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THE DYNAMIC ADJUSTMENT OF OPTIMAL DURABILITY AND QUALITY*

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'They don't make them like they used to' is a well-known adage which is investigated in this paper. We show that when the marginal cost with respect to durability or quality per unit of production does not increase with production then: (a) A competitive firm and a monopolist will choose an optimal durability or quality path that decreases over time. (b) The more likely it is that quality and quantity are substitutes, either in consumption or production, the more likely it is that quality will deteriorate over time, as the market approaches the steady state. (c) Substitutability of quality and durability will tend to drive quality down even faster when durability declines.

1. Introduction

'They don't make them like they used to' is a well known common wisdom statement. It reflects the belief that the quality and durability of goods decline through time. This is the main issue we address in this paper.

Unlike most previous works that dealt with the question of optimal durability or quality we do not restrict ourselves to analysis of the steady state or to the assumption that durability is fixed initially and remains constant thereafter. For models of this type see Kleiman and Ophir (1966), Levhari and Srinivasan (1969), Schmalensee (1970), and Swan (1970). Studies such as those by Lancaster (1966), Spence (1975), Sheshinsky (1976), Leland (1977), Schmalensee (1979), among others, analyze the policy of optimal quality in stable markets, such that the quality does not change over time.

There have been some works that explicitly consider the time periods prior to the steady state such as Levhari and Peles (1973), Kamien and Schwartz (1974), Auernheimer and Saving (1977). They do not, however, characterize the durability adjustment before the industry reaches its steady state.

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Schmalensee (1979) provides an interesting review and synthesis of many of these and other related papers.

We show that when the marginal cost with respect to quality or durability per unit of production either decreases or remains constant with production then the competitive firm, monopolist seller and monopolist renter will all choose an optimal durability path that decreases over time.

Increasing marginal cost implies the existence of an adjustment period (usually an infinite period) prior to the steady state. Thus, this period, while it can be ignored in the constant returns case, is important enough to warrant investigation both on theoretical grounds – steady state is usually attained at infinity, and on empirical grounds – emergence of new technologies in many cases distorts the market even before it can reach a neighborhood of the steady state.

The adjustment considered in this study should be distinguished from intertemporal price discrimination exercised by monopolist as discussed in Stokey (1979). In our study there are no limitations on the consumers' preference and the production or cost functions do not change over time. Thus, price discrimination occurring from consumers of differing preferences adopting the product at different periods cannot occur and in addition the same production technology prevails throughout the adjustment process.

2. Choice of durability over time

In this section we deal with a durable good that breaks down abruptly as in the 'one hoss shay' case. It can be shown that the main results are valid with exponential decay as well.

We assume that the firm produces a good which supplies some type of a service. The demand for the good produced is for its service supplied during the same period. That is, the periodic rental price depends on the total quantity Q available in that specific period. Firms have the usual U-shaped average cost curve and production takes place at the rising section of the marginal cost function. We assume that quantity available in the market and the prices in the path leading to the steady state behave in the following manner: Total Q will rise and price (i.e., the period rental price) p will decline over time, approaching the steady state quantity and price.

In a competitive market structure, at the initial periods, as long as the prices (and profits) are above the steady state ones, firms will produce such that total quantity increases, driving prices and profits down towards the steady state levels. At the steady state there is no excess profit. Note that initially, total quantity is zero while it is positive at the steady state. Thus, in general, total quantity has to increase and the question is whether overshooting occurs. If there is an overshooting of quantity, prices and returns are lower than the steady state ones. A firm entering an overshooting stage will suffer losses as long as there exists this excess available quantity. Later, at the steady state it will just break even, having normal returns. Overall, the firm therefore will suffer losses. As a result, at some period of time before the (already known) overshooting periods, firms will exit the industry so that they will not have to enter the loss period. A similar argument can be made for the multiplant monopolist.

We assume that firms are operating at decreasing returns to scale and so the steady state is not reached immediately. We also assume that the interest rate remains constant over the entire period.

The decision each firm faces is the optimal quantity to produce each period (x) and its durability (N). All goods produced at a given period have the same durability N, yet the durability can (and will) differ between different periods.

