Quality and Competition

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In recent years, the practitioner literature in operations management has seen a dramatic surge in articles on quality management. It reflects the increased emphasis on quality by U.S. firms, which has been attributed largely to increased competition faced by them. The question of how quality is influenced by competitive intensity, however, has not received much attention, either in the practitioner or the academic research literatures. The notion of competitive intensity itself has not been defined precisely. In this paper, we develop formal models of oligopolistic competition to investigate whether equilibrium levels of quality increase as competition intensifies. We consider three different competitive settings: (i) asymmetric duopolistic competition where the dominant firm's intrinsic demand potential decreases; (ii) a symmetric duopoly where the firms are precluded from cooperating in setting quality levels; and (iii) symmetric oligopolistic competition where the number of firms increases. We find that the relation between equilibrium quality and competitive intensity depends on what is understood by increased competition and, in addition, the relation is contingent on the values of parameters describing the cost and demand structure for the industry.
(*Quality*; *Competition*; *Cooperation*; *Oligopoly*; *Investment*)

1. Introduction

The last decade has seen a dramatic surge in the focus on quality issues by firms in the United States that promises to continue in the years ahead. Thus, we see statements in the popular press such as "Quality is the most important strategic issue facing top management in the 1990s" (Fortuna 1990) and advertising by-lines that emphasize a firm's focus on ensuring quality to its customers (e.g., "Quality is Job 1," used by Ford Motor Company).

The increased emphasis on quality has largely been attributed to increased competition faced by U.S. firms, especially from Japanese competitors. Hayes et al. (1988), for instance, state: "In virtually every industry in which American manufacturers lost market share over the past decade, there was evidence that their products were perceived by consumers as offering poorer quality than equivalently priced foreign products." The 1980s saw Japanese firms make dramatic gains in market share in industries such as automobiles, semiconductors, and consumer electronics. A major reason for the success of these firms was the superior quality and reliability of their products. For example, in the automobile industry in 1979, Toyota averaged 0.71 defects per vehicle shipped, while Ford averaged 3.70 defects (Garvin 1988). This, in turn, led to U.S. automobile firms' improving the quality of their products.[1]

If increased competition is the primary basis for the renewed focus on quality today, it is important to understand how the quality improvement decision of a firm is linked to its competitors' choice of quality levels and the degree of competitive intensity between the firms. Before we can investigate this link, however, we

[1] Tom Peters (1989), a popular management consultant, states: "The reasons for Ford's [surge in profitability], of course, are complex. But chief among them, in my mind, is the payoff from Ford's quality improvement program. Though all of the Big Three have improved, Ford's gains have been dramatic. . . . Poor quality and the management inattention that has induced it rank far ahead of Tokyo, Washington, or union headquarters as a cause of our precipitous decline."

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need to define clearly what we mean by both "quality" and "competitive intensity."

Quality is defined in many different forms in the operations management literature. A typical example, illustrative of what is frequently found in operations management textbooks, is the following: "The quality of a product may be defined in the quality of its design and the quality of its conformance to that design." (Chase and Aquilano 1992).[2] The intent behind quality improvements is to make the product more attractive to the customers. In this study, therefore, we will use the term "quality" to refer to both design and conformance quality characteristics that are of interest to the customer when evaluating the product offered by the firm. A higher quality level selected by a firm is reflected in our models in an upward shift in the firm's demand function and a downward shift in its competitors' demand functions.[3]

How should a firm decide on its investment in quality improvement? Crosby's (1979) *Quality Is Free* is representative of the popular press in suggesting that quality levels should be as high as possible, since the benefits far outweigh the costs. The benefits that are commonly cited include "stronger customer loyalty; more repeat purchases; less vulnerability to price wars; ability to command higher relative price without affecting share; lower marketing costs; and share improvements" (Fortuna 1990). Less attention is given to how the firm competes in the market and the actions of the competing firms. As Buzzell and Gale (1987) state, "the notion that quality and value depend on what competitors are doing is alien to most managers. Yet it is the essence of the competitive aspect of value, and it is an area where businesses frequently get into competitive difficulty."

In order to study the link between quality and competition, we also need to be more precise about what is meant by "competitive intensity." Articles on quality in the popular press, when they have not been vague about what increased competition implies, have discussed the issue of competition in several different ways. We model the intensity of quality competition in three different ways:

(i) A duopoly setting where firms have different intrinsic demand potentials. In this setting, competition increases as the dominant firm's intrinsic demand potential decreases.

(ii) A duopoly setting where firms cooperate to set quality levels. Such cooperation is often perceived to violate the tenets of free competition.

(iii) An oligopoly setting where increased competition is reflected in an increased number of firms.

Each case raises a different question about how the equilibrium quality level changes when competition, as operationalized by the specific oligopolistic model, becomes more intense.

In the first setting we consider, a less competitive market is one where one of the competing firms has a strong intrinsic demand potential for its product. A naïve expectation in this context is that the quality of the product, from the perspective of the customer, would be higher if no single firm dominated the market. Consider, for example, the competition between AT&T and MCI to offer new services to their customers. Because of its large customer base, AT&T has a distinct advantage over MCI, which must persuade customers to buy its product based on its quality valued relative to its price. Which of these two companies is likely to offer the higher quality product? According to a recent survey (Jander 1990), AT&T was ranked number one in customer satisfaction, technology, and service and on related quality measures such as lowest average bit error rate, lowest transmission interference, and fastest call setup. On the other hand, the success of small Japanese firms in the automobile and consumer electronics industries during the 1970–1980s

[2] *Design quality* refers to the product's characteristics such as performance, features, reliability, durability, and serviceability. *Conformance quality* refers to the degree to which product specifications are met. The issue of identifying the dimensions along which each firm must think of quality is not easy to resolve, and firms have not always viewed quality in the same way as their customers have (Garvin 1988). Our analysis here assumes that firms and their customers view quality along similar lines. Improvements on any of Garvin's eight dimensions of quality—performance, features, reliability, conformance, durability, serviceability, aesthetics, and perception—however, make a firm's product more attractive to customers relative to its competitors' products. For expositional convenience, we consider quality along an aggregated single dimension of interest to the customers.

[3] This general structure to represent quality includes advertising and promotion expenditures that enhance the customers' perception of the product's quality without actually upgrading its physical quality. Our two-stage game-theoretic formulation (developed in the next section), in which firms commit to quality levels before setting prices, however, precludes any short-term manipulation of quality.

has been attributed to the high quality of their products, which allowed them to compete effectively against larger, more established firms. What explanation would a theoretical analysis of this situation provide for this differing anecdotal evidence?

The second setting examines the popular notion that free market competition leads to higher quality, and therefore by implication firms should be discouraged from cooperating in setting quality levels. In today's business environment, however, there are an increasing number of examples of firms that have set up partnerships or joint ventures to develop and manufacture products. In 1992, IBM and Apple announced a joint venture to develop a new computer with a new operating system. Ford and Mazda compete in the marketplace, yet they have designed and developed cars together. In such instances, is an inferior quality product offered by these firms than would be offered if they were in competition?

