$$

2.2. Competitive equilibrium with status-quo quality technology

Suppose that all firms have adopted status quo quality technology T_0 , ($\Delta T = 0$ for all firms). Then

the optimal quality and quantity levels for each firm are found from (1) and (2):

$$q(0, P) = \frac{P}{3\lambda} \tag{4}$$

and

$$Q(0, P) = \frac{T_0 P^2}{9\lambda V}. \tag{5}$$

With the status quo technology, full price must be such that profits in the market are zero, else there will be entry: $\Pi(0, P_0) = 0$, which implies that

$$P_0 = 3\sqrt[3]{\lambda V \frac{F}{T_0}} \tag{6}$$

is the equilibrium full market price. The firm's price is $p_0 = P_0 - \lambda q(0, P_0) = 2P_0/3 = 2\sqrt[3]{\lambda V F/T_0}$. Using this price, the equilibrium production decision is

$$Q_0 = \sqrt[3]{\frac{T_0 F^2}{\lambda V}}, \tag{7}$$

and the equilibrium quality decision is

$$q_0 = \sqrt[3]{\frac{VF}{T_0 \lambda^2}}. \tag{8}$$

At the equilibrium, the number of incumbent firms in the market, m_0 , must be sufficient to satisfy demand, or

$$d(P_0) = \alpha - \beta(P_0) = m_0 \frac{T_0 P_0^2}{9\lambda V},$$

so that

$$m_0 = \sqrt[3]{\frac{\lambda V}{T_0 F^2} \left(\alpha - 3\beta \left(\lambda V \frac{F}{T_0} \right)^{1/3} \right)}.$$

2.3. Justifying quality technology investments

Now, suppose quality related technological innovation has occurred and a firm chooses technology to maximize its profits. If the firm chooses technology to maximize profit at price level P , the firm's problem is to choose ΔT to satisfy the first order

conditions. Differentiating (3) and then solving this equation, the optimal technology increment satisfies

$$\Delta T^* = \left(\frac{P}{4f} - 3 \frac{T_0}{4} \right)^+, \tag{9}$$

where $(x)^+ = \max(0, x)$. That is, no investment is justified unless $\Delta T^* > 0$. Assuming that $\Delta T^* > 0$, substituting (9) into (3) and (2), profit is

$$\Pi(\Delta T^*, P) = \frac{(P + T_0 f)^4}{256 \lambda V f} - F,$$

and the firm's output is

$$Q(\Delta T^*, P) = \frac{(P + f T_0)^3}{64 \lambda V f}. \tag{10}$$

All firms that can profitably do so will adopt the new technology. As more firms adopt, production quantities will increase and full market price will fall as production increases. Firms will invest and stay in the market if relevant profits are non-negative. Firms that are unable to earn non-negative profits exit. Market prices drop to the point where technology adopting firms earn zero profit, so that full price, P^* , satisfies

$$\Pi(\Delta T^*, P^*) = 0.$$

This full price can be found by solving this equation, yielding

$$P^* = 4 \sqrt[4]{\lambda V f F} - f T_0. \tag{11}$$

Technology chosen by the firms is found from Eq. (9) by considering the equilibrium full price:

$$\Delta T^* = \frac{1}{f} \sqrt[4]{\lambda V f F} - T_0. \tag{12}$$

Technology increment ΔT^* is positive if $(1/f) \times \sqrt[4]{\lambda V f F} > T_0$, which is equivalent to $\lambda V F > f^3 T_0^4$. We conclude that investment in quality related technology is economically justified if customers' cost of quality is high enough, variable cost is high enough, fixed cost is high enough or cost of technology is low enough. By similar analysis it can be shown that the quantity produced by a firm is

$$Q^* = \sqrt[4]{\frac{F^3}{\lambda V f}}. \tag{13}$$

The quality produced by a firm is

$$q^* = \sqrt{\frac{4 \sqrt[4]{\lambda V f F}}{\lambda}}. \tag{14}$$

Eqs. (12)-(14) yield testable hypotheses about the relationship between of the size of technology investment and the customers' cost of quality, variable cost, fixed cost and the cost of technology.

Proposition 2. *Equilibrium full price is an increasing function of λ, V, F and f . Technology increment ΔT^* is an increasing function of λ, V, F and a decreasing function of f . Quantity produced is a decreasing function of λ, V, f and an increasing function of F . Quality improves if V, f or F fall, or λ rises. Further, the following statements are equivalent:*

- (a) $\Delta T^* > 0$,
- (b) $P^* < P_0$,
- (c) $Q^* > Q_0$,
- (d) $q^* < q_0$,
- (e) $p^* < p_0$.