In order to formalize the maximization problem of the firm consider two products produced at period t with the first product having a durability of N periods and the second – a durability of $N+1$. They share the same rental prices prevailing in periods t to $t+N$. Product two, however, rents at a price of P_{t+N+1} at period $t+N+1$. The differences between the two *selling* prices will therefore be the present value of P_{t+N+1}.

Thus, price is the present value of the future stream of the periodic service prices as given by

$$P(N(t),t) = \int_t^{t+N(t)} p(Q(s))\, e^{-r(s-t)}\, \mathrm{d}s, \tag{1}$$

where P is the selling price at time t that depends on the choice of durability.

The firm maximizes discounted profits J given by

$$J = \int_0^{\infty} \{P(N(t),t)x(t) - C(x(t),N(t))\}\, e^{-rt}\, \mathrm{d}t.$$

First order condition for optimal durability path is given by the following:

$$x\, \mathrm{d}P(N(t),t)/\mathrm{d}N = \partial C/\partial N.$$

Substituting eq. (1) using Leibnitz's rule yields

$$[1/x(t)]\, \partial C(x(t),N(t))/\partial N = p(t+N(t))\, e^{-rN(t)}. \tag{2}$$

In order to show that durability decreases over time, consider two time periods $T_1 < T_2$, and assume, a contrario, that $N(T_1) \leqq N(T_2)$. Since the periodic rental price declines over time, we have

$$p(T_1 + N(T_1)) > p(T_2 + N(T_2)).$$

Multiplying eq. (1) by e^{rN}, and comparing the L.H.S. of the equation at the two time points yields

$$e^{rN_1}[(1/x)\,\partial C/\partial N]_{t=T_1} > e^{rN_2}[(1/x)\,\partial C/\partial N]_{t=T_2}, \tag{3}$$

where N_1 and N_2 denote $N(T_1)$ and $N(T_2)$.

The form of the cost function is now of importance and we assume the following general cost function:

$$C(x, N) = x\psi(N)\phi(x) + f(x), \tag{4}$$

where ψ'' is non-negative, f'' is positive and ϕ is some function that can decrease or increase in x.

(a) Let the marginal cost with respect to durability per unit of x be independent of x, i.e., $(1/x)\,\partial C/\partial N = \psi'(N)$. Since ψ' is nondecreasing (i.e., $\psi'' \geqq 0$) and e^{rN} is increasing in N, our assumption that $N_1 \leqq N_2$ contradicts inequality (3). Therefore it follows that $N_1 > N_2$ as we set out to prove.

Thus durability declines as the market approaches the steady state. In other words, the earlier is production, the higher the expected future price of period N, and hence the higher the equilibrium marginal cost with respect to durability per unit of production, implying higher durability.

(b) Let the marginal cost with respect to durability per unit of x depend on the level of x. First let $(1/x)\,\partial C/\partial N$ be decreasing in x, i.e., $\phi' < 0$.

With a usual U-shaped average cost and increasing marginal cost curves lowering prices implies lowering quantity produced by each firm over time. Thus $x(T_1) > x(T_2)$. If we assume, as before, that $N(T_1) \leqq N(T_2)$, these two facts contradict inequality (3). Having this type of cost function implies a durability path that declines over time at even faster rate than the previous cost function where the marginal cost is independent of x.

As the firm approaches the steady state, durability decreases not only since future price goes down, but also as periodic production declines, the cost of extending durability goes up. Hence both these effects work in the same direction to lower durability as time goes on.

(c) If $\partial[(1/x)\,\partial C/\partial N]/\partial x = \phi' > 0$, i.e., the marginal cost with respect to N (per unit of x) increases in x, the path of durability over time can increase, decrease, or remain constant.

Durability is affected by two opposing forces. The decline in future rental price tends to lower future durability. The decline in cost of extending durability, resulting from the decline in production, tends to increase future durability. The final result depends therefore on the magnitude of $(1/x)\,\partial^2 C/\partial x\,\partial N$ versus dp/dt. The stronger the first effect is, the higher is the probability of having a durability path which increases over time.