In the third setting, we investigate whether quality improves when the number of firms competing in an oligopolistic industry increases. In 1985, the G.A.O. concluded that the increased competition due to new firms entering the recently deregulated airline industry had led to increased customer responsiveness and reconfiguring of fleets. More recently, the airline industry has seen a major consolidation where the number of competing firms has been reduced significantly. Should we expect quality always to decrease in such a situation? In contrast, the automobile industry is no longer dominated by the Big Three U.S. firms as in the 1970s. Does the increase in the number of significant competitors in the industry imply an improvement in quality?

The plan for the rest of the paper is as follows. We begin in §2 by detailing our primary assumptions and describing the duopoly model where the two firms differ in their intrinsic demand potential. In §3 we study the situation where the two firms cooperate in determining quality levels. In §4 we study the behavior of the equilibrium quality level as the number of firms in an oligopoly increases. Section 5 concludes the paper.

2. Impact of Market Dominance on Quality

We begin our analysis by developing a simple noncooperative game theoretic model to consider quality competition when the two firms differ in their intrinsic demand potential. The question we ask here is: what happens to the quality levels of the two firms if one firm dominates the market? An intuitive answer to this question is that the customer will be offered lower quality products because the industry is not as evenly competitive. In this section, we develop a duopoly model to verify this intuition.

Our primary interest, of course, is in the quality decision. However, this decision cannot be viewed in isolation. It also depends on the price that the firm plans to offer to the customers, since the customers will make their decision to purchase the product from a firm based on both its price and quality (Thomas 1970, Eliashberg and Steinberg 1991). The computer industry provides a good example of this link. Compaq has traditionally been viewed as a manufacturer of high-quality personal computers and thus commanded a significant price premium over other manufacturers of IBM-compatible PCs. In 1992, Compaq announced a significant change in its pricing and quality strategies in response to its low-price, low-cost competitors (Lancaster and Allen 1992). It slashed the prices of its products and decided that it would "no longer pursue peak performance (in its products) at all costs" (Rick Smith, Director of quality engineering at Compaq, quoted in Lancaster and Allen 1992). In our model, we will seek to reflect such interactions between price and quality decisions.

The study of quality competition has received attention primarily in the economics and marketing literatures. Many of these papers have been inspired by Hotelling (1929), who studied the price and quality competition between two symmetric firms assuming that consumers have heterogeneous tastes that lie on a continuum (e.g., Moorthy 1988, Polo 1991). Quality is usually modeled as a location decision on this continuum, with no direct implications for manufacturing costs. As discussed below, our model will differ in that we will model consumer demand as a linear function of the price and quality levels selected by the two firms. Moreover, for each firm we will explicitly model the impact of quality on both fixed and variable production costs. In the operations management literature, the only study we are aware of that considers quality competition in an economic framework is by Karmarkar and Pitbladdo (1992). They conclude by suggesting that "one direction for future research is to examine the issue of investing in quality improvement." This is the issue we pursue in our analytical model described below.

We begin our analysis by studying the price and quality competition in a duopoly setting. The model we construct is based on the following assumptions.

(1) There are two firms, labeled 1 and 2. Each firm has one product, for which it must choose a price level p and a quality level x. We assume that quality is a measurable attribute with values in the interval $[0, \infty)$.

(2) Extending Dixit (1979), we assume that the demand functions for the two firms are linear in price and quality:

$$q_i \equiv Q_i(p, x) = k_i\alpha - \beta p_i + \gamma p_j + \lambda x_i - \mu x_j, \quad i, j = 1, 2, i \neq j, \tag{2.1}$$

where $k_1 + k_2 = 1$. Here $k_i\alpha$ is the intrinsic demand potential parameter for firm i, $i = 1, 2$. The parameter β (λ) denotes the demand responsiveness to the firm's own price (quality), while γ (μ) denotes the demand responsiveness to the competitor's price (quality). We refer to β/γ (λ/μ) as the relative responsiveness to price (quality) and assume that it is greater than one, i.e.,

$$\beta > \gamma \quad \text{and} \quad \lambda > \mu.$$

Thus, the demand q_i for each firm i's product is affected more by changes in its own price and quality than those of its competitors. This condition is necessary because if both firms were to raise their prices by \$1 or to decrease their quality by one unit, then both firms should lose sales (Tirole 1990).

(3) The cost function for firm i is given by

$$c_i \equiv C_i(q_i, x_i) = (v + \epsilon x_i)q_i + f + \phi_i x_i^2, \quad i = 1, 2. \tag{2.2}$$

Thus, the quality level selected by a firm affects total costs in two ways:

(i) Investment in a quality improvement program increases fixed production costs. These costs arise because of new investment for high-precision, high-reliability, fast, or flexible equipment; organizational training and restructuring to implement a quality management program; or additional effort to redesign the product or process to achieve the desired quality level. The fixed costs, $f + \phi_i x_i^2$, are increasing and convex in the quality level x_i. In this regard, our model is similar to other studies which have modeled the selection of quality (e.g., Moorthy 1988). We allow the fixed cost parameter ϕ_i to differ between firms to capture the possibility that one of the two firms may enjoy an advantage in implementing quality improvement. For example, a firm with a smaller intrinsic demand potential may be "leaner" in its organizational structure and thus be able to introduce quality improvements at a lower cost than its rival with a larger intrinsic demand potential.

(ii) The quality level also has an impact on the production cost per unit. Specifically, v denotes the variable production cost per unit *not including* the quality related costs. Given a quality level x selected by the firm, the unit variable cost increases (decreases) by $|\epsilon x|$, where $\epsilon > 0$ (<0). Allowing ϵ to be negative enables us to model the possibility that the production costs actually decline when quality is improved, a phenomenon frequently cited in the literature. Garvin (1988), for instance, reports an inverse relationship between the number of direct labor hours needed to assemble various brands of air conditioners and their relative quality ranking.

The competition between the two firms takes place in the following sequence in time:

(i) The two firms simultaneously select their quality levels.

(ii) The two firms observe each other's quality choices.

(iii) Each firm selects a price for its product.

(iv) Demand is realized based on the prices and quality levels set by the two firms. Our model also reflects the assumption that price decisions are made after the quality decisions, since the choice of a quality level reflects a long-term decision which cannot be changed as easily or frequently as prices.[4]

To solve this two-stage game, we first calculate the Nash equilibrium in prices, assuming a given quality level for each firm, and then determine the Nash equilibrium in quality levels given the equilibrium prices as functions of quality levels. We concentrate on finding pure-strategy equilibria at each of the two stages de-

[4] Our results extend readily to a model in which the quality-choice stage is followed by $T > 1$ stages where price (but not quality) is adjusted based on current demand information.

scribed above. As Tirole (1990) points out, pure strategy equilibria are attractive for two reasons. First, the simplicity of their structure makes it possible to link them to the actual behavior of the competing firms. Second, no firm has *ex post* regret after observing the choice of the other firm.

In our subsequent analysis, we shall explicitly specify three additional assumptions: A2.1, A2.2, and A2.3. At an intuitive level, A2.1 places an upper bound on v to ensure that the demand for each firm at its equilibrium price is positive at all quality levels. A2.2 places an upper bound on ϵ to ensure that equilibrium price and demand for a firm do not increase when the firm does not improve its quality but its competitor does, or when both firms lower their quality levels by the same amount. Without the upper bounds on v and ϵ, the production cost per unit would be too high for a firm to manufacture its product profitably under any situation A2.3 places a lower bound on ϕ_i to ensure that the profit function is concave and a pure-strategy Nash equilibrium in quality level exists.

2.1. Price Equilibrium

The profit functions for the two firms are as follows:

$$\Pi_i(p, x) = (p_i - v - \epsilon x_i)(k_i\alpha - \beta p_i + \gamma p_j + \lambda x_i - \mu x_j) - f - \phi_i x_i^2, \quad i, j = 1, 2, i \neq j. \tag{2.3}$$

The first-order conditions characterizing equilibrium prices are:

$$\frac{\partial \Pi_i}{\partial p_i} = (k_i\alpha - \beta p_i + \gamma p_j + \lambda x_i - \mu x_j) + (p_i - v - \epsilon x_i)(-\beta) = 0, \quad i, j = 1, 2, i \neq j. \tag{2.4}$$

Since $\partial^2\Pi_i/\partial p_i^2 = -2\beta < 0$, the profit function given quality levels is strictly concave in prices. Solving for p_1 and p_2 simultaneously from the above two equations, we obtain the equilibrium price for each firm:

$$p_i^*(x) = v + \epsilon x_i + \frac{1}{W}[R_i + Sx_i - Tx_j], \quad i, j = 1, 2, i \neq j, \tag{2.5}$$

where

$$W = (4\beta^2 - \gamma^2),$$

$$R_i = 2k_i\alpha\beta + k_j\alpha\gamma - v(\beta - \gamma)(2\beta + \gamma), \quad i, j = 1, 2, i \neq j,$$

$$S = 2\beta\lambda - 2\beta^2\epsilon - \gamma\mu + \epsilon\gamma^2, \text{ and}$$

$$T = 2\beta\mu - \beta\gamma\epsilon - \gamma\lambda.$$

The corresponding profit and demand quantities at the equilibrium prices are:

$$\Pi_i^*(x) \equiv \Pi_i(p_i^*(x), x) = \frac{\beta}{W^2}[R_i + Sx_i - Tx_j]^2 - f - \phi_i x_i^2, \quad i, j = 1, 2, i \neq j. \tag{2.6}$$

$$Q_i^*(x) \equiv Q_i(p_i^*(x), x) = \frac{\beta}{W}[R_i + Sx_i - Tx_j], \quad i, j = 1, 2, i \neq j. \tag{2.7}$$

To ensure that $Q_i^*(x)$ is positive at $x_i = x_j = 0$, we need $R_i > 0$, $i = 1, 2$, for which we require the following assumption:

$$\text{A2.1.} \quad \nu < \frac{\alpha\gamma}{(\beta - \gamma)(2\beta + \gamma)}.$$

Also, from (2.5) and (2.7), note that when $T < 0$, for a fixed choice of firm i's quality level, firm i will see its equilibrium price as well as the demand at this equilibrium price increase as competing firm j increases its quality level. Thus the equilibrium price and demand for firm i increase without the firm's changing its own quality, but its competitor improving its quality, an implausible scenario. Therefore, in our ensuing analysis, we assume that $T > 0$, i.e.,

$$T > 0 \Leftrightarrow \epsilon < \frac{(2\beta\mu - \gamma\lambda)}{\beta\gamma}. \tag{2.8}$$

Similarly, we also see that when $S < T$, both firms find their equilibrium prices *and* demands increasing when they both reduce their quality levels by the same amount, which is again implausible. Therefore, we assume $S > T$, i.e.,

$$S > T \Leftrightarrow (2\beta + \gamma)[\lambda - \mu - \epsilon(\beta - \gamma)] > 0 \Leftrightarrow \epsilon < \frac{\lambda - \mu}{\beta - \gamma}. \tag{2.9}$$

To satisfy the two conditions, (2.8) and (2.9), we require the following assumption:

A2.2. $\epsilon < \min\left\{\frac{(2\beta\mu - \gamma\lambda)}{\beta\gamma}, \frac{\lambda - \mu}{\beta - \gamma}\right\}.$

2.2. Quality Equilibrium

Having characterized the price equilibrium, we now analyze the quality equilibrium. Differentiating (2.6) with respect to x_i and equating it to zero, we obtain the following reaction function for firm i that gives the best action for firm i given that firm j chooses x_j:

$$x_i = \frac{\beta S}{(W^2\phi_i - \beta S^2)}[R_i - Tx_j], \quad i, j = 1, 2, i \neq j. \quad (2.10)$$

The profit function is strictly concave in the quality level x_i if

$$\phi_i > \frac{\beta S^2}{W^2}, \text{ i.e., } W^2\phi_i - \beta S^2 > 0, \quad i = 1, 2.$$

Further, for a pure-strategy Nash equilibrium to exist, we require that the reaction functions for the two firms intersect once. A sufficient condition for this to happen is the following (Tirole 1990):

$$\left|\frac{\partial^2 \Pi_i}{\partial x_i^2}\right| > \left|\frac{\partial^2 \Pi_i}{\partial x_i \partial x_j}\right| \Leftrightarrow W^2\phi_i - \beta S^2 - \beta ST > 0. \quad (2.11)$$

Solving the two equations in (2.10) simultaneously, we obtain the equilibrium quality levels:

$$x_i^N = \frac{S\beta[R_i(W^2\phi_j - \beta S^2) - R_j ST\beta]}{[(W^2\phi_i - \beta S^2)(W^2\phi_j - \beta S^2) - (ST\beta)^2]},$$
$$i, j = 1, 2, i \neq j, \quad (2.12)$$

where we have used the superscript N to indicate that it is the Nash equilibrium quality level. To ensure that $x_i^N > 0$ (when its numerator and denominator are both positive) and that the condition (2.11) holds, we require the following assumption:

A2.3. $\phi_i > \frac{1}{W^2}\left\{\beta S^2 + \frac{2\alpha\beta - v(\beta - \gamma)(2\beta + \gamma)}{\alpha\gamma - v(\beta - \gamma)(2\beta + \gamma)}\beta ST\right\},$
$i = 1, 2.$