Proof. By comparing (6) and (11) it can be shown that $P^* < P_0$ if and only if $\Delta T^* > 0$, that, the equilibrium full price falls with new quality technology. Likewise, comparing (7) and (13), $Q^* > Q_0$ if and only if $\Delta T^* > 0$. Also, quality improves if investment in technology is justified: $q^* < q_0$ if and only if $\Delta T^* > 0$. Notably, equilibrium quantity and quality are both independent of T_0 as long as $\Delta T^* > 0$. The firm's price satisfies, $p^* = P^* - \lambda q^* = 4 \sqrt[4]{\lambda V f F} - f T_0 - \sqrt[4]{\lambda V f F} = 3 \sqrt[4]{\lambda V f F} - f T_0$. Therefore, $p^* < p_0$ if and only if $\Delta T^* > 0$. Price falls with adoption of quality related technology. \square

The next result shows that average costs declines with the adoption of quality technology.

Proposition 3. *Average cost declines as new quality technology is adopted.*

Proof. In equilibrium, firms earn zero profits so that price is equal to average cost. Proposition 2(e) shows that price falls with the introduction of quality technology, so average cost does, too.

In summary, the last two propositions yield a host of testable hypotheses. As firms adopt new quality technology, the full and actual prices fall, as does average cost while quality improves and quantity produced increases.

Although each firm's production increases, its market share may rise or fall with the adoption of quality technology. This is because as new quality technology is introduced, some firms may be forced from the market, or there may be new entry. The number of firms, m^* , active in the market is found by satisfying the equation

$$d(P^*) = \alpha - \beta(P^*) = m^*(Q^*),$$

or

$$m^* = \sqrt[4]{\frac{\lambda V f}{F^3} \left(\alpha - \beta \left(4 \sqrt[4]{\lambda V f F} - f T_0 \right) \right)}.$$

The number of firms m^* can be greater than or less than m_0 . If

$$\frac{\alpha - \beta(P^*)}{\alpha - \beta(P_0)} < \frac{Q^*}{Q_0},$$

then firms will be forced from the market ($m^* < m_0$), while if

$$\frac{\alpha - \beta(P^*)}{\alpha - \beta(P_0)} > \frac{Q^*}{Q_0},$$

there is entry ($m^* > m_0$). However, if

$$\frac{\alpha - \beta(P^*)}{\alpha - \beta(P_0)} < \frac{Q^*}{Q_0},$$

then an adopter's market share will rise, while if

$$\frac{\alpha - \beta(P^*)}{\alpha - \beta(P_0)} > \frac{Q^*}{Q_0},$$

then an adopter's market share will fall. If market demand is very elastic, then m^* will be greater than m_0 , and there is entry and decreasing market shares. If demand is relatively inelastic, there is exit, and an adopter's market share rises. Fig. 2 displays two demand functions for the price range from P^* to P_0 . For one demand function, firms exit the market after adoption of quality technology, while for the other, firms enter. One limitation of our modeling assumptions is that if market exit occurs, m^* cannot become so small that the remaining firms behave as

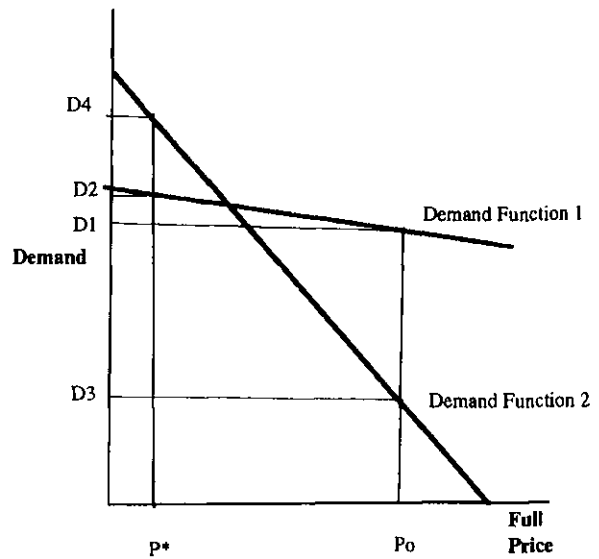


Fig. 2. With Demand Function 1, as quality related technology is adopted, demand rises from D1 to D2, while with Demand Function 2, as quality related technology is adopted, demand rises from D3 to D4. Suppose $D2/D1 < Q^*/Q_0 < D4/D3$. As quality related technology is adopted, firms will be forced out of the market with Demand Function 1 and firms will enter the market with Demand Function 2. With Demand Function 1, surviving firms' market shares will rise, and with Demand Function 2, all firms' market shares will fall.

oligopolists. Extension of the model to study oligopoly competition would solve this potential problem, but is left for future research.