We have assumed throughout that the rate of interest r, is constant. If r declines over time, then from eq. (2) this tends to increase durability over time.

Hence the likelihood of an increasing path of durability will be higher when both r declines and when the marginal cost with respect to durability increases with production.

The same analysis can be extended to the monopoly case. The monopoly's marginal revenue should replace the competitive price in eq. (2).

3. Optimal quality path

In this section we deal with the question of adjustment of optimal quality. The behavior over time analyzed here, as with durability, is restricted to the period that begins with the production of new goods and ends at the steady state period. Firm i produces x_i quantity periodically. In a competitive market there are a large number of firms, all of them having identical cost function and hence producing the same quantity. The total quantity available at any given period is Q_i. If all goods have durability of T periods and depreciation is one-hoss shay, that is, the product yields equal amount of services per year over its entire finite life time and then suddenly evaporates and yields zero units of services thereafter, then $Q_i=\sum_{j=i-T}^{i} n_j x_j$, where n_j denotes the number of firms in the market.

For simplicity we assume that durability is predetermined and is the same for all periods. Durability is longer than one period so that the market is approaching, but is not yet in, a steady state condition. That is $n_i x_i \leqq Q_i$ where $n_i x_i = Q_1$ only in period 1. Notice that under the present conditions the firms are assumed to produce goods of the same quality at any certain period of time. Differences in quality prevail only between yields of different periods.

Quality raises prices over all the periods in which the product endures, such that $dp_j/dq>0$, where $p_j=\sum_{i=j}^{j+N} p_i e^{-ir}$, where q denotes quality, r the rate of interest, and N denotes durability.

The market is not yet in a steady state in that output is still accumulated in the market. We assume that the total output in the market is continuously growing such that $Q(t_1)<Q(t_2)$, where t denotes time and $t_1<t_2$. Hence, since $\partial p/\partial Q<0$, prices, given a constant quality, decline over time, and this is known by all traders in the market.

The cost function with respect to quantity is the usual one of increasing marginal cost, such that the firm does not arrive at the steady state condition immediately. From the above characteristics of prices and costs, the optimal periodic output $n_i x_i$ declines over time, and so also the firm's output x_i. That is, $x(t_1) > x(t_2)$, where $t_1 < t_2$.

Note that $Q_i = (\sum_{j=i-T}^{i-1} n_j x_j) + n_i x_i$. The first term on the right is already given by past production and the only way to change Q_i is by changing x_i; namely, changing production of the latest period only, either by changing the number of firms operating n_i or the firm's production, or, and that is generally the case with competition and the assumed cost function, by changing both n_i and x_i together in the same direction. In a way similar to our treatment of optimal durability, the marginal conditions with respect to quality of a firm operating in a competitive market structure are as follows:

$$\partial p(q,Q)/\partial q - (1/x)\,\partial C(x,q)/\partial q = 0, \tag{5}$$

where $C(x,q)$ is the cost function and thus $(1/x)C(x,q)$ is the average cost per unit, given the specific quality produced.

To analyze the behavior of quality over time we differentiate eq. (5) with respect to time to achieve the following:

$$\dot{q}\,\partial/\partial q[\partial p/\partial q - (1/x)\,\partial C/\partial q] + \dot{Q}\,\partial^2 p/\partial q\,\partial Q - x\,\partial/\partial x[(1/x)\,\partial C/\partial q] = 0. \tag{6}$$

Note that the second order necessary conditions for the optimality of the chosen quality of q guarantee that $\partial/\partial q[\partial p/\partial q - (1/x)\,\partial C/\partial q]$ is negative.

Case A. Let the marginal per unit cost with respect to quality be independent of the periodic production level, i.e., $\partial^2(C/x)/\partial x\,\partial q = 0$. Since $\dot{Q}$ is positive, the sign of $\dot{q}$ is the same as the sign of $\partial^2 p/\partial p\,\partial Q$. There are three possible cases:

A.1. $\partial^2 p/\partial q\,\partial Q = 0$. This is a case where the price premium for quality is not affected by changes in the quantity available. The quality, therefore, remains the same throughout the entire period. The optimization is, in effect, a static one in which current quality levels do not have any future effects.