The equilibrium prices, demand and profits are as follows:

$$p_i^N = v + \frac{[W\phi_i + \epsilon\beta S][R_i(W^2\phi_j - \beta S^2) - R_j ST\beta]}{[(W^2\phi_i - \beta S^2)(W^2\phi_j - \beta S^2) - (ST\beta)^2]},$$
$$i, j = 1, 2, i \neq j. \quad (2.13)$$

$$q_i^N = \frac{(\beta W\phi_i)[R_i(W^2\phi_j - \beta S^2) - R_j ST\beta]}{[(W^2\phi_i - \beta S^2)(W^2\phi_j - \beta S^2) - (ST\beta)^2]},$$
$$i, j = 1, 2, i \neq j. \quad (2.14)$$

$$\Pi_i^N = \frac{\beta\phi_i[W^2\phi_i - \beta S^2][R_i(W^2\phi_j - \beta S^2) - R_j ST\beta]^2}{[(W^2\phi_i - \beta S^2)(W^2\phi_j - \beta S^2) - (ST\beta)^2]^2} - f,$$
$$i, j = 1, 2, i \neq j. \quad (2.15)$$

Our primary interest is in how the average quality level in the industry changes when competition increases. Let $\tilde{x} = \omega_1 x_1^N + \omega_2 x_2^N$ denote the weighted average equilibrium industry quality level, where $\omega_i = q_i^N/(q_1^N + q_2^N)$, $i = 1, 2$. The following proposition summarizes our findings.

PROPOSITION 1. *Suppose firm 1 has an intrinsic demand advantage over firm 2, i.e., $k_1 > k_2$. Then as competition (k_2) increases, firm 1's quality, price, and market share decrease, and firm 2's quality, price, and market share increase,*

$$\text{i.e., } \frac{\partial x_1}{\partial k_2} < 0, \frac{\partial p_1}{\partial k_2} < 0, \frac{\partial q_1}{\partial k_2} < 0,$$

$$\frac{\partial x_2}{\partial k_2} > 0, \frac{\partial p_2}{\partial k_2} > 0, \frac{\partial q_2}{\partial k_2} > 0.$$

Also,

(i) *if $\phi_2 \geq \phi_1$, the firm 1 has the higher quality level (i.e., $x_1 > x_2$) and as competition increases the average industry quality level decreases (i.e., $(\partial\tilde{x}/\partial k_2) < 0$);*

(ii) *if $\phi_1 > \phi_2$ and $(\phi_1/\phi_2) > (R_1/R_2)$, firm 1 adopts a lower quality strategy (i.e., $x_1 < x_2$), and as competition increases the average industry quality level increases (i.e., $(\partial\tilde{x}/\partial k_2) > 0$).*

PROOF. See Banker et al. (1996).

The above proposition indicates that if the industry is dominated by a firm (firm 1) that holds an advantage over its competitor in not only the intrinsic demand potential but also in the fixed cost of quality improvement, then as competition increases, i.e., as the difference in the intrinsic demand potentials decreases, the average industry quality level declines. On the other hand, if the weaker firm (firm 2) has a relative cost advantage in quality improvement which offsets the intrinsic demand advantage of firm 1 (i.e. $R_1/R_2 < \phi_1/\phi_2$), then the average industry quality level increases as competition increases.

Proposition 1 provides a qualified theoretical basis for the extensive anecdotal evidence in the popular business literature that increased competition from a new firm leads to higher quality in industries that have traditionally been dominated by an established firm. We see that average industry quality increases when the new firm has a sufficient advantage in the fixed cost of quality improvement parameter ϕ_i to overcome the intrinsic demand advantage of the established firm. If this condition does not hold, the new firm has the lower quality in equilibrium, and the average industry quality level decreases with competitive intensity.

The threshold level for the ratio of fixed cost parameters is R_1/R_2. In the next corollary, we see that R_1/R_2 increases with the demand responsiveness to the firm's own price (β) and decreases with the demand responsiveness to the competitor's price (γ).

COROLLARY 1.1. *Let* $Z = R_1/R_2$. *Then*:

$$(1)\quad \frac{\partial Z}{\partial \beta} > 0;\ (2)\quad \frac{\partial Z}{\partial \gamma} < 0.$$

PROOF. Straightforward and therefore omitted.

Proposition 1 and Corollary 1.1 together show that if the weaker firm has a cost advantage in the fixed cost of quality improvement over the dominant firm (i.e., $\phi_1 > \phi_2$), then the industry quality level is likely to rise as competition increases if each firm's demand responsiveness to its own price (β) is low and the demand responsiveness to its competitor's price (γ) is high.

2.3. Bertrand Versus Cournot Competition

Until this point, we have assumed Bertrand competition in the subgame after firms select their quality levels. An alternative model would be to replace the Bertrand subgame by a Cournot subgame where the firms choose equilibrium quantities rather than prices for these products. Prices are determined by the inverse demand functions matching customer demand with the quantities supplied by the competing firms.

In Banker et al. (1996), we determine the equilibrium quality levels when the price competition is replaced with quantity competition in the second stage of our two-stage game. It can be shown that results similar to Proposition 1 and Corollary 1.1 obtain also for Cournot competition. Thus, our results are robust with respect to the way the second stage of our two-stage game is modeled.

3. Impact of Cooperation on Quality

The question we address in this section is whether the quality levels selected by two symmetric firms in a competitive duopolistic environment decline if they cooperate in choosing the quality levels. Trade associations, joint ventures, and imposition of industry standards are all institutional mechanisms that promote quality cooperation. In 1992, the Big Three automakers announced "the formation of an umbrella organization to oversee a growing stable of joint research ventures, (including) . . . research into strategically important pollution control technology . . . (and) into advanced battery technology for electric vehicles." (*Wall Street Journal* 1992).[5] To evaluate the quality offered to the customers in such environments, we consider a duopoly setting where the firms jointly choose their quality levels and then compete on prices.

One of the reasons frequently cited in the popular press for firms to form partnerships and cooperate on determining quality levels is the possibility of sharing the high cost of quality improvement, especially when improved quality involves extensive research and development. In order to consider this synergistic possibility, we assume in the cooperative models developed below that the parameter ϕ in the fixed cost of quality becomes $\theta\phi$ for each firm, where $\theta > 0$. When $1 > \theta > 0$, our model captures the synergies that result from such cooperative arrangements. In particular, when $\theta < \frac{1}{2}$, the total cost for the two firms, $2\theta\phi$, is less than the cost ϕ incurred by each firm if it were to invest in quality improvement on its own. However, when the technological specifications for the two firms are not compatible, joint development of improved quality technology may be counterproductive, resulting in $\theta > 1$, when the fixed costs of quality improvement exceed the costs incurred if the two firms were in competition (Herman and Power 1990).

[5] The article also reports that "by pooling resources, Detroit's Big Three could cut development costs. . . . However, . . . in 1969, the U.S. Justice Department barred (them) from sharing information on pollution control systems. That restraint, . . . under the Reagan administration . . . disappeared entirely in 1987."