These results lead to insights about the justification of quality technology. When making investments, a firm's optimal action is to anticipate equilibrium prices (11) and production levels (13) and invest in new quality technology up to the optimal level. A firm must look ahead at market prices when investing, or it will tend to over invest and earn negative returns on investment. In any case, when all firms are quick to adopt a new quality oriented technology, firms earn zero profits. Zero profits corresponds to normal returns on investment, that is zero net present value. Thus in competitive markets, firms will not earn excess profits from investment in quality.

Also, this model shows that adoption of quality technology is a strategic necessity. When firms quickly adopt new quality technology ($\Delta T^* > 0$), firms that do not adopt quality technology are forced

from the market because they cannot earn positive profits. Therefore, in these markets, quality is a strategic necessity that does not yield high returns on investments, but insures survival. However, with quality investments adopters will have higher product quality, lower average cost, greater total market demand compared with their earlier performance, and survive. One way to check these hypotheses is to examine the stock price performance of firms. The model predicts that when quality technology is quickly adopted, adopters do not earn abnormal stock returns on their stock, but laggards earn negative abnormal returns, and exit markets.

2.4. Two period problems: lags in adoption of quality technology

We have assumed that firms quickly respond to innovation in quality related technology and adopt technology soon after it is introduced. This may not be a realistic assumption. In many industries, some firms lead in the innovation of technologies that enable them to reduce variable production cost and improve quality. For example, Japanese manufacturers were leaders in automobile product quality, with U.S. firms followers in quality related investments. In 1980, Japanese cars' quality (as measured by problems per 100 delivered new cars) was 40 defects/100 cars, versus U.S. makers' 80 defects/100 cars (Consumer Reports, 1991). Despite large investments during the 1980's, U.S. firms still trail in quality. In 1990, Japanese firms raised their quality to 15 defects/100 cars, while U.S. firms had 40 defects/100 cars.

Consistent with this evidence, we show that firms that compete against other firms that are slow to adopt quality technology, have incentive to invest more in technology, and tend to maintain their quality advantage over time.

A simple model of delayed investment in quality technology is presented. Here, firms produce for two periods, investing in period 1. To simplify analysis, assume cash flows occur at the end of each of the two periods. The firms' fixed and variable cost functions and the customers' demand functions are the same as before.

Assume that a firm (dubbed the "leader") has access to quality technology (and the inclination to

adopt it) at the beginning of period 1, and other firms (called "followers") do not. Assume that the cost of technology depends on the scale of operations in the period of adoption. Assume that the leader can add new technology at the beginning of both periods, and chooses its investments to maximize profits. Because the marginal value of investment is larger in the first period than in the second and the quantity produced is lower in the first period, it can be analytically shown that the leader will always choose to adopt technology only at the beginning of period 1. In contrast, the followers use technology T_0 , until period 2, when they invest. This two period problem is analyzed by finding the equilibrium prices in each of the periods.

The leader's problem is to

$$\begin{aligned} \text{Max}_{q_1, q_2, Q_1, Q_2, \Delta T} \pi = & (P_1 - \lambda q_1)Q_1 - F - Q_1 f \Delta T - \frac{VQ_1^2}{(\Delta T + T_0)q_1} \\ & + \frac{1}{1+r} \left((P_2 - \lambda q_2)Q_2 - F - \frac{VQ_2^2}{(\Delta T + T_0)q_2} \right), \end{aligned} \tag{15}$$

where r is the risk free one-period discount rate. P_1 and P_2 are the market full prices in each period. Similarly, Q_1 and Q_2 are the firm's production quantities in each period and q_1 and q_2 are its quality decisions in each period. We analyze the problem by considering period 2, then period 1.