A.2. $\partial^2 p/\partial q\,\partial Q < 0$. The price premium for quality declines with increase in quantity. Thus quality and quantity are substitutes in consumption and improved quality makes the demand function more elastic. Quality in this case will deteriorate over time. As total quantity increases its substitute (quality) can gradually decrease.

An extreme case is where quality is a perfect substitute for quantity. An example for such a case is razor blades. Consumers might very well be indifferent between having twice the number of blades or a blade of higher quality which just supplies twice the number of shaves. Therefore, we expect periodic quantity and quality to have the same behavior over time – downwards.

A.3. $\partial^2 p/\partial q\, \partial Q > 0$. The price premium for quality increases with increases in quantity. Quantity and quality are complements in demand. In this case $\dot{q} > 0$, i.e., quality improves over time. Thus as total quantity increases, its complement, quality, increases as well.

Case B. Let the marginal per unit cost with respect to quality be decreasing in the periodic production level, i.e. $\partial^2(C/x)/\partial x\, \partial q < 0$. Since periodic production declines over time, i.e., $\dot{x} < 0$, then if $\partial^2 p/\partial q\, \partial Q < 0$ then $\dot{q} < 0$. Thus, if quality and quantity are substitutes both in consumption and production, then quality deteriorates over time.

Case C. Let the marginal per unit cost with respect to quality be increasing in periodic production, i.e., $\partial^2(C/x)/\partial x\, \partial q > 0$. If in addition $\partial^2 p/\partial q\, \partial Q > 0$ then $\dot{q} > 0$. Thus, if quality and quantity are complements both in consumption and production, quality improves over time.

As for the case where the marginal per unit cost with respect to quality and the price premium for quality move in opposite directions when quantity changes, i.e., $\partial^2 p/\partial q\, \partial Q \cdot \partial^2(C/x)\, \partial x\, \partial q < 0$, no a priori clear cut direction of quality change over time can be established. However, the following general statement can be made: the more quality and quantity are substitutes, either in consumption or in production, the more likely it is that quality will deteriorate over time, as the market approaches the steady state. Two such examples are: first, the previously mentioned razor blades example, and second: a product where a higher quality takes the form of longer durability, which is one way to increase quantity available. In addition, the more quality and quantity are complements, the more likely it is that quality will improve over time.

4. The effects of declining durability on quality

In this section we find out what would be the effects on quality of a durability path which declines over time. Since price is written as: $P_j = \sum_{i=j}^{j+N} p_i e^{-ir}$, where N is the durability, shorter durability period will imply lower price. Intuitively, this reduces the incentive to produce high quality products since the payoff period, i.e., the period in which the product endures, is smaller. Formally price will be a declining function of time because of the above relationship. Eq. (5) can now be written as

$$\partial P(N, q, Q)/\partial q - (1/x)\, \partial C(N, x, q)/\partial q = 0.$$

Differentiation with respect to time yields

$$\dot{N}\,\partial/\partial N(\partial P/\partial q)+\dot{q}\,\partial/\partial q[\partial P/\partial q-(1/x)\,\partial C/\partial q]+\dot{Q}\,\partial^2 P/\partial q\,\partial Q$$
$$-\dot{x}\,\partial/\partial x[(1/x)\,\partial C/\partial q]-\dot{N}\,\partial/\partial N[(1/x)\,\partial C/\partial q]=0. \qquad (7)$$

Since we wish to investigate the additional effect of durability, we will concentrate on cases A and B of section 3, i.e., when quality and quantity are substitutes (or independent) in production. In this case a straightforward inspection of (7) reveals that $\dot{q}<0$ if also durability and quality are substitutes in production, i.e., $\partial^2 C/\partial q\,\partial N<0$, and if they are complements in consumption, i.e., $\partial^2 P/\partial q\,\partial N>0$.

The last inequality, does not seem to conform to our general findings that substitutability between quality, quantity, and durability is the main cause for declining quality. Indeed this is the one exception. The reