A Dynamic Pricing Game Investigating The Interaction Of Price And Quality On Sales Response

Eric C. Jackson, Penn State – Erie, USA
Ram Narasimhan, Michigan State University, USA

ABSTRACT

There is some question as to whether or not consumers use price as an indicator of product quality. In the case of non-durable goods there is some evidence that consumers do equate higher price products with higher quality products. These products are those that the consumer must experience personally before making a judgment on the product quality. In the case of durable goods there is less empirical evidence to support the price-quality connection. This paper develops a dynamic game model to investigate the price-quality connection in the presence of competition. Specifically, the paper investigates whether or not the optimal pricing strategy in the case of a durable good, where consumers may collect quality information about the product as units diffuse into the market, should be a high quality-high price strategy or a high quality-low price strategy. This question is examined by means of a dynamic game model, which is an extension of the Narasimhan-Ghosh-Mendez (NGM) quality diffusion model. The paper explicitly incorporates competition into the NGM model. Price trajectories for two competing firms are derived so that profits are maximized for the two competitors. It is shown that the price trajectory for the firm using quality as a strategic lever is shown to be lower than that of the firm that was not using a quality strategy. This result strongly suggests that a firm pursuing a quality strategy should couple this strategy with a lower price than its competition and should not couple high prices with high quality in an effort to signal the product's superior quality to consumers.

Keywords: Quality, Diffusion, Pricing, Operations Strategy, Optimal Control

INTRODUCTION

*P*roduct pricing is an important strategic decision. Firms must evaluate the price they feel they should charge for their products against a price that the market will accept as an appropriate measure of the value of their products. An important consideration in pricing is the quality of the product relative to competing products. If a product has a higher quality than that which the competition offers, a firm could charge a price that is higher than its competitor's price, reflecting a price premium for higher quality. This high-quality, high-price strategy is one way of leveraging high product quality to realize superior profits. There are two reasons for adopting such a quality-based pricing strategy. First, higher quality products provide consumers with more value when compared with lower quality products and second, consumers might associate higher quality with higher price.

The idea that a rational consumer might use price as a signal of quality dates back to the mid-twentieth century (Scitovsky, 1945). There is no consensus, however, as to how accurately consumers interpret the price-quality relationship. There is evidence that indicates that consumers use price as a signal of quality associating higher levels of quality with higher prices (Irandoust, 1998; Jacobson & Aaker, 1987; Leavitt, 1954). Other researchers have found that this relationship is weak (Gerstner, 1985; Riesz, 1978, 1979; Sprokes, 1977) and that it may not reflect actual consumer behavior for some classes of products.

Therefore, the issue of whether or not price is a signal of quality remains unresolved. If consumers associate higher prices with higher quality, it would be optimal to charge a high price for a high quality product. If the price-quality relationship holds, then a higher price should signal to the consumer high quality. This, in turn, should increase sales resulting in greater profits over time. Conversely, if price as an indicator of quality does not hold, it can be argued that it would be better to charge a lower price than competition, thus offering greater value for consumers (effectively adopting a value maximization strategy). In this case consumers would be attracted to the lower priced, higher quality product, thus increasing total sales and, therefore profits.

Complicating the price-quality interaction is the fact that the quality of a product evolves over time. Product quality improves due to learning curve influences and due to continuous quality-improvement efforts of the firm. As a result, the dynamic quality levels can be expected to influence the evolution of how consumers interpret price as a signal of product quality.

Several researchers have used optimal control models to demonstrate that, optimally, prices should decrease as quality increases (Narasimhan, Ghosh, & Mendez, 1993; Narasimhan, Mendez, & Ghosh, 1996; Sethi & Bass, 2003). Narasimhan et al., (1993) developed an optimal control model investigating quality diffusion into the market, referred to as the NGM model. The NGM model shows that the optimal price trajectory for a durable good over its product lifetime should initially increase then decrease, eventually ending at a lower level than the initial price, given that the product's quality increases while it is in production (See Figure 1)

However, the NGM model did not explicitly model competition. Competition was implicit in the model via product price elasticity. This paper contributes to the existing literature by reexamining the dynamic interaction of price and quality by explicitly incorporating competition via a dynamic game model. This paper also examines the price-quality relationship over the life of a product as well as whether or not it is efficacious to couple high price with high quality. The rest of the paper is organized as follows: the next section reviews the extant literature that relates to the research questions of interest in this paper; the dynamic game model is then discussed, followed by experimentation with the model; discussion of the model results is then undertaken; and the concluding section offers suggestions for future research.

LITERATURE REVIEW

The use of price by consumers as an indicator of product quality has received much attention in the literature. As early as 1945, Scitovsky considered this issue and came to the conclusion that such behavior on the part of the consumer is rational, in so far as it reflects an ordering of products on a price scale driven by supply and demand. Since then several researchers have found that there is indeed a relationship between price and consumer perception of quality; see, for example (Irandoust, 1998; Jacobson & Aaker, 1987; Leavitt, 1954; Lichtenstein & Burton, 1989; Oxenfeldt, 1950; Rao & Monroe, 1989). In developing a typology useful in classifying signals of unobservable product quality, Kirmani and Rao (2000) include price as a quality signal. Several researchers have examined the ability of price to signal quality across cultures (Agarwal & Teas, 2002; Schniederjans, Cao, & Olson, 2004; Zhou, Su, & Bao, 2002). Price has been connected to quality in internet physical distribution service (Rabinovich & Bailey, 2004). Other researchers, however, have found that using price to signal quality to consumers is tenuous at best (Gerstner, 1985; Riesz, 1978, 1979; Sprokes, 1977). Furthermore, there is evidence in the extant literature that price as a quality signal may be moderated by other factors such as durability (Agarwal & Teas, 2001; Dodds, 1991; Dodds, Monroe, & Grewal, 1991; Teas & Agarwal, 2000).

Lichtenstein (1989) examined price as a signal of quality for both durable and non-durable goods and concluded that while a consumer's ability to evaluate objective quality distinct from its price generally is only moderate, it is still better for non-durable goods than it is for durable goods. Lichtenstein concluded that durable goods typically represent more of an investment to the consumer and as such the price-quality relationship might not be strong. In contrast, Gerstner (1985) found that infrequently purchased expensive goods had a stronger price-quality signaling relationship when compared with frequently purchased inexpensive goods. In a meta-analysis, Rao and Monroe (1989) found that the price-quality relationship did seem to be positive and significant for low-priced, frequently purchased goods but not for high-priced, less frequently purchased goods. This suggests that a firm whose products are purchased frequently by consumers, i.e. repeatedly <u>experienced</u> by consumers, might be able to

effectively signal increasing quality by increasing price. Conversely, a firm producing durable goods, those infrequently purchased by consumers, might not be able to signal increasing quality by increasing price.

Nelson (1970, 1974) subdivided products into two categories. He identified goods as either "search goods" or "experience goods". Depending on how consumers use information, in general, in their product selection. Search goods are those products about which consumers can collect information. Products that a consumer must experience before making a purchasing decision are called experience goods.   It can be argued that as a prerequisite for consumers to gather information about a search good, there must be units of the product in the marketplace. Furthermore, as the number of units in the marketplace increases, more information is available to the consumer about that product. In other words, information about the product is diffused into the market with the number of units sold. This diffusion process has long been examined in literature.

Bass (1969) developed a product diffusion model that considered how durable goods sales are influenced by units in the market over the life of the product. The Bass model initiated a series of studies examining product diffusion (Krishnan, Bass, & Jain, 1999; Mahajan, Muller, & Bass, 1990; Putsis, 1989; Robinson & Lakhani, 1975; Rogers, 1976; Sultan, Farley, & Lehmann, 1990)). Quality has been incorporated into diffusion models to study how it impacts the diffusion of a product into the market (Jackson, 2004; Narasimhan, et al., 1993; Narasimhan & Mendez, 2001; Narasimhan, et al., 1996).