At the end of period 2, the equilibrium full price is given by (11) since the other firms earn zero profit, or

$$P_2 = 4\sqrt{\lambda V f F} - f T_0.$$

In period 2, the leader's technology increment is fixed at its first period choice, ΔT_{leader} . The leader's first order conditions for production and quality in period 2 are

$$\frac{\partial \pi}{\partial Q_2} = P_2 - \lambda q_2 - \frac{2VQ_2}{(\Delta T_{\text{leader}} + T_0)q_2} = 0$$

and

$$\frac{\partial \pi}{\partial q_2} = -\lambda Q_2 + \frac{VQ_2^2}{(\Delta T_{\text{leader}} + T_0)q_2^2} = 0.$$

Solving, the production in period 2, Q_2 , is

$$Q_2(\Delta T_{\text{leader}}) = \frac{(\Delta T_{\text{leader}} + T_0)P_2^2}{9V\lambda}, \quad (16)$$

and its quality in period 2 is

$$q_2(\Delta T_{\text{leader}}) = \frac{P_2}{3\lambda}. \quad (17)$$

The undiscounted profit of the leader in period 2 is

$$\left(\frac{P_2^3(\Delta T_{\text{leader}} + T_0)}{27\lambda V} \right).$$

In period 1, the equilibrium full price is given by (6), since the followers have not adopted new technology,

$$P_1 = 3\sqrt[3]{\lambda V \frac{F}{T_0}}.$$

The leader chooses technology in the first period to maximize two period profits. The technology choice problem is found by differentiating (15) and solving

$$\begin{aligned} \frac{\partial \Pi(\Delta T_{\text{leader}})}{\partial \Delta T_{\text{leader}}} &= 0, \text{ or} \\ &= \frac{(P_1 - f\Delta T_{\text{leader}})^2}{27\lambda V} (-4f\Delta T_{\text{leader}} - 3fT_0 + P_1) \\ &\quad + \frac{1}{1+r} \left(\frac{P_2^3}{27\lambda V} \right) = 0, \end{aligned} \quad (18)$$

which has a solution $\Delta T_{\text{leader}} > \Delta T^*$, (where ΔT^* is the solution to the one period problem (12)). Given full price P_1 and technology increment ΔT_{leader} , the leader's first period quality is given by (1) and its first period production is given by (2).

In both periods the leader earns positive profit and followers earn zero profit. In the second period, followers adopt technology identical to that of the one-period problem, ΔT^* , as given by (12):

$$\Delta T_{\text{follower}} = \frac{1}{f} \sqrt[4]{\lambda V f F} - T_0,$$

which is a smaller investment than made by the leader. Its quantity and quality are the same as the one period problem and are given by (13) and (14), respectively. In both periods, the leader offers a

product with higher quality, produces more and charges a higher price.

The following results follow from the above analysis, and yield testable conclusions.

Proposition 4. *When competing against those slow to adopt new technology, firms that lead in adoption of technology earn positive profits, that is, above normal returns on their investment. Leaders invest more in aggregate than followers. Followers must invest in quality or be forced from the market, but they will only earn normal returns on their investment. The leader will have larger market share, offer higher quality goods and earn higher profits than competitors even after the followers have adopted quality technology.*

The proposition suggests that quality leaders earn higher returns on quality investments than followers. Weak confirmation of this result is offered by Jarrell and Easton (1993), who show that firms who have better developed quality programs, and thus have invested more, enjoy better operating results than firms that have not adopted TQM, as measured by net income/sales, sales/assets, return on assets, and inventory/cost-of-goods sold ratios. However, they find that in contrast to the above proposition, abnormal stock market returns for the leaders are not statistically greater than those of non-TQM adopters. This contradicts the proposition, which implies that a leader's stock price ought to earn positive abnormal returns.

3. Quality management in a decentralized firm

This section studies organizational benefits of TQM by examining quality decisions within a decentralized firm. Specifically, we study whether quality decisions can be made in a decentralized manner, and if TQM principles can improve firm competitiveness. This model studies a serial production system with decentralized decision making. We use investment, variable cost and customer quality cost functions similar to those of Section 2.

Suppose a firm produces and markets a single good in a two-staged process. Let us denote the two stages by 1 and 2, with stage 1 incorporating market-

ing and assembly and stage 2 responsible for parts fabrication. Each stage chooses a quality level, denoted q_1 and q_2 , respectively, and customers' cost of quality is now assumed to be λq , where $q = q_1 q_2$. Now, quality is dependent upon both stages' decisions and increases as either increases its quality.

The divisions both choose technology, denoted by the scalars T_1 and T_2 . The cost of technology T_i is $f_i Q t_i$. As in the previous section, higher technology levels help to reduce production cost (fixing output and quality). The variable production cost of process 1 is $(V_1 Q^2 q_2)/(T_1 q_1)$ and for process 2 it is $(V_2 Q^2)/(T_2 q_2)$. These cost functions capture the following effects: process 1's costs rise with decline in process 2's quality (q_2 rises), production cost is monotone increasing and convex in production output, and higher own quality output increases variable cost. Process 2 is unaffected by process 1's quality because it does not use inputs from this division. The firm's fixed cost can be ignored.