As in the previous duopoly model, we need to assume upper bounds on v and ϵ, and a lower bound on $\theta\phi$. We make the following assumptions:

$$\text{A3.1.} \quad \nu < \frac{\alpha}{\beta - \gamma}.$$

$$\text{A3.2.} \quad \epsilon < \min\left\{\frac{(2\beta\mu - \gamma\lambda)}{\beta\gamma}, \frac{\lambda - \mu}{\beta - \gamma}\right\}.$$

$$\text{A3.3.} \quad \theta\phi > \frac{\beta(S - T)^2}{W^2}.$$

We assume that the firms are symmetric and their demand functions are given by:

$$q_i \equiv Q_i(p, x) = \alpha - \beta p_i + \gamma p_j + \lambda x_i - \mu x_j, \quad i, j = 1, 2, i \neq j. \tag{3.1}$$

The sequence of events is the same as in the duopoly model developed in §2: The quality levels are selected first, followed by the prices. The equilibrium prices are obtained in the same manner as in the duopoly model in §2. Given quality level choices x_i, $i = 1, 2$, the equilibrium prices for each firm are as follows:

$$p_i^*(x) = v + \epsilon x_i + \frac{1}{W}[R + Sx_i - Tx_j], \quad i, j = 1, 2, i \neq j, \tag{3.2}$$

where $R = (2\beta + \gamma)(\alpha - v(\beta - \gamma))$ and W, S and T are as defined in §2.

We assume that the two firms cooperate in choosing the quality levels $x_1 = x_2 = x$ to maximize:

$$\Pi^*(x) = \Pi_1^*(x) + \Pi_2^*(x)$$
$$= \frac{2\beta}{W^2}[R + (S - T)x]^2 - 2f - 2\theta\phi x^2, \tag{3.3}$$

where θ denotes the level of synergies in quality improvement when the firms cooperate in selecting the quality level and compete on prices.

The first order conditions characterizing the cooperative quality levels are:

$$\frac{\partial \Pi^*}{\partial x_i} = \frac{4\beta(S - T)}{W^2}[R + (S - T)x] - 4\theta\phi x = 0,$$

which yield

$$x_i^C = \frac{\beta R(S - T)}{\theta\phi W^2 - \beta(S - T)^2} \quad i = 1, 2$$
$$= \frac{\beta[\alpha - v(\beta - \gamma)][\lambda - \epsilon(\beta - \gamma) - \mu]}{\theta\phi(2\beta - \gamma)^2 - \beta(\lambda - \epsilon(\beta - \gamma) - \mu)^2}, \tag{3.4}$$

where we use the superscript C to indicate that it is the solution when the two firms cooperate in selecting the quality level.

To ensure that the above solution is a global maximum, we require that the second derivative be negative, i.e.,

$$\frac{\partial^2 \Pi^*}{\partial x^2} < 0 \Leftrightarrow \frac{4\beta(S - T)^2}{W^2} - 4\theta\phi < 0 \Leftrightarrow$$

$$\theta\phi > \frac{\beta(S - T)^2}{W^2}, \tag{3.5}$$

i.e., assumption A3.3 holds.

Proposition 2. *The average industry quality level is higher under competition than under cooperation if and only if θ is sufficiently large. Formally,*

$$x_i^N > x_i^C \Leftrightarrow \theta > \frac{(S - T)}{S}$$
$$= \frac{(2\beta + \gamma)[\lambda - \epsilon(\beta - \gamma) - \mu]}{[2\beta\lambda - 2\beta^2\epsilon + \gamma^2\epsilon - \gamma\mu]}.$$

Proof. Straightforward and therefore omitted.

Proposition 2 states that if the fixed cost synergy parameter θ is not less than a certain threshold, then the competitive quality level will be higher than the cooperative quality level. In particular, if $\theta \geq 1$, i.e., if cooperation does not have a beneficial impact on the fixed cost of quality improvement, then the competitive quality level will always be higher than when the firms cooperate on quality and compete on prices.

Corollary 2.1. *Let $U = (S - T)/S = (2\beta + \gamma)[\lambda - \epsilon(\beta - \gamma) - \mu]/[2\beta\lambda - 2\beta^2\epsilon + \gamma^2\epsilon - \gamma\mu]$. Then*

$$(1) \quad \frac{\partial U}{\partial \lambda} > 0; \; (2) \quad \frac{\partial U}{\partial \mu} < 0; \textit{ and,}$$

$$(3) \quad \frac{\partial U}{\partial \epsilon} > 0 \Leftrightarrow \lambda/\mu > \beta/\gamma.$$

Proof. Follows directly from the partial derivative expressions, using the fact that $S > T > 0 \Rightarrow \lambda - \epsilon\beta > \mu - \epsilon\gamma > 0$. $\square$

Proposition 2 and Corollary 2.1 together show that cooperation in quality is more likely to result in a higher quality level for the industry than in the competitive setting when each firm's demand responsiveness to its own quality (λ) is higher and when the responsiveness to its competitor's quality (μ) is lower. We also see that if the relative quality responsiveness λ/μ is greater than the relative price responsiveness β/γ, then a higher variable production cost per unit due to quality improvement is more likely to lead to a higher quality level under cooperation than when the firms are in competition.

When will the two firms prefer a cooperative arrangement to competition in the quality level decision? It is straightforward to show that:

$$\Pi_1^N + \Pi_2^N > \Pi_1^C + \Pi_2^C \Leftrightarrow \frac{2\beta\phi R^2(W^2\phi - \beta S^2)}{[W^2\phi - \beta S^2 + \beta ST]^2} > \frac{2\beta\phi\theta R^2}{\phi\theta W^2 - \beta(S-T)^2} \Leftrightarrow \theta S[W^2\phi(S-2T) - \beta S(S-T)^2] > (\phi W^2 - \beta S^2)(S-T)^2. \tag{3.6}$$

Define $\Omega = (\phi W^2 - \beta S^2)(S-T)^2/S[W^2\phi(S-2T) - \beta S(S-T)^2]$. Note that $\Omega > 1$.

If $2T > S > T$ then $\Pi_1^C + \Pi_2^C > \Pi_1^N + \Pi_2^N$ for all values of θ.

If $S > 2T$ then $\Pi_1^N + \Pi_2^N > \Pi_1^C + \Pi_2^C \Leftrightarrow \theta > \Omega > 1$.

Now,

$$\frac{\lambda}{\mu} > \frac{\beta}{\mu} \Rightarrow S > 2T, \text{ and}$$

$$\frac{\beta}{\mu} > \frac{\lambda}{\mu}, \epsilon > \frac{2\beta\lambda - 4\beta\mu - \gamma\mu + 2\gamma\lambda}{2\beta^2 - 2\beta\gamma - \gamma^2} \Rightarrow 2T > S.$$

Therefore, when the relative price responsiveness is greater than the relative quality responsiveness and quality improvement provides little or no reduction in the variable production costs per unit, we have $2T > S$ and it follows from (3.6) that, regardless of the level of synergies provided by the cooperative arrangement, the two firms will always prefer cooperation to competing in the quality decision. This is because competition in quality simply drives quality levels up without providing commensurate gains either in demand or in the reduction of variable costs, thereby decreasing profits. In contrast, for large values of θ, cooperation leads to both firms' choosing lower levels of quality, thereby increasing profits.