The first quality diffusion model, the NGM model (Narasimhan, et al., 1993; Narasimhan, et al., 1996) examines how an exogenous quality trajectory influences the endogenous price trajectory that maximizes the cumulative profits a firm realizes over the life of a product. Two distributed delays, one capturing the length of time a unit remains in service in the market and the other capturing the length of time that a unit influences quality perception and thus sales are used in the NGM model to examine how changes in quality diffuse into the market and impact sales. The dynamic model derived the optimal price trajectory under continuous quality improvement. The NGM model demonstrates that when the firm's objective is to maximize cumulative profits under continuous quality improvement the optimal price trajectory will initially increase and then decrease over time. The authors found that the exact trajectory of price varies with price elasticity, the amount of time a unit influences consumer purchases, and the useful life of the unit in the market (see Figure 1).
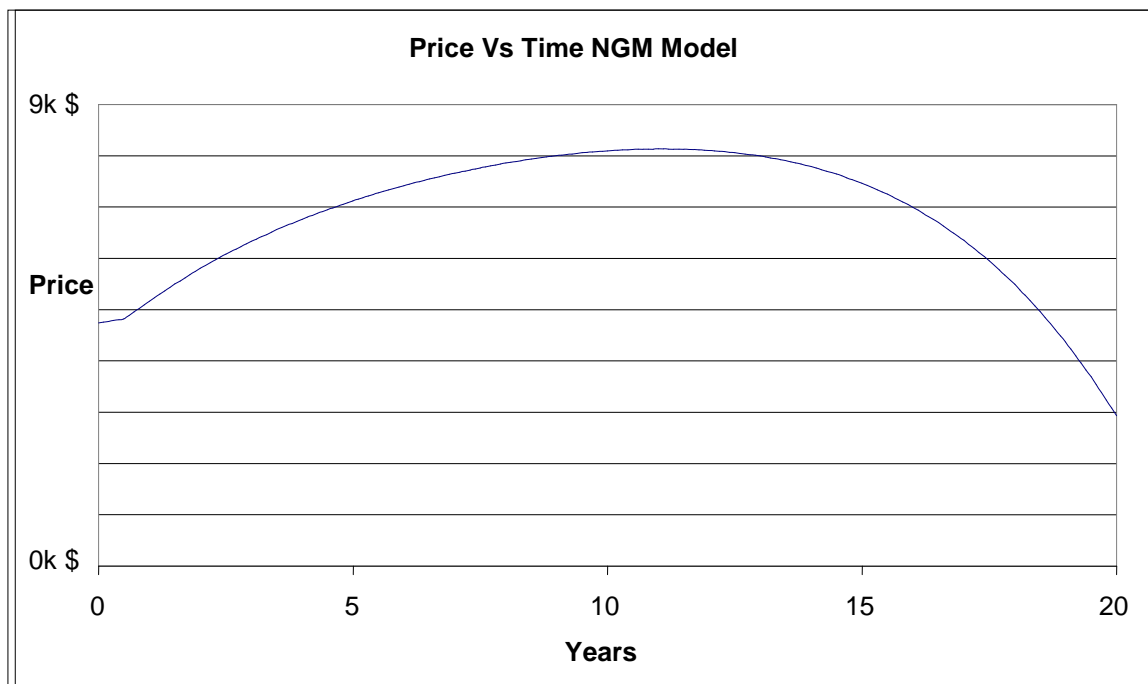
Figure 1: Price Trajectories for the Original NGM Model

This result suggests that firms should adopt a "mixed" quality based price strategy. That is, it would <u>initially increase price</u> with increasing quality and then <u>decrease price</u> as the quality continues to improve over the life of the product.

In its original form the NGM model did not include competition explicitly. This paper extends the NGM model to include competition explicitly so that it is possible to investigate how price trajectories evolve in a competitive environment. In the next section we develop the dynamic game model.

THE MODEL

Since the model used in this dynamic game is based on the NGM model (Narasimhan, et al., 1993) it is useful to review that model here. The full mathematical representation is as follows:

$$\Pi_t = \int_0^T (P_t - C_t) * S_t * e^{-(rt)} dt \tag{1}$$

$$M(P) = \left[\frac{P_o}{P}\right]^e M_o \tag{2}$$

$$Q(t) = (D_1) * Y(t) \tag{3}$$

$$EQ(t) = D_2 * X(t) \tag{4}$$

$$S(t) = \alpha * EQ(t) * (M(t) - Q(t)) \tag{5}$$

$$\frac{\partial Y}{\partial t} = \frac{1}{D_1}(S(t) - Y(t)) \tag{6}$$

$$\frac{\partial X}{\partial t} = \frac{1}{D_2} * (q(t) * S(t) - X(t)) \tag{7}$$

Where:

P(t)   = Price in dollars
M(P)   = Market Potential in units
M_0 = Market potential at time 0
P_0 = Price at time 0
Q(t)   = # of units in the market in units
S(t)   = Sales rate in units/time
Y(t)   = Rate at which units leave market in units/time
X(t)   = Rate at which quality weighted quantity of goods in the market ceases to influence consumers' buying in units/time
EQ(t)   = Quality weighted quantity of goods in the market in units
q(t)   = Quality index at time t, $q(t) \in [0,1]$
D_1 = Average life of the unit in time
D_2 = Average time a unit affects consumer's buying behavior
α = Proportionality constant used to calculate sales rate in reciprocal times*units
e   = Price elasticity characterizing how sensitive the market potential is for the specific product relative to price.

Price *(P)* and quality *(q)* are inputs to the model. The price determines the market potential *(M)* via a demand function, equation 2 above. The quantity or number of units existing in the market *(Q)* is removed from the market potential and the sales rate *(S)* is generated by multiplying *(EQ)* the quality weighted number of units in the market at time t by the market potential and a constant alpha used to set the sales rate in units of (times x Units)$^{-1}$. The sales rate is used to determine the rate at which units leave the market and the rate at which units stop influencing purchasing decisions by consumers, equations 6 and 7 above. The conceptualization of the NGM model is shown in Figure 2.
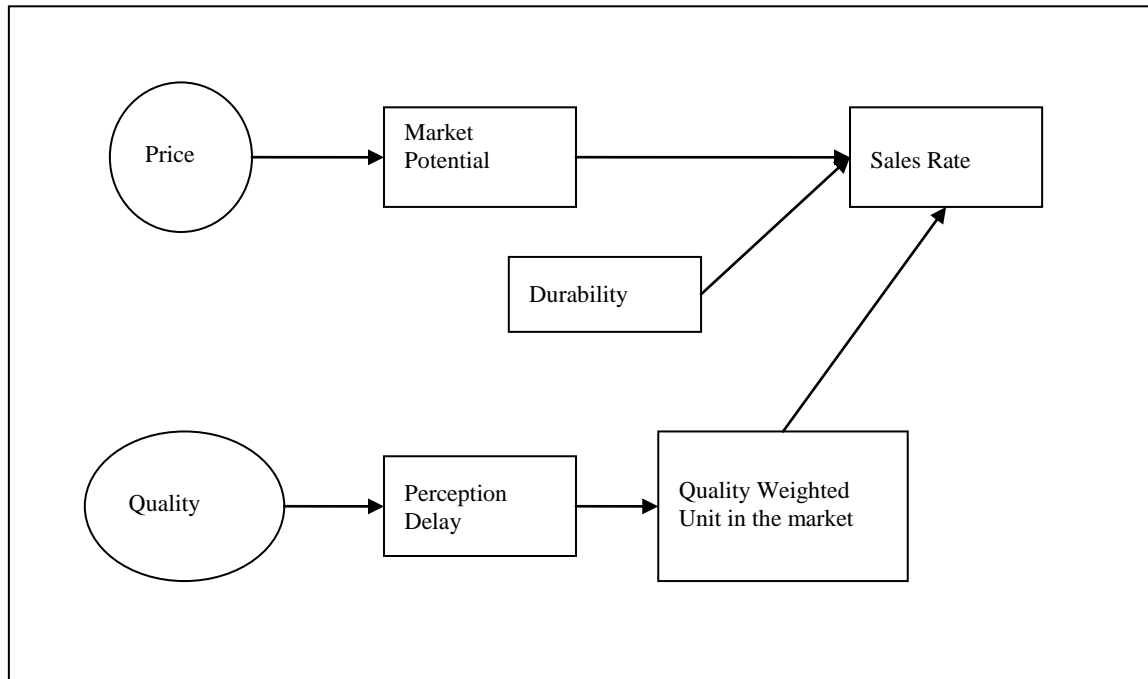
Figure 2: NGM Conceptualization