The firm's problem is to maximize its profit through choice of quality, quantity and technology. As in the previous section, the firm is a full price taker. The firm's problem is

$$\begin{aligned} \text{Max}_{q_1, q_2, Q, T_1, T_2} \Pi = & (P - \lambda q_1 q_2) Q - f_1 Q T_1 - f_2 Q T_2 \\ & - \frac{V_1 Q^2 q_2}{T_1 q_1} - \frac{V_2 Q^2}{T_2 q_2} \end{aligned} \quad (19)$$

Assuming an interior solution for all the variables, first order conditions of this problem are

$$\begin{aligned} \frac{\partial \Pi}{\partial Q} = & P - \lambda q_1 q_2 - f_1 T_1 - f_2 T_2 - \frac{2V_1 Q q_2}{T_1 q_1} \\ & - \frac{2V_2 Q}{T_2 q_2} = 0, \end{aligned} \quad (20a)$$

$$\frac{\partial \Pi}{\partial q_1} = -\lambda q_2 Q + \frac{V_1 Q^2 q_2}{T_1 q_1^2} = 0, \quad (20b)$$

$$\frac{\partial \Pi}{\partial q_2} = -\lambda q_1 Q - \frac{V_1 Q^2}{T_1 q_1} + \frac{V_2 Q^2}{T_2 q_2^2} = 0, \quad (20c)$$

$$\frac{\partial \Pi}{\partial T_1} = -f_1 Q + \frac{V_1 Q^2 q_2}{T_1^2 q_1} = 0, \quad (20d)$$

$$\frac{\partial \Pi}{\partial T_2} = -f_2 Q + \frac{V_2 Q^2}{T_2^2 q_2} = 0. \quad (20e)$$

In a decentralized firm the two processes could be organized as profit centers or with process 1 as a profit center and process 2 as a cost center:

Process 1-Profit Center:

$$\begin{aligned} \text{Max}_{q_1, Q, T_1} \Pi_1 = & (P - \lambda q_1 q_2) Q - t Q - f_1 Q T_1 \\ & - \frac{V_1 Q^2 q_2}{T_1 q_1}, \end{aligned} \quad (21)$$

Process 2-Cost Center:

$$\text{Min}_{q_2, T_2} \Pi_2 = f_2 Q T_2 + \frac{V_2 Q^2}{T_2 q_2}. \quad (22)$$

Parameter t is the transfer price that process 1 is charged for inputs from process 2. The first order conditions for these centers are:

Process 1-Profit Center:

$$\frac{\partial \Pi_1}{\partial Q} = P - \lambda q_1 q_2 - f_1 T_1 - \frac{2V_1 Q q_2}{T_1 q_1} - t = 0, \quad (23a)$$

$$\frac{\partial \Pi_1}{\partial q_1} = -\lambda q_2 Q + \frac{V_1 Q^2 q_2}{T_1 q_1^2} = 0, \quad (23b)$$

$$\frac{\partial \Pi_1}{\partial T_1} = -f_1 Q + \frac{V_1 Q^2 q_2}{T_1^2 q_1} = 0. \quad (23c)$$

Process 2-Cost Center:

$$\frac{\partial \Pi_2}{\partial q_2} = -\frac{V_2 Q^2}{T_2 q_2} = 0, \quad (23d)$$

$$\frac{\partial \Pi_2}{\partial T_2} = -f_2 Q + \frac{V_2 Q^2}{T_2^2 q_2} = 0. \quad (23e)$$

By comparing (20a) with (23a) incentives for the profit center can be aligned with those of the firm as a whole if the transfer price is set at

$$t = \frac{\partial \left(\frac{V_2 Q^2}{T_2 q_2} + f_2 Q T_2 \right)}{\partial Q},$$

which is the marginal production cost for process 2.

There are problems aligning the incentives of the cost center with those of the firm as a whole: the cost center does not have incentive to meet customer's quality needs, and low quality output from

process 1 raises process 2's production costs. In fact, the cost center has incentive to decrease quality levels so that $q = 1$ (producing all rejects!). Realistically, cost centers handle this problem by specifying a quality standard (for example, see (Kaplan, 1982, p. 436)). That is, the cost center's quality is chosen for it. But this centralizes the cost center's quality choice, which may be more efficiently set using knowledge of the production technology possessed by cost center managers. The following example demonstrates the sensitivity of profit with respect to quality standards.