When the relative quality responsiveness is greater than the relative price responsiveness, we have $S > 2T$, and investment in quality provides significant gains in demand. We see that when $0 < \theta < \Omega$, the two firms together will be better off in a cooperative arrangement rather than competing in the quality decision.

How should the two firms decide to share the fixed costs of quality improvement? To answer this question, consider the following Nash bargaining game that occurs between the two firms before the quality decision.

Move 1: Firm 1 offers to cooperate with firm 2 in the quality decision and pay a fraction ω, $0 < \omega < 1$, of the total fixed cost of quality improvement.

Move 2: Firm 2 decides whether to accept or reject the offer. If firm 2 accepts the offer, it pays the remaining fraction $(1 - \omega)$ of the total cost, and the two firms jointly select the quality level. If firm 2 rejects the offer, the two firms compete in the quality decision.

We seek to determine the bounds that must be placed on ω to make cooperation the preferred option for both firms over the alternative of competing in the quality decision.

Let $\Pi_i^C(\omega)$ denote the optimal profits for firm i, $i = 1, 2$, under cooperation when it pays $\omega[2\theta\phi x^2]$ toward the total fixed quality improvement costs. Then

$$\Pi_i^C(\omega) \geq \Pi_i^N \Leftrightarrow \frac{\beta\phi\theta R^2[\theta\phi W^2 - 2\omega\beta(S-T)^2]}{[\theta\phi W^2 - \beta(S-T)^2]^2} \geq \frac{\beta\phi R^2[\phi W^2 - \beta S^2]}{[\phi W^2 - \beta S^2 + \beta ST]^2} \Leftrightarrow \omega \leq \Delta$$

$$= \frac{(S-T)^2(\phi W^2 - \beta S^2)\{2\theta\phi W^2 - \beta(S-T)^2\} - \theta^2\phi S W^2\{\phi W^2(S-2T) - \beta S(S-T)^2\}}{2\theta(S-T)^2[\phi W^2 - \beta S^2 + \beta ST]^2}.$$

Thus, firm 1 will not be willing to pay a fraction ω of the total quality improvement costs unless $\omega \leq \Delta$. Similarly, firm 2 will not be willing to pay a fraction $(1 - \omega)$ of the total quality improvement costs unless $(1 - \omega) \leq \Delta$, i.e., $\omega \geq 1 - \Delta$. Therefore, both firms will benefit from cooperation if $\omega \in [1 - \Delta, \Delta]$. If there are no other factors affecting the relative bargaining positions of the two firms, then the Nash solution to the bargaining game is given by $\omega = \frac{1}{2}$, that is, both firms split the fixed costs of quality improvement equally.

Cooperation in quality and competition in prices between firms is increasingly observed in today's business environment. For example, Ford and Mazda have designed and developed the same car together (Mazda's Navajo and Ford's Explorer) and then sold them separately through their dealerships. The rationale provided most prominently for this partnership is the sharing of the high cost of developing a new car, which can be as high as $2 billion (Treece et al. 1992). In addition, firms that set up such cooperative arrangements often bring complementary technical skills to the design and development of the new product. This can result in a higher quality product being manufactured for the same total investment than if each firm had developed the product separately. Our analysis shows that if the savings in quality improvement investments are significant, then, in fact, such cooperative arrangements will result in the customers being offered a higher quality product. However, absent such synergistic benefits, quality levels will be higher in a more competitive industry.

4. Impact of Number of Competitors on Quality

In this section we address the following question: Does the quality improve or decline as the number of firms competing in the industry increases? For this purpose, we consider an oligopoly with n symmetric firms.[6] The demand function for each firm i is given by:

$$Q_i^n(p, x) = \alpha_n - \beta_n p_i + \gamma_n \sum_{j \neq i} p_j + \lambda_n x_i - \mu_n \sum_{j \neq i} x_j. \quad (4.1)$$

We obtain the aggregate industry demand function by adding the demand functions of the n firms:

$$\sum_{i=1}^{n} Q_i^n(p, x) = n\alpha_n - n(\beta_n - (n-1)\gamma_n)\bar{p} + n(\lambda_n - (n-1)\mu_n)\bar{x}, \quad (4.2)$$

where $\bar{p} = (\Sigma_{j=1}^n p_j)/(n)$ and $\bar{x} = (\Sigma_{j=1}^n x_j)/n$. Our interest is in studying how the equilibrium quality level changes as the competitive intensity (measured by n, the number of firms) changes, keeping the functional representation of the aggregate demand invariant to the number of firms in the industry.[7] To ensure that the aggregate industry demand function is independent of n, we set

$$\alpha_n = \alpha/n, \quad \beta_n = \beta/n, \quad \gamma_n = \gamma/n(n-1),$$
$$\lambda_n = \lambda/n \text{ and } \mu_n = \mu/n(n-1). \quad (4.3)$$

The cost function for each firm is as in the duopoly model of §2, except for the parameter for the fixed cost of quality improvement, which we write as ϕ_n to allow for its dependency on the competitive intensity. As in §2, we need upper bounds on v and ϵ, and a lower bound on ϕ_n. Assumptions [A3.1] and [A3.2] are sufficient for the upper bounds on v and ϵ, but Assumption [A3.3] is modified as follows:

A4.3. $\phi_n > \dfrac{\beta S_n^2}{n W_n^2}$ *for each*

$n = 2, 3, 4, \cdots$ (*where* S_n *and* W_n *are defined below*).

4.1. Price Equilibrium

The profit function for firm i is given by:

$$\Pi_i(p, x) = (p_i - v - \epsilon x_i)\left(\frac{\alpha}{n} - \frac{\beta}{n} p_i + \frac{\gamma}{n(n-1)} \sum_{j \neq i} p_j + \frac{\lambda}{n} x_i - \frac{\mu}{n(n-1)} \sum_{j \neq i} x_j\right) - f - \phi_n x_i^2, \quad i, j = 1, 2, \ldots, n. \quad (4.4)$$

Equating the first derivative of the profit function in (4.4) with respect to p_i to zero for each i and solving for the equilibrium prices p_i^*, we get:

$$p_i^* = \frac{1}{2\beta}\left[\alpha + \beta v + (\lambda + \epsilon\beta)x_i - \frac{\mu}{n-1} \sum_{j \neq i} x_j + \frac{\gamma}{n-1} \sum_{j \neq i} p_j^*\right]. \quad (4.5)$$

[6] A potentially fruitful extension of our research is to consider the possibility that firms operate inefficiently and the level of organizational slack decreases (or increases) with increased competition.

[7] An alternative formulation would involve modeling the number of firms in the industry as a function of fixed costs of quality improvement and then examining how the equilibrium level of quality changes with the fixed costs of quality.