Quality in the NGM model is incorporated as an index increasing from zero to one during the time horizon and is incorporated in equation 7. Some modifications are made in this work to the NGM model. We incorporate competition in the form of a duopoly and allow the quality trajectory to range from an initial value to a terminal value in a linear manner as in Narasimhan et al., (1996) for each of the two competitors.

The quality trajectory is determined exogenously to the model. An initial quality level is selected for each of the competitors and the rate of change of quality is allowed to vary at some predetermined rate. This change in quality is incorporated into the price as a change in product cost.

There is some debate in the literature as to exactly how quality improvements affect the cost of a product. Plunkett and Dale (1988) examined several models relating quality to cost. They found empirical support for models which assert that a minimum cost exists corresponding to an "optimal quality level".   As quality increases, costs begin to decline until a minimum cost is realized whereupon further increases in quality add cost to the product. However, they also found support for a model that indicates improvements in quality will continuously decrease costs. This paper follows the lead of Narasimhan et al., (1996) who incorporate both conformance quality and perceived quality into a cost function that initially decreases and then increases as quality continues to increase.

In order to accommodate two competitive products a total market potential *(M$_t$)* is determined from the initial prices of the two competitors, an initial market potential *(M$_{int}$)* which remains constant and the prices charged by the competing firms at any given time *t*. This is relationship is given in equation 8.

$$M_t = M_{\text{int}} \left[\left(\frac{P_{1,0}}{P_{1,t}} \right)^e + \left(\frac{P_{2,0}}{P_{2,t}} \right)^e \right]$$

(8)

Where:

$P_{1,0}$ is the price for product one at time zero.
$P_{2,0}$ is the price for product two at time zero.
$P_{1,t}$ is the price of product 1 at time t.
$P_{2,t}$, is the price of product 2 at time t.
M_{int} is an initial potential of the market segment at time zero.

The market share for the individual competitors at any time t becomes:

$$M(P_{j,t}) = \left(1 - \left(\frac{P_{j,t}}{P_{i,t} + P_{j,t}} \right) \right) * M_t \quad i, j = 1, 2 \ \ i \neq j$$

(9)

Where:

$M(P_{j,t})$ is the market share in units for product j at time t.
$P_{j,t}$ is the price for product j at time t.
$P_{i,t}$ is the price for product i at time t.

In this expression the market potential is divided proportionately according to the prices charged by the competing firms. The dynamic game model considered in this paper replicates the model in equations 1-7 for each competitor, with the market potential overall being determined in equation 8 and the potential market share for each competing firm given by equation 9. The conceptualization for the model is shown in Figure 3.
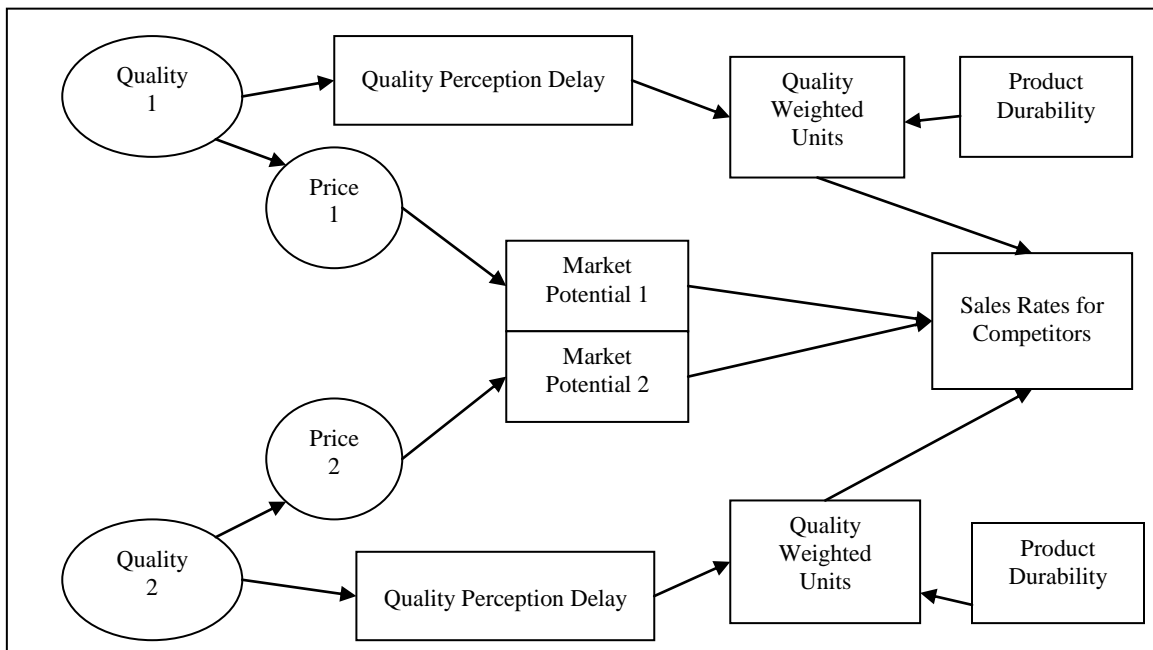

Figure 3: Dynamic Game Model Conceptualization

These changes to the NGM model allow us to examine how the diffusion of quality into the market is impacted by price. How a competitor may respond to changes in their competitors price by using quality as a lever. We can also examine how the acceleration of quality improvements is affected by a pricing policy and if a high-price, high-quality strategy dominates a low-price low quality strategy. In order to examine which strategy, high quality-high price or high-quality-low price, is most effective four scenarios were developed depicting different quality trajectories so that the relationship to optimal pricing may be studied with the model.

The Generalized Reduced Gradient (GRG2) method embedded in the Frontline Systems Premium Solver Platform add-on for Excel was used to numerically optimize profits for each of the firms by allowing the price to change over the time horizon until an optimum price was established. Once the optimal price trajectory was determined for Firm 1 the information on price and market share was passed from the spreadsheet calculating these values for Firm 1 to the spreadsheet calculating the price and market share for Firm 2. The values were used to establish the price trajectory for Firm 2 and the data was passed back to the Firm 1 spreadsheet. This process was repeated until both price trajectories converged to their respective optimal trajectories. Steady state was typically achieved in 10 to 15 iterations but the process was allowed to continue through 50 cycles to ensure convergence.