Example. Suppose the firm establishes a quality standard for the cost center. That is, the cost center must produce at this quality level or better. Then, the cost center chooses its quality technology to minimize its cost subject to the quality standard and the quantity chosen by the profit center. Based upon the cost center's quality technology decision and the profit center's quantity choice, the transfer price is

set at the cost center's marginal production cost. The profit center chooses quantity, quality and its quality technology to maximize its profit. Assume that $P = 150$, $f_1 = 5$, $V_1 = 100$, $f_2 = 5$, $V_2 = 5$, and $\lambda = 500$. Fig. 3 reports the firm's optimal profits as a function of the quality standard (q_2). In this example, profit (as measured as percentage of optimal profits) is very sensitive to the quality standard. A small error in choosing the standard results in large opportunity losses. The firm may be only imperfectly informed about the cost center's cost function, and make these errors.

These opportunity losses disappear if the cost center's incentives are aligned with the profit center. Incentives can be aligned by evaluating the cost center on the satisfaction of the final customers ($\lambda q_1 q_2 Q$) and the cost of process 1 that it supplies: $((V_1 Q^2 q_2)/(T_1 q_1))$. Let $\mu = \lambda q_1 Q + (V_1 Q^2)/(T_1 q_1)$. If this weight is used in the cost center's performance system to evaluate the cost center's

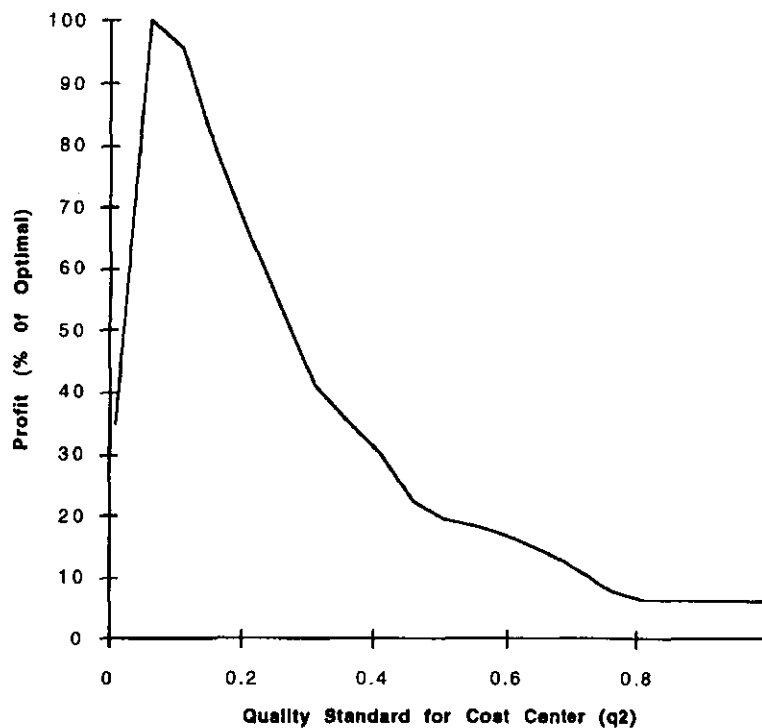


Fig. 3. Profit as a function of the quality standard for a cost center. Here process 2 is a cost center whose output must meet quality standard q_2 . Given the cost center's quality related technology choice, the profit center chooses production quantity, quality, and its quality related technology to maximize its profit. In this example, the firm's profit is very sensitive to the quality standard. A small error in setting the standard results in large opportunity losses. The values of the parameters are $P = 150$, $f_1 = 5$, $V_1 = 100$, $f_2 = 5$, $V_2 = 5$ and $\lambda = 500$.

quality, the cost center's incentives will be aligned with the firm as a whole. If the cost center manager is evaluated on its own cost plus μq_2 , then the cost center is evaluated on customer satisfaction plus the cost center's costs. Redefining process 2's problem as

Process 2-Cost Center With Customer Satisfaction:

$$\text{Min}_{q_2, T_2} \Pi'_2 = f_2 Q T_2 + \frac{V_2 Q^2}{T_2 q_2} + \mu q_2, \quad (24)$$

yields first order conditions:

$$\frac{\partial \Pi'_2}{\partial q_2} = \mu - \frac{V_2 Q^2}{T_2 q_2^2} = 0 \quad (25a)$$

and

$$\frac{\partial \Pi'_2}{\partial T_2} = f_2 Q - \frac{V_2 Q^2}{T_2^2 q_1} = 0. \quad (25b)$$

Now, the cost center problem coincides with the firm's problem at the firm's optimum. Term μ captures the idea that the process 2 internalizes the *revenue externality* ($\lambda q_1 q_2 Q$) and the *cost externality* ($(V_1 Q^2 q_2)/(T_1 q_1)$) that it imposes on the rest of the firm. Customer satisfaction measures can eliminate these two sorts of quality related externalities.

Note that in the above model, the profit center is not evaluated on quality: its effect on quality is captured by reduced revenue. For more complex examples, two internal production groups may be evaluated by using a common customer satisfaction measure of final customers. This encourages these groups to cooperate in satisfying the customer. The analysis can be generalized to a firm with many subunits engaged in complex internal transfers with many external customers.

In this model, the quality externalities are linear in the cost center's quality choice. However, this can clearly be generalized to nonlinear externalities in q_2 . Viewed in this way, customer satisfaction is measured as the marginal effect of quality on externality costs.

Customer satisfaction measures are expressed quantitatively, but in practice, they could be set qualitatively. Both customers and downstream departments can be asked how to assess actual performance and whether it matches expectations. In particular, measures can be independent of the account-

ing system. For example, a quality performance system can be established by asking customers the importance of product attributes. Internal groups (such as marketing and production) can be rated according to actual quality performance, for example as assessed by a questionnaire survey or focus groups. Rating satisfaction in this way, allows performance rating on appropriate local dimensions.

Customer satisfaction measures can be locally defined according to utility and the cost of measurement. Although we did not consider the cost of implementing customer satisfaction measures, the party that generates the externality can be required to measure its customer's satisfaction. This internalizes the cost of measurement as well as the revenue and cost externalities *within a single performance unit*, so that the firm does not overinvest in customer satisfaction assessment. Thus, customer satisfaction provides a flexible way to solve cost and revenue externality problems in an efficient way.

One interpretation of the use of customer satisfaction as a performance measure is to view it as a quality related technological innovation requiring investment. By using this new "organizational technology", product quality is raised and costs (which are both real and opportunity costs) are reduced compared to when centralized quality decisions are made. There is investment expense to adopt the new organization that must be traded off against benefits. The success of the program is a function of the magnitude of the investment made in it. For example, without adequate internal communication and training, benefits of changing the performance system will be reduced. If units are not properly trained to identify their customer, or find out their needs, and are not given adequate tools to identify and solve problems, then the program's effectiveness is reduced. In the above analysis, we have ignored the effect of investment size on effectiveness of the reorganization, but could alter the model to endogenously study this issue.

4. Summary and conclusions

This paper has presented two models of economics of quality management. The models suggest a host of testable hypotheses that can be checked

using company operating and stock price data. The first model suggests that if a firm competes against others quick to adopt quality technology, adopter's investments will generate normal returns, thus their stock price will not display abnormal (positive) returns. Operating data will show that over time, its quality and production volumes will increase, and its price will fall. On the other hand, we predict that if the firm competes in an industry where others are slow to adopt, an early adopter's stock price will display positive abnormal returns. The firm will invest more in technology than laggards, its quality will be superior to competitors, its market share will be larger than competitors and the firm's quality and market share advantages will persist over time. The second model shows that for a decentralized firm, use of customer satisfaction as a performance measure will raise firm value by aligning incentives. Although this model yields fewer testable hypotheses, it does suggest that the adoption of customer satisfaction measures is correlated with the magnitude of revenue and cost externalities.

Besides testing these hypotheses, there are many ways to generalize and extend these models. The first model was one of perfect competition between identical firms. The competitive situation can be extended to oligopoly with firms with asymmetrical cost functions. Only one dimension of quality is considered, but in practice there are many quality dimensions in terms of attributes and variability of attributes. We also considered homogenous customers. In real markets, customers have different tastes that complicate quality planning and competitive analysis. Also, customers may be only partially informed about firm quality. The problem of quality related investment when customers' knowledge of quality is imperfect, but improves with time and experience could be analyzed. In this paper issues of risk associated with the adoption of quality technology have been ignored and could be studied. For example, when quality investments are risky and industry learning is possible, firms may delay quality investments until the success of other's investments are evident.

The second model can be generalized by considering costs of training and communication required to implement a customer satisfaction program. Modeling how program effectiveness can be improved by

investment would be a valuable extension. Empirical and theoretical research is required to understand what types of quality related problems are best solved using decentralized customer satisfaction measures, and which are best solved by using the traditional method of quality standards.

References

- Akerlof, G.A., 1970. "The market for lemons: Quality uncertainty and the market mechanism", *Quarterly Journal of Economics*, vol. 84, pp. 488–500.
- Banker, R.D. and I.S. Khosla, 1992. "Quality and competition", University of Minnesota, Carlson School of Management, Department of Management Science Working Paper.
- Consumer Reports, 1991. "Is Detroit closing the reliability gap?", vol. 56, no. 4, pp. 248–249.
- Crosby, P., 1979. *Quality is Free*, McGraw Hill, New York.
- Deming, W.E., 1990. *Out of the Crisis*, MIT Press, Cambridge, MA.
- Devany, A. and T.R. Saving, 1983. "The economics of quality", *Journal of Political Economy*, vol. 91, pp. 979–1000.
- Economides, N., 1989. "Quality variations and maximal differentiation", *Regional Science and Urban Economics*, vol. 19, pp. 21–29.
- Feigenbaum, A., 1956a. *Total Quality Control*, McGraw Hill, New York.
- Feigenbaum, A., 1956b. "Total quality control", *Harvard Business Review*, November–December.
- Fine, C.H., 1986. "Quality improvements and learning in productive systems", *Management Science*, vol. 32, pp. 1301–1315.
- Fine, C.H., 1988. "A quality control method with learning effects", *Operations Research*, vol. 36, pp. 437–444.
- Fine, C.H. and E. Porteus, 1989. "Dynamic process improvement", *Operations Research*, vol. 37, pp. 580–591.
- Garvin, D.A., 1988. *Managing Quality*, Free Press, New York.
- Hendricks, K. and V.R. Singhal, 1994. "Quality awards and the market value of the firm: An empirical investigation", *Management Science*, Forthcoming.
- Hiam, A. 1992. *Closing the Quality Gap: Lessons From America's Leading Companies*, Prentice Hall, Englewood Cliffs, NJ.
- Jarrell, S. and G.S. Easton, 1993. "An exploratory investigation of the effects of total quality management on corporate performance", Presented at Field Studies In Quality Management Conference, Simon School, March 1993, and to be published in a proceedings volume for the conference.
- Juran, J.M., 1951. *Quality Control Handbook*, McGraw Hill, New York.
- Kaplan, R. 1982. *Advanced Management Accounting*, Prentice-Hall, Englewood Cliffs, NJ.
- Karmarkar, U.S., 1990. "Quality management", CMOM working paper, University of Rochester.
- Karmarkar, U.S. and R. Pitbladdo, 1992. "Quality, class and competition", Simon School Working Paper, 92-02.

- Kearns, D.T. and D.A. Nadler, 1992. *Prophets In The Dark*, Harper Collins.
- Kolesar, P., 1993. "Scientific quality management and management science", in: S.C. Graves et al. (Eds.), *Logistics of Production and Inventory: Handbook of OR and MS*, Volume 4.
- Moorthy, K.S., 1988. "Product and price competition in a duopoly", *Marketing Science*, vol. 7, pp. 141–168.
- Moorthy, K.S. and I.P.L. Png, 1992. "Market segmentation and the timing of product introductions", *Management Science*, vol. 38, pp. 345–359.
- Mussa, M. and S. Rosen, 1978. "Monopoly and product quality", *Journal of Economic Theory*, vol. 18, pp. 301–317.
- Schoenberger, R.J., 1990. *Building A Chain of Customers*, Free Press, New York.
- Shewhart, W.A., 1931. *Economic Control of Quality of Manufactured Product*, Van Nostrand Company, New York.
- Tapiero, C.S., 1987. "Production learning and quality control", *IIE Transaction*, vol. 19, pp. 362–370.
- Tellis, G., and B. Wernerfelt, 1987. "Competitive price and quality under asymmetric information", *Marketing Science*, vol. 6, pp. 240–253.
- Wood, R.C., 1991. "A hero without a company", *Forbes*, 18 March 1991, pp. 112–114.
- Wruck, K., and M. Jensen, 1994. "Science, specific knowledge and total quality management", Presented at Field Studies In Quality Management Conference, Simon School, March 1993; *Journal of Accounting and Economics*, vol. 18, pp. 247–287.
- Zeithaml, V.A., A. Parasuraman and L.L. Berry, 1990. *Delivering Quality Services*, Free Press, New York.