The profit function is strictly concave in p_i given p_j, $j \neq i$, because $(-2\beta p_i)/n < 0$. Solving the equations in (4.5) simultaneously, we obtain:

$$p_i^*(x) = v + \epsilon x_i + \frac{1}{W_n}\left[R_n + S_n x_i - \sum_{j\neq i} T_n x_j\right],$$

where

$$W_n = [2(n-1)\beta + \gamma][2\beta - \gamma],$$

$$R_n = [2(n-1)\beta + \gamma][\alpha - v(\beta - \gamma)],$$

$$S_n = [2(n-1)\beta - (n-2)\gamma](\lambda - \epsilon\beta) + \epsilon\gamma^2 - \gamma\mu, \text{ and}$$

$$T_n = 2\beta\mu - \epsilon\beta\gamma - \gamma\lambda.$$

The demand and profit functions for firm i at the equilibrium prices given quality levels x are as follows:

$$Q_i^*(x) \equiv Q_i(p^*(x), x) = \frac{\beta}{nW_n}\left[R_n + S_n x_i - \sum_{j\neq i} T_n x_j\right], \tag{4.6}$$

and

$$\Pi_i^*(x) \equiv \Pi_i(p^*(x), x) = \frac{\beta}{nW_n^2}\left[R_n + S_n x_i - \sum_{j\neq i} T_n x_j\right]^2 - f - \phi_n x_i^2. \tag{4.7}$$

Since $Q_i^*(x)$ must be positive at $x_i = x_j = 0$, we require that $R_n > 0$:

$$R_n > 0 \Leftrightarrow v < \frac{\alpha}{\beta - \gamma}, \text{ i.e., assumption A3.1 holds.} \tag{4.8}$$

As in the duopoly model of §2, we also require that $S_n > \Sigma_{j\neq i} T_n > 0$:

$$T_n > 0 \Leftrightarrow \epsilon < \frac{2\beta\mu - \gamma\lambda}{\beta\gamma}. \tag{4.9}$$

$$S_n - \sum_{j\neq i} T_n > 0 \Leftrightarrow \epsilon < \frac{\lambda - \mu}{\beta - \gamma}. \tag{4.10}$$

Conditions (4.9) and (4.10) are both satisfied when Assumption A3.2 holds.

4.2. Quality Equilibrium

In the second stage, we determine the quality equilibrium given equilibrium prices. Differentiating the profit function in (4.7) with respect to x_i we obtain:

$$\frac{\partial \Pi_i}{\partial x_i} = \frac{2\beta S_n}{nW_n^2}\left[R_n + S_n x_i - \sum_{j\neq i} T_n x_j\right] - 2\phi_n x_i, \tag{4.11}$$

and

$$\frac{\partial^2 \Pi_i}{\partial x_i^2} = \frac{2\beta S_n^2}{nW_n^2} - 2\phi_n. \tag{4.12}$$

To ensure that the profit function is strictly concave in x_i, we require $\phi_n n W_n^2 - \beta S_n^2 > 0$. Expanding this condition, we obtain:

$$\epsilon + \frac{(\sqrt{\phi_n n/\beta})[2(n-1)\beta + \gamma][2\beta - \gamma]}{\beta[2(n-1)\beta - (n-2)\gamma] - \gamma^2} > \frac{\lambda[2(n-1)\beta - (n-2)\gamma] - \mu\gamma}{\beta[2(n-1)\beta - (n-2)\gamma] - \gamma^2}. \tag{4.13}$$

Note that this condition is consistent with the earlier requirement that ϵ be less than the right-hand side of the above inequality. This inequality emphasizes the relationship between the fixed cost of quality improvement, ϕ_n, and the variable cost of quality, ϵ, for a given n. If there is a large reduction in the variable cost per unit when quality improves, i.e., $\epsilon < 0$ and $|\epsilon|$ is large, then the above condition (Assumption A4.3) requires that ϕ_n be correspondingly large in order that the inequality be satisfied. If this condition does not hold, then the existence of the equilibrium cannot be ensured. In particular, all firms may have the incentive to increase their quality levels indefinitely, as suggested by Crosby (1979).

The first-order conditions characterizing the equilibrium quality levels are:

$$x_i^N = \frac{\beta S_n}{(\phi_n n W_n^2 - \beta S_n^2)}\left[R_n - \sum_{j\neq i} T_n x_j^N\right], \quad i, j = 1, 2, \ldots, n. \tag{4.14}$$

Solving these n equations simultaneously, we obtain

$$x_i^N(n) = \frac{\beta R_n S_n}{\phi_n n W_n^2 - \beta S_n^2 + (n-1)\beta S_n T_n}, \quad i = 1, 2, \ldots, n, \tag{4.15}$$

where we have written the equilibrium quality levels as $x_i^N(n)$ to emphasize their dependency on n.

The primary question of interest here is what happens to the equilibrium quality level as the number of firms increases. To be able to answer this explicitly, we need to impose some additional structure on ϕ_n. Suppose $\phi_n = \phi/n^{1-\rho}$, where $0 \le \rho \le 1$ and $\phi > 0$. When $\rho = 1$, we see that the fixed cost of quality improvement is independent of the competitive intensity (as measured by the number of firms in the industry) and when $0 \le \rho < 1$, the fixed cost of quality improvement is a decreasing function of the competitive intensity, where the synergistic decrease in cost is greater for small ρ.[8] The latter situation may occur when the fixed cost of quality improvement represents an expenditure for goods or services in another market. If the demand in this factor market increases with n, and economies of scale prevail, then the cost of quality improvement will decline as the number of firms increases. Alternatively, this assumption could be interpreted as capturing spillovers across firms in the process of learning how to do quality improvement efficiently.

Figure 1 displays a graph plotting the equilibrium quality level $x_i^N(n)$ as a function of n for different values of ρ and specific values for the other parameters (α, β, γ, λ, μ, v, ϵ, ϕ). We see that when the number of firms in the industry increases, the equilibrium quality level may decrease for all n ($\rho = 0.7, 1.0$), increase initially for small n and then decrease for large n ($\rho = 0.1, 0.3$), or increase for all n ($\rho = 0$). The following proposition specifies conditions under which the equilibrium quality changes monotonically with the number of firms in the industry.

PROPOSITION 3. *As competition increases, the average industry quality level increases if and only if ϕ_n decreases sufficiently rapidly with n. Formally, $\{x_i^N(n)\}$ is a monotonically increasing sequence in $n \Leftrightarrow \rho \le Z_n$, where*

$$Z_n = \ln\left[\frac{S_{n+1}[2(n-1)\beta + \gamma]}{S_n[2n\beta + \gamma]}\right] \Big/ \ln\left[1 + \frac{1}{n}\right].$$

In particular,

(i) *when $\rho = 0$, $\{x_i^N(n)\}$ is monotonically increasing;*[9]

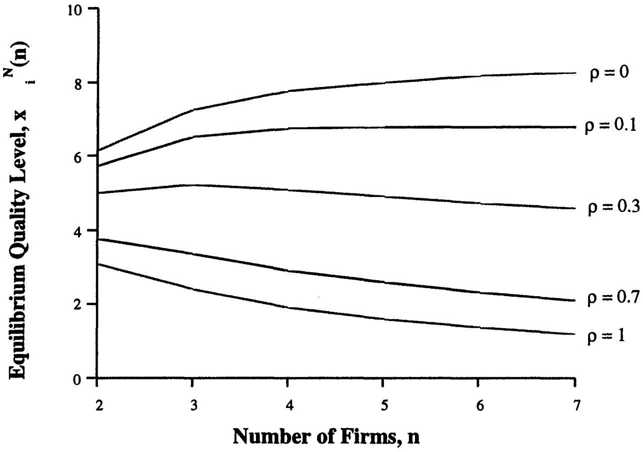
(ii) *when $\rho = 1$, $\{x_i^N(n)\}$ is monotonically decreasing;*

(iii) *when $0 < \rho < 1$, $\{x_i^N(n)\}$ is monotonically decreasing for sufficiently large n.*

[8] Note that if ρ is negative, then Assumption A4.3 is violated for sufficiently large n.