The model was parameterized by setting *e* equal to 1.3 and α to 0.001424 which is consistent with the original NGM model and in subsequent modifications (Narasimhan, et al., 1993; Narasimhan, et al., 1996). The time horizon was set to twenty years. Two values for the average life of the product in the market, D_1, were used, 3 years and 10 years respectively representing a short-lived product and a long lived one. Two values were used for D_2 which represents the length of time that the units in the market impacted quality perceptions and hence purchasing decisions. They were 0.25 D_1 and 0.75 D_1 respectively.
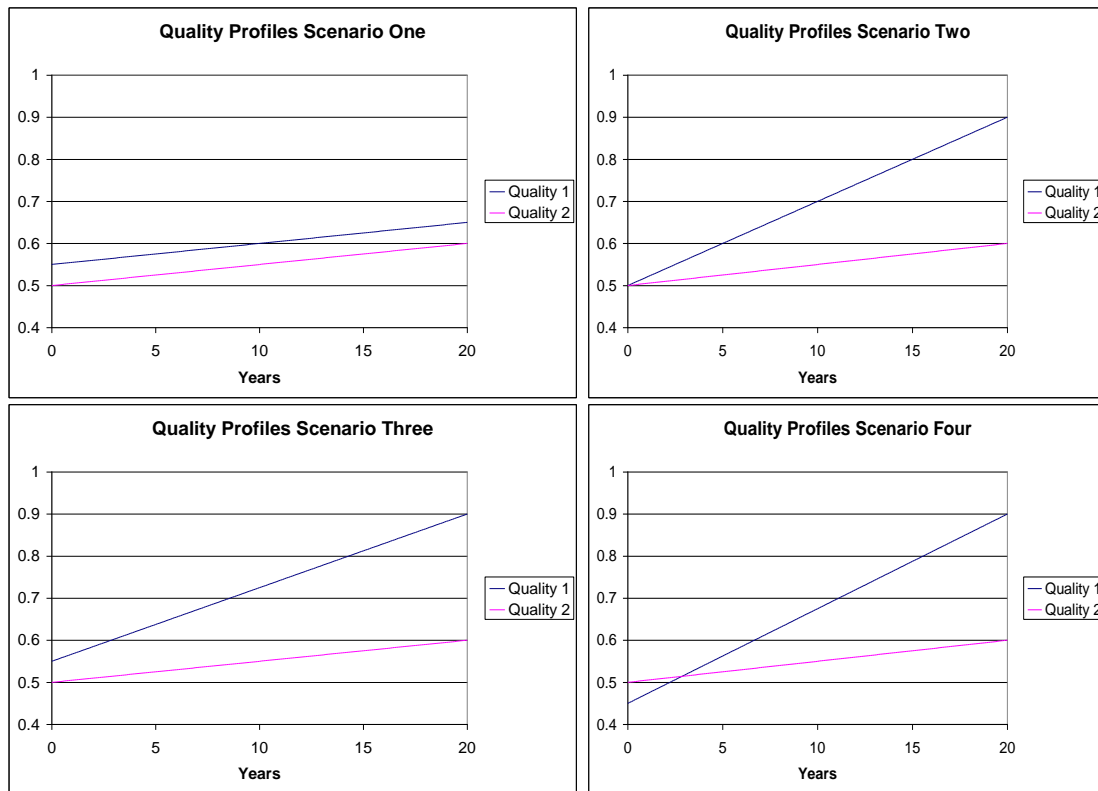
Figure 4: Exogenous Quality Profiles

As noted above, the quality trajectories were exogenous inputs to the dynamic game model. In all scenarios the quality trajectories for the second firm increases quality from an initial value of 0.5 to a terminal value of 0.6. This case represents a firm that improves its quality trajectory gradually with no response to changes in its competitor's quality position. In other words this firm has no emphasis on quality as a strategic lever.

The four scenarios were developed as follows. The first scenario examines the case where Firm 1 has a quality advantage and makes no effort to improve beyond maintaining the same incremental quality advantage it has at time zero. In the second scenario, Firm 1 begins with the same quality position as Firm 2, but it aggressively improves its quality creating and increasing the quality gap continuously over the entire time horizon. The third scenario considers a situation where Firm 1 has a quality advantage initially and aggressively improves its advantage during the entire life of the product line. In the fourth scenario Firm 1 starts with a quality deficit but aggressively improves its product quality surpassing Firm 2's quality position and continuing to improve its quality to the end of the time period. These profiles are depicted in Figure 4.

The four scenarios examined with the model are shown in Table 1.

Table 1: Summary Scenario Conditions

	Initial Quality	Rate of Quality Change	Unit life D1	Influence on sales,D2	Product Line life
Scenario 1	q1>q2	$\dot{q}_1 = \dot{q}_2$	3 and 10 years	0.25D1 and 0.75D1	20 years
Scenario 2	q1=q2	$\dot{q}_1 \gg \dot{q}_2$	3 and 10 years	0.25D1 and 0.75D1	20 years
Scenario 3	q1>q2	$\dot{q}_1 \gg \dot{q}_2$	3 and 10 years	0.25D1 and 0.75D1	20 years
Scenario 4	q1<q2	$\dot{q}_1 \gg \dot{q}_2$	3 and 10 years	0.25D1 and 0.75D1	20 years

RESULTS

Scenario 1

In the first scenario, Firm 1 begins with a slight quality advantage over the second firm. (Figure 4) Neither firm aggressively pursues a quality improvement strategy. Both simply accept the gradual improvements in quality that may be expected through learning. This scenario establishes a base case of a simple quality advantage with no significant efforts at quality improvements. It shows how a firm with this type of an advantage may best exploit this quality advantage by using either a high price or a low price strategy. The optimal price trajectories for this scenario may be seen in Figure 5.

The four sets of product parameters are: 1) a short unit life with a relatively short period of sales influence from existing units in the market; 2) a short unit life span with a relatively long period of sales influence due to existing units in the market; 3) a long unit life span with a relatively long period of sales influence; and, 4) a long unit life span with a relatively long period of sales influence. In all four cases the most profitable price strategy for the firm with the superior product quality (i.e. Firm 1) is to lower the product price below that of the competition (Figure 5). In all four cases, the profitability of Firm 1, is greater than the firm with the lower quality and a higher price trajectory. Table 2 shows the relative profit advantage of Firm 1 for each of the scenarios investigated.

An examination of Table 2 reveals how product life and the length of time quality is perceived in the market impacts sales. The combination of values that result in the greatest profit advantage for Firm 1 over Firm 2 occurs when a _short_ product life span is coupled with a _short_ period of time where the units in the market have influence on sales. The least profit advantage for Firm 1 over Firm 2 occurs when the unit life is long and the period of influence of the units in the market place is also long. Implying that a long product life may negate some of the

influence minor quality improvements have on sales. It is also important to note here that there is a difference in the price trajectories between the NGM model where competition was not explicitly modeled and our model where it is explicitly modeled.
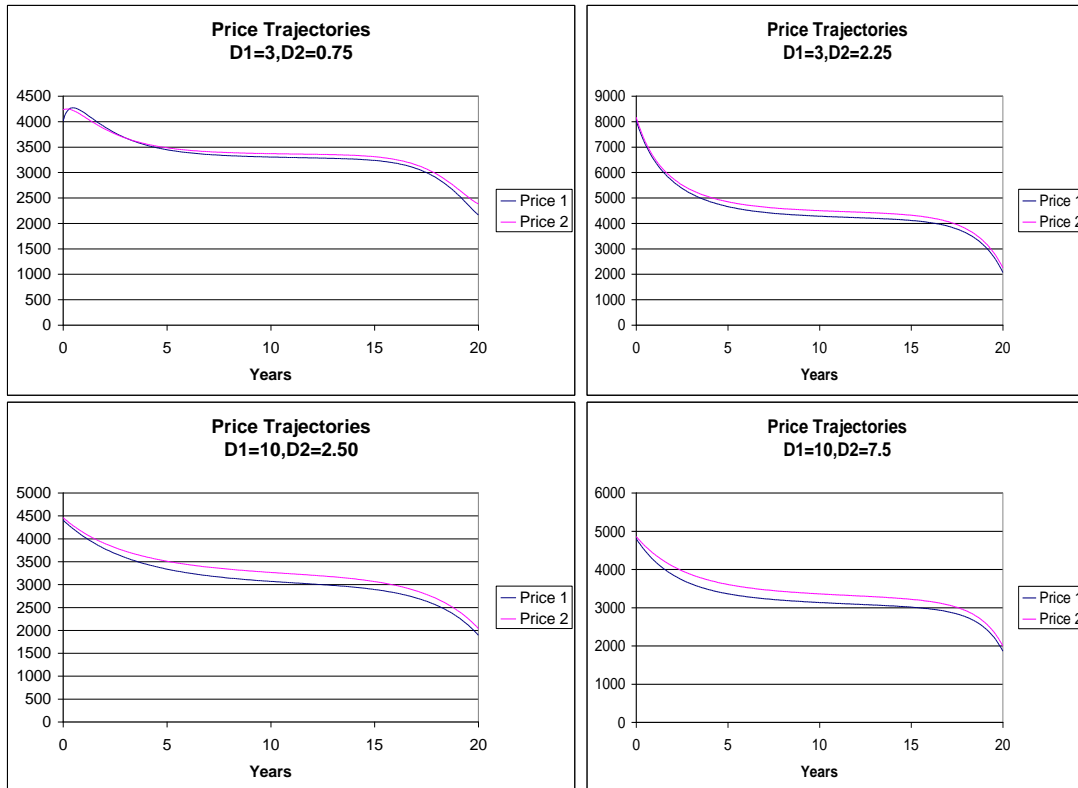

Figure 5: Price Trajectories: Scenario 1

Table 2: Profit Advantage of Firm 1 from Quality Strategy

| Durability of Unit, D1	Unit Influence, D2	Scenario 1	Scenario 2	Scenario 3	Scenario 4
3 Years	0.75 Years	113%	131%	135%	126%
3 Years	2.25 Years	105%	111%	112%	110%
10 Years	2.5 Years	105%	113%	112%	114%
10 Years	7.5 Years	102%	106%	105%	107%

In the NGM model the price trajectories initially increased and then decreased to a point lower than the initial price. In the model considered in this paper, except for the case where the product life is shortest and the influence units have on sales is also the shortest, the price immediately decreases and continues a downward trajectory. In the one case where it increases, it only does so for a very brief period before it begins to decrease. This differs from the NGM model where the price increases for approximately half of the product's life for this combination of product parameters. The presence of a competing product in our model prevents the price from increasing and predicts a downward trajectory sooner than in the original NGM model. In which the only downward pressure on the price stems from the price elasticity (Figure 1 and Figure 5).

A second point of interest is that in the case where the product life is short but the length of time in which the units in the market influence sales is large relative to that life. In this case the prices have an initial level much higher than in the other cases. This is in agreement with Narasimhan and Mendez (Narasimhan & Mendez, 2001)

who show that a stable price equilibrium greater than zero exists when quality is greater than $1/\alpha MD_2$. They also show that in cases where q is equal to or less than $1/\alpha MD_2$ the stable equilibrium at an elevated price does not exist and prices tend downwards.

Scenario 2

In the second scenario the quality for Firm 1 begins at the same value as that for Firm 2 and steadily improves at a faster rate than that in scenario 1 while the quality trajectory for Firm 2 improves at the same rate as in the first scenario. This represents the case where one competitor is complacent and does not modify its quality position in the face of the competitor's aggressive quality improvements. Four cases are examined as in the first scenario. D_1 assumes the values of 3 and 10 years representing a short and long unit lifetimes in the market and D_2 assumes the values of $0.25*D_1$ and $0.75*D_1$ representing short and long lengths of time during which the units in the market influence sales (Figure 6).
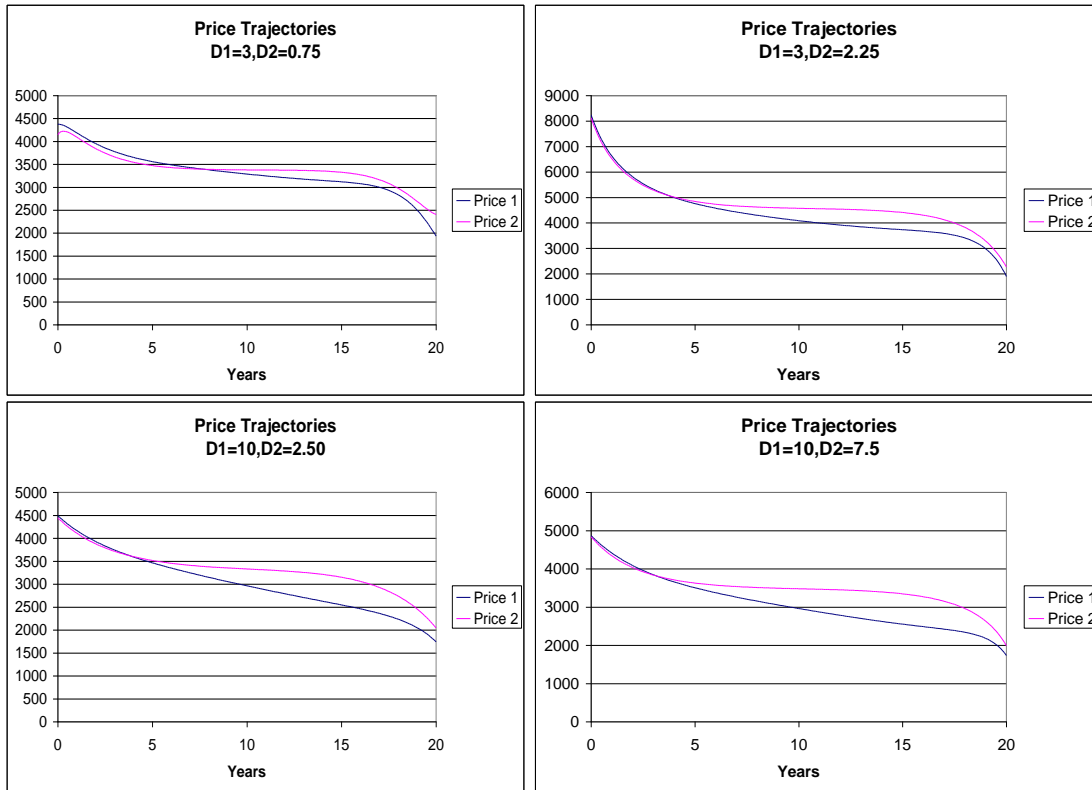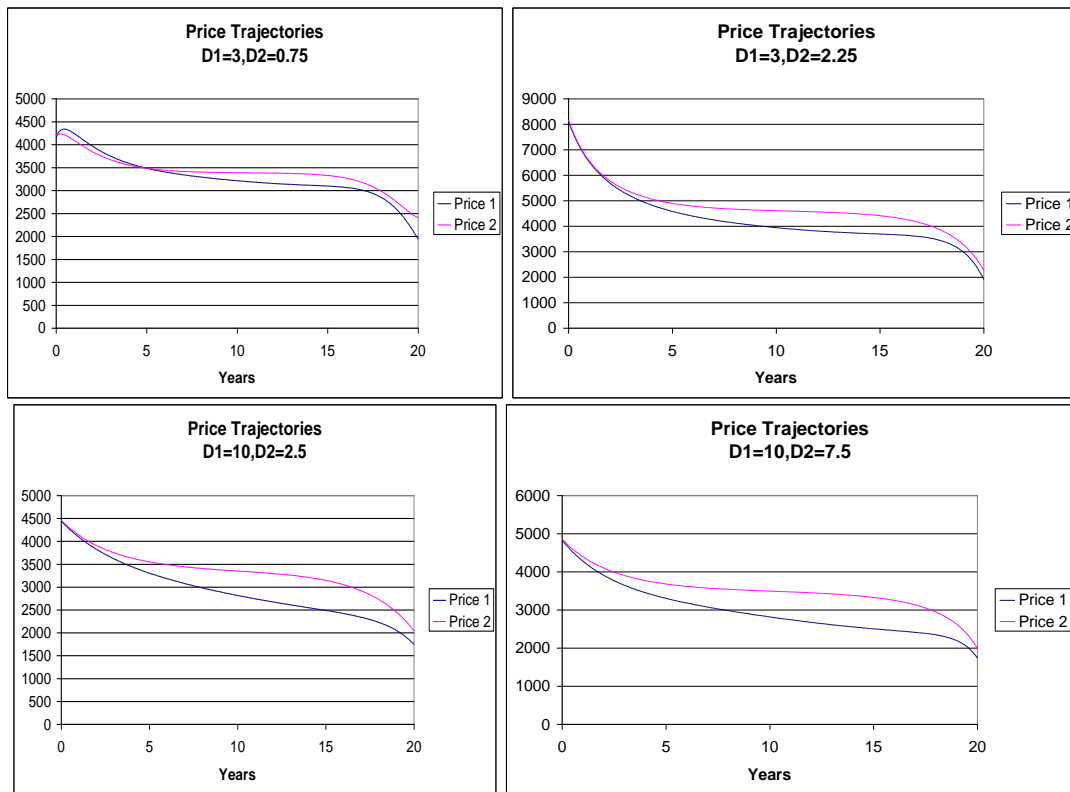