[9] When $\rho < 0$, $\{x_i^N(n)\}$ is monotonically increasing provided Assumption A4.3 is not violated.

Figure 1 **Graph of the Equilibrium Quality Level as a Function of the Number of Firms in the Industry** ($\alpha = 1000$, $\beta = 10$, $\gamma = 8.8$, $\lambda = 6$, $\mu = 5.4$, $\nu = 3$, $\epsilon = 0.5$, $\phi = 5$)



PROOF. See Banker et al. (1996).

The above proposition states that the equilibrium quality level increases as the number of firms in the industry increases, if the rate of reduction in the fixed cost of quality improvement is above a particular threshold; otherwise, it decreases. This result can be explained intuitively as follows. As the number of firms in the industry increases, each firm has a smaller market share. If the fixed cost of quality improvement does not decrease at a sufficiently rapid rate, each firm will be able to recover its investment in quality improvement only for a smaller quality level. However, if the fixed cost of quality improvement does decline sufficiently, then, even with the declining market share, each firm can offer higher quality and recover its fixed cost.

COROLLARY 3.1.

$$(1)\quad \frac{\partial Z_n}{\partial \lambda} > 0;\ (2)\quad \frac{\partial Z_n}{\partial \mu} < 0;\ \textit{and},$$

$$(3)\quad \frac{\partial Z_n}{\partial \epsilon} > 0 \Leftrightarrow \lambda/\mu > \beta/\gamma.$$

PROOF. Follows directly from the expressions for the partial derivatives, using the fact that $S_n > (n-1)T_n > 0$.

Proposition 3 and Corollary 3.1 together indicate that the equilibrium quality level is more likely to increase as the number of firms in the industry increases when each firm's demand responsiveness to its own quality (λ) is higher and when the responsiveness to its competitor's quality (μ) is lower. We also see that if the relative quality responsiveness (λ/μ) is greater than the relative price responsiveness (β/γ), then a higher variable production cost per unit due to quality improvement is more likely to lead to a higher equilibrium quality level as the number of firms in the industry increases.

A comparison of the results from Corollary 3.1 with the results from Corollary 2.1 underscores the importance of understanding the nature of competition and its link to the equilibrium quality level. When competition is interpreted to mean that firms are not allowed to cooperate in the quality decision, we see from Corollary 2.1 that increased competition leads to higher quality levels when λ is small or μ is large. However, when competition is interpreted to mean that there is a larger number of firms in the industry, we conclude from Corollary 3.1 that increased competition leads to higher quality levels when λ is large or μ is small.

It is also interesting to consider the asymptotic behavior of the equilibrium quality level.

COROLLARY 3.2. *As n approaches infinity, the sequence* $\{x_i^N(n)\}$ *converges to the limit*

(i) *zero when* $0 < \rho \leq 1$;

(ii) $(\lambda - \epsilon\beta)[\alpha - \nu(\beta - \gamma)]/2\phi(2\beta - \gamma) - (\lambda - \epsilon\beta)[\lambda - \mu - \epsilon(\beta - \gamma)]$ *when* $\rho = 0$.

PROOF. See Banker et al. (1996).

The automobile industry in the U.S. is often presented as an example where an increase in the number of firms has resulted in an increase in the quality of the product. Our theoretical analysis suggests that a useful direction for empirical inquiry would be to study whether the fixed costs of quality have declined as the number of firms in this industry has increased in the last two decades. Possible explanations for this decline in the costs of quality improvement include improved planning and control systems used in manufacturing, improved links with suppliers of component parts and improved product design through tools like computer-aided design, all of which may have become less expensive to implement as the demand for them has increased with the number of firms in the industry.

5. Conclusion

In this study we examined equilibrium quality levels in three different competitive environments. Our analysis showed that when increased competition is interpreted to mean that no firm has a strong intrinsic demand potential for its product, the average industry quality level increases as competition increases, provided the weaker firm has a relative cost advantage in quality improvement that is sufficiently large to offset the intrinsic demand advantage of the dominant firm, or if the market displays a relatively low price responsiveness. In such a case, the equilibrium strategy for the weaker firm is to select a higher quality level than the dominant firm. However, increased competition leads to a lower average industry quality level if the dominant firm also has a relative cost advantage in the fixed cost of quality improvement.

When increased competition is interpreted to mean that firms are not allowed to cooperate in setting the quality levels, quality levels are higher under competition if cooperation does not offer substantial synergy in the fixed costs of quality improvement and if the variable production costs are lowered with quality improvement when the demand function exhibits high relative quality responsiveness. However, we also identify several circumstances under which a higher quality product results when firms cooperate rather than when they compete with each other. Such circumstances include situations where cooperative arrangements synergistically reduce the fixed costs of quality improvement and when the demand function exhibits high relative quality responsiveness.

Finally, when increased competition is interpreted to mean that a large number of firms compete in that product market, then we find that increased competition leads to higher quality levels if the fixed costs of quality improvement display economies of scale and decrease at a sufficiently rapid rate as the number of firms in the market increases or if the market displays a relatively high quality responsiveness. However, increased competition leads to lower quality levels if these fixed costs remain constant or decrease at a relatively slow rate as the number of firms in the market increases, or if the customer demand exhibits a relatively low quality responsiveness.

We have made a number of assumptions to make our models tractable. These include linear demand functions and quadratic and linear cost structures. While these assumptions limit the number of scenarios where our model can be applied directly, simulation analyses with more general functional forms suggest that our findings are robust with respect to the underlying assumptions. Our results thus provide a conceptual benchmark to guide systematic empirical investigations in this important field of inquiry.

There are numerous significant issues pertaining to quality decisions in competitive environments, and we have addressed only some of them in this paper. The usefulness of our approach is demonstrated in the formalization and clarification of what have so far been only intuitive arguments. In particular, we have shown how the notion of increased competition can be interpreted in a number of different ways. In each of these instances, the structure of the equilibrium quality level varies and we see that equilibrium quality level is driven by different factors. Any analysis and discussion of quality management in a competitive environment must, therefore, be predicated by a precise understanding of the nature of competition that exists between firms.[10]

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