Figure 6: Price Trajectories: Scenario 2

In all four of the cases in scenario two, the firm actively pursuing a continuous quality strategy has a greater cumulative profit than the firm that is relying only on improvements due to learning. In all four cases, the price point of the firm with the superior quality strategy is again lower than its competitor just as it was in scenario one. The greatest advantage is seen when the life of the product is shortest and the length of time the units influence sales is short (Table 2). Clearly the short unit life allows replacement of the greatest number of units over the life of the product line so the total number of sales is the greatest. The short length of time for influencing sales allows the newer units, those with the greatest level of quality, to begin influencing sales sooner hence accelerating the diffusion of information about the product's quality in the market.

One other difference between the results of Scenario 1 and Scenario 2 may be observed. In Scenario 2 there is a slight increase in the profitability of Firm 1 when the unit life is long and the length of influence is short relative to Scenario 1. This increase, while slight, is noticeable. The relatively higher quality in Scenario 2 leads to higher sales influence faster. In other words, new units enter the market faster at higher levels of quality and begin to influence sales sooner compared with older units thereby enhancing sales and cumulative profits.

Scenarios 3-4

The third and fourth scenarios examine the cases where the first firm has an initial quality position differing from the second firm. Specifically, scenario three considers the case where the initial product quality for Firm 1 begins at a higher level than Firm 2 and the fourth scenario considers the case where Firm 1 has an initial quality level lower than the second firm. In both scenarios Firm 1 aggressively pursues a quality improvement strategy and Firm 2 adopts a passive quality improvement strategy. The price trajectories may be seen in Figure 7 and Figure 8. In each case Firm 1, the firm using a high quality strategy in combination with a low price trajectory has a profit advantage over the life of the product line relative to the firm not pursuing a quality strategy. A summary of the profitability advantage differences are shown in Table 2.

Figure 7: Price Trajectories: Scenario 3
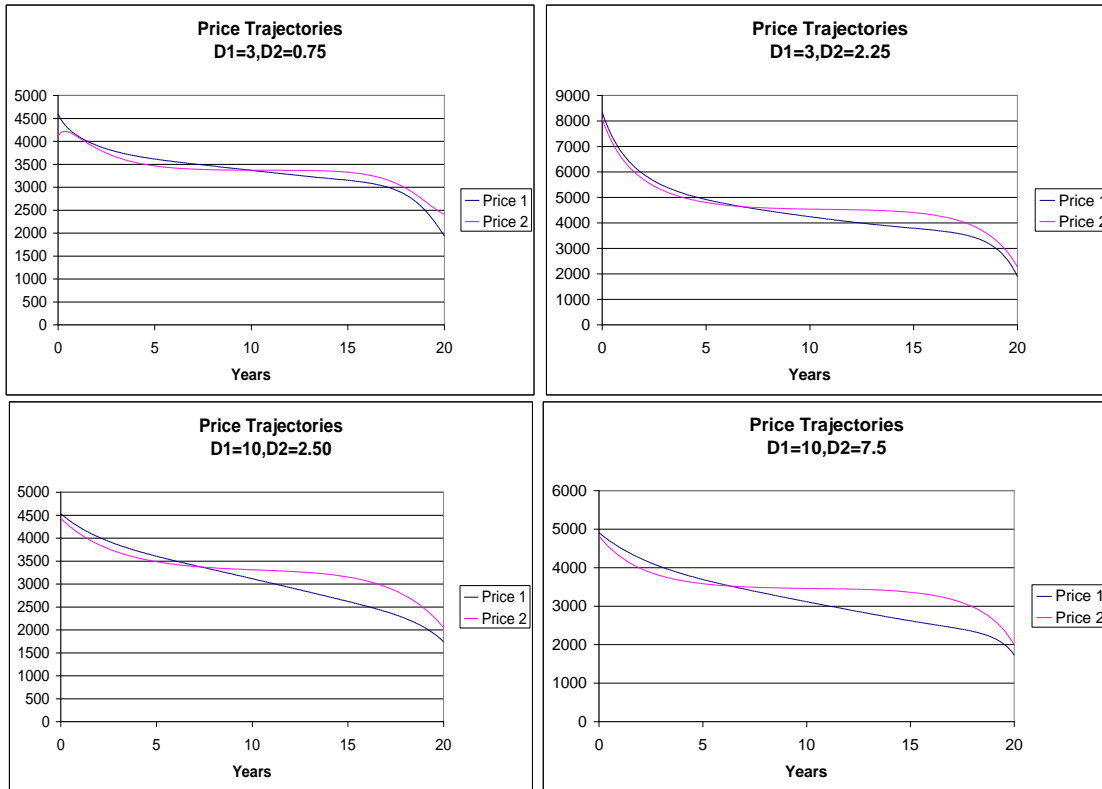
Figure 8: Price Trajectories: Scenario 4

DISCUSSION

Much attention has been paid in the literature as to whether or not product price is seen as a signal of high quality by consumers. Some evidence exists that in the case of non-durable or experience goods, price may be an effective way to convey a signal of a product's quality to consumers. In the case of durable, or search goods, there is less empirical evidence to support this position. This paper uses optimal control in a dynamic game to examine which price trajectory maximizes profits over the life of a durable good when quality is used as a strategic lever by a firm in a duopoly. By using quality as an exogenous factor and allowing the price trajectory to dynamically change to maximize profits it is possible to examine what product-price best exploits the quality strategy.

Four applications of this model were examined in this paper. In the first, Firm 1 had an initial quality advantage over Firm 2. This position was followed by a complacent quality improvement strategy on the part of Firm 1 no effort was made to extend the advantage by improving product quality. In the second case Firm 1 had an initial product quality inferior that of Firm 2 but made quality improvements aggressively ending the scenario with a superior product quality. In the third case Firm 1 and Firm 2 had equivalent initial quality positions but Firm 1 aggressively improved its quality while Firm 2 accepted only quality improvements that would have been gained from learning. The last case Firm 1 began with a superior initial quality position followed by an aggressive quality improvement strategy. In all four cases the price trajectory that maximized profit for the firm with a strategy of improving quality was lower when compared with the firm not using quality as a strategic lever. In other words superior profits are generated when aggressive quality improvements are coupled with low prices.

A strategy using a higher price than the competition's as a signal of superior quality dose not generate maximum profit, rather maximum profit is generated when a lower price is combined with superior quality. This is true when a firm has an initial quality advantage when compared with the competitor and when the corporate strategy involves improving product quality to a superior level than the competition's. As such, a manager who

wishes to exploit a superior quality strategy should not presume that a higher price will signal an improvement in quality to consumers. A much better strategy would be to price his product line with a lower price and allow the diffusion of improving products into the market to communicate the improved quality to consumers. This finding is consistent with Kornish, (2001) who found that in a monopoly a firm must lower its prices in subsequent periods as an enticement for consumers to repurchase products. This is consistent with several other researchers (Curry & Riesz, 1988; Dalen & Bode, 2004; Deneckere & Palma, 1998) all of whom found that as consumer knowledge increases in a competitive environment prices declined.

The results of the simulation (i.e., the numerical solution of the optimal control model) also suggest how a manager might take advantage of a quality strategy by considering how the combination of product unit-life and the length of time a unit influences sales in the market interact to influence quality strategy. When the results of the four scenarios are placed into two by two grids it is clear that in all four scenarios the combination of shortest unit life and shortest unit influence results in the greatest profitability advantage over the competition, the first quadrant. Conversely, the least advantage in profitability over the combination is when the unit life is the longest and those units in the market influence sales the longest (Figure 9). Curry and Riesz (Curry & Riesz, 1988) show that as consumer awareness increases prices decline. Both an increase in the durability of a unit and/or an increase in the length of time a unit influences sales will result in an increase of consumer awareness of a product. This should reduce the price of the product. In the special case of the Dutch new passenger car market from 1990 to 1999 Van Dalen and Bode (Dalen & Bode, 2004) find this increase in quality and price reduction relationship empirically.
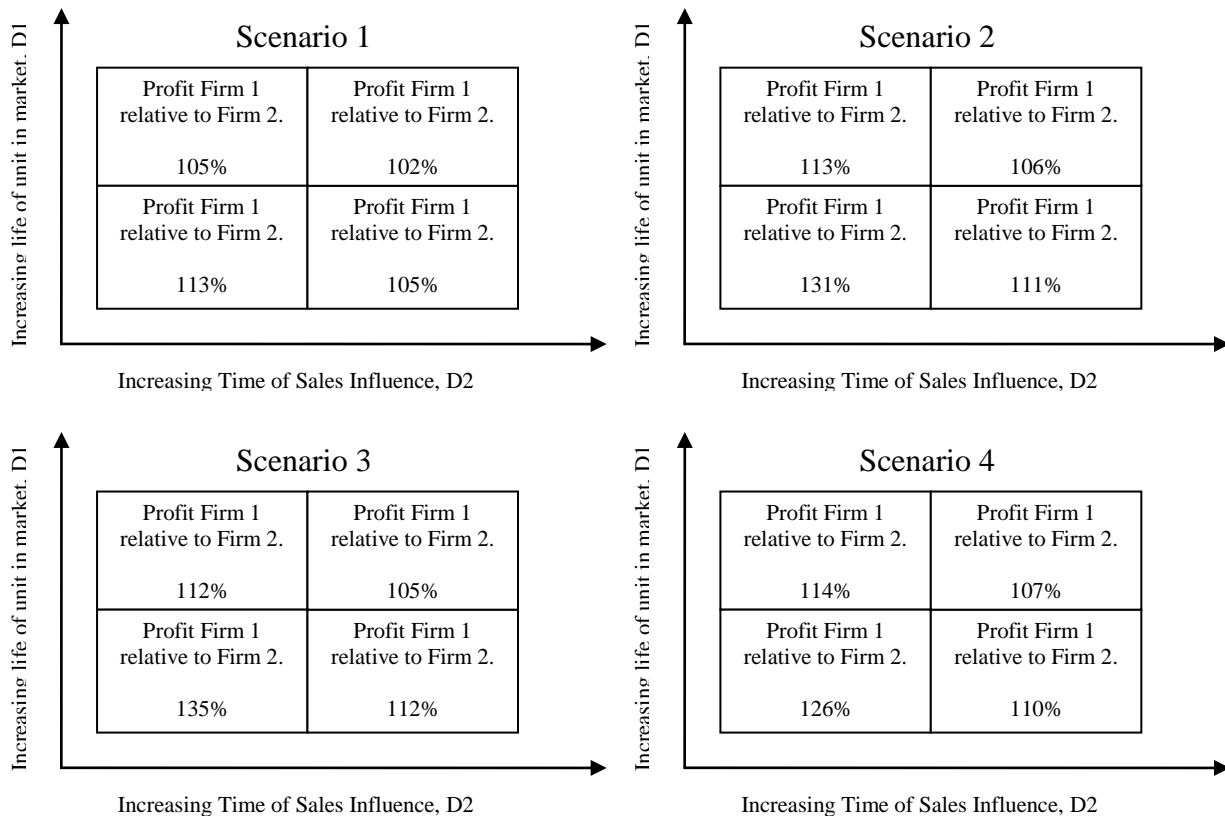

Figure 9: Scenario 1 Profit Advantage Grids

The results shown in Figure 9 demonstrate that a reduction in revenue is generated in each of the four scenarios when the length of time that the units impact sales increases. This is irrespective of the total length of time

that the units survive. The results (y) also show that the maximized profit <u>decreases</u> as the length of time units influence sales <u>increase</u>. Both of these cases correspond with an increase in consumer awareness. With this in mind, a manager should consider quality innovations that have the effect of shorting the length of time units influence sales, i.e., this suggests the need for frequent product revisions or new product introductions. In the former case, for a durable good (such as a car), it calls for perceptible changes to such aspects of quality as features and options, fit and finish and perhaps styling changes that cue the consumer to changes in discernable aspects of quality. In the latter it suggests more frequent revisions to the product and shortening design cycle times and product introductions. Large paradigm shifts in product quality as opposed to incremental improvements are one way to shorten the length of time units remain in the market and the length of time units influence sales. If large paradigm changes shifting quality improvements are not developed, the adoption of incremental quality improvements should be enhanced as much as possible. This has the effect of increasing the aggregate quality levels of the latest units in the marketplace and reduces the impact older lower quality units have on sales.

FURTHER RESEARCH

While this work shows that a manager should combine a low price with a high quality strategy and not attempt to signal high quality with high prices, there is much more that can be investigated. For example, the addition of an advertising component to the model would allow investigations into whether or not the profitability of the product line could be accelerated or increased when advertising is used in conjunction with a quality strategy. An advertising component would also provide insight as to whether or not advertising could be used to offset the quality advantage of one firm by slowing the diffusion rate of new units into the market or if quality diffusion dominates the impact of an advertising campaign. Quality increases were continuous and incremental in the model created in this paper. Not all quality improvements are incremental. Large shifts in quality, a paradigm shift, frequently occur. An investigation into what the impact of a paradigm shift in quality has on sales and profit in a competitive environment should be investigated.

AUTHOR INFORMATION

Dr. Eric Jackson received his Ph.D. from Michigan State University. His Research interests include SCM, Project Management, and Complex Dynamic Systems. He was the technical director for a multi-national specialty chemical firm for ten years and worked in the chemical field for seven years before that. He has served as managerial assistant for Decision Science Journal and as an Engineering/Business consultant for small firms in Toledo, Ohio and Detroit Michigan.

Ram Narasimhan is a University Distinguished Professor and the John H. McConnell Professor of Business in the Eli Broad Graduate School of Management at Michigan State University. He has published in Management Science, Decision Sciences Journal, Journal of Operations Management, Production Operation Management Journal, European Journal of Operational Research, IIE Transactions and other peer reviewed journals. He is a Fellow of the Decision Sciences Institute and Past President. He serves as an associate editor of Journal of Operations Management and Decision Sciences Journal.

REFERENCES

1.   Agarwal, S., & Teas, R. K. (2001). Perceived value: Mediating role of perceived risk. *Journal of Marketing Theory and Practice, 9*(4), 1.
2.   Agarwal, S., & Teas, R. K. (2002). Cross-national applicability of a perceived quality model. *The Journal of Product and Brand Management, 11*(4/5), 213.
3.   Bass, F. M. (1969). A New Product Growth Model for Consumer Durables. *Management Science, 15*, 215-227.
4.   Curry, D. J., & Riesz, P. C. (1988). PRices And Price Quality Relationships A Longitudinal Analy. *Journal of Marketing, 52*(1), 36-51.
5.   Dalen, J. v., & Bode, B. (2004). Quality-corrected price indices: the case of the Dutch new passenger car market, 1990-1999. *Applied Economics, 36*(11), 1169-1197.

6.   Deneckere, R. J., & Palma, A. d. (1998). The diffusion of consumer durables in a vertically differentiated oligopoly. *The Rand Journal of Economics, 29*(4), 750-771.
7.   Dodds, W. B. (1991). In Search of Value: How Price and Store Name Information Influence Buyers' Product Perceptions. *The Journal of Consumer Marketing, 8*(2), 15.
8.   Dodds, W. B., Monroe, K. B., & Grewal, D. (1991). Effects of Price, Brand, and Store Information on Buyers' Product Evaluations. *JMR, Journal of Marketing Research, 28*(3), 307.
9.   Gerstner, E. (1985). Do Higher Prices Signal Higher Quality? *Journal of Marketing Research, 22*, 215-227.
10.   Irandoust, M. (1998). Pricing Policy in the Swedish Automobile Market. *Journal of Economics and Business, 50*, 309-317.
11.   Jackson, E. C. (2004). An Investigation of the Interaction of Advertising, Pricing and Quality on Sales Response. Unpublished Doctoral dissertation, Michigan State University, E. Lansing, MI.
12.   Jacobson, R., & Aaker, D. A. (1987). The Strategic Role of Product Quality. *Journal of Marketing, 51*(4), 31.
13.   Kirmani, A., & Rao, A. R. (2000). No pain, no gain: A critical review of the literature on signaling unobservable product quality. *Journal of Marketing, 64*(2), 66.
14.   Kornish, L. J. (2001). Pricing for a durable-goods monopolist under rapid sequential innovation. *Management Science, 47*(11), 1552-1561.
15.   Krishnan, T. V., Bass, F. M., & Jain, D. C. (1999). Optimal Pricing Strategy for New Products. *Management Science, 45*(12), 1650-1663.
16.   Leavitt, H. J. (1954). A Note on Some Experimental Findings About the Meaning of Price. *Journal of Business, 27*(July), 205-210.
17.   Lichtenstein, D. R., & Burton, S. (1989). The Relationship Between Perceived And Objective Price-Quality. *JMR, Journal of Marketing Research, 26*(4), 429.
18.   Mahajan, V., Muller, E., & Bass, F. M. (1990). New Product Diffusion Models in Marketing: A Review and Direction for Research. *Journal of Marketing, 54*, 1-26.
19.   Narasimhan, R., Ghosh, S., & Mendez, D. (1993). A Dynamic Model of Product Quality and Pricing Decisions on Sales Response. *Decision Science, 24*(5), 893-908.
20.   Narasimhan, R., & Mendez, D. (2001). Strategic aspects of quality: A theoretical analysis. *Production and Operations Management, 10*(4), 514-526.
21.   Narasimhan, R., Mendez, D., & Ghosh, S. (1996). An Examination of the Effect of Continuous Quality Improvements on Optimal Pricing for Durable Goods. *Decision Science, 27*(3), 389-413.
22.   Nelson, P. (1970). Information and Consumer Behavior. *The Journal of Political Economy, 78*(2), 311-329.
23.   Nelson, P. (1974). Advertising as Information. *The Journal of Political Economy, 82*(4), 729-754.
24.   Oxenfeldt, A. R. (1950). Consumer Knowledge: Its Measurement and Extent. *Review of Economics and Statistics, 32*, 300-314.
25.   Plunkett, J. J., & Dale, B. G. (1988). Quality Costs: A Critique of some "Economic Cost of Quality" Models. *International Journal of Production Research, 26*(11), 1713-1726.
26.   Putsis, W. P. J. (1989). Product Diffusion, Product Differentiation and the Timing of New Product Introduction. *Managerial and Decision Economics, 10*(1), 37-50.
27.   Rabinovich, E., & Bailey, J. P. (2004). Physical distribution service quality in Internet retailing: service pricing, transaction attributes, and firm attributes. *Journal of Operations Management, 21*(6), 651.
28.   Rao, A. R., & Monroe, K. B. (1989). The Effect of Price, Brand Name and Store Name on Buyers' Perceptions of Product Quality: An Integrative Review. *Journal of Marketing Research, 26*, 351-357.
29.   Riesz, P. C. (1978). Price Versus Quality in the Marketplace, 1961-1975. *Journal of Retailing, 54*, 15-28.
30.   Riesz, P. C. (1979). Price-Quality Correlations for Packaged Food Products. *Journal of Consumer Affairs, 13*, 236-247.
31.   Robinson, B., & Lakhani, C. (1975). Dynamic Price Models for New-Product Planning. *Management Science, 21*(10), 1113-1122.
32.   Rogers, E. M. (1976). New Product Adoption and Diffusion. *Journal of Consumer Research, 2*(4), 290-301.
33.   Schniederjans, M. J., Cao, Q., & Olson, J. R. (2004). Consumer Perceptions of Product Quality: Made In China. *The Quality Management Journal, 11*(3), 8.
34.   Scitovsky, T. (1945). Some Consequences of the Habit of Judging Quality by Price. *Review of Economic Studies, 12*(32), 100-105.

35. Sethi, S. P., & Bass, F. M. (2003). Optimal pricing in a hazard rate model of demand. *Optimal Control Applications & Methods, 24*(4), 183-196.
36. Sprokes, G. B. (1977). New Evidence on Price and Product Quality. *Journal of Consumer Affairs, 11*, 63-77.
37. Sultan, F., Farley, J. U., & Lehmann, D. R. (1990). A Meta-Analysis of Applications of Diffusion Models. *JMR, Journal of Marketing Research, 27*(1), 70-77.
38. Teas, R. K., & Agarwal, S. (2000). The effects of extrinsic product cues on consumers' perceptions of quality, sacrifice, and value. *Academy of Marketing Science. Journal, 28*(2), 278.
39. Zhou, K. Z., Su, C., & Bao, Y. (2002). A paradox of price-quality and market efficiency: A comparative study of the US and China markets. *International Journal of Research in Marketing, 19*(4), 349.

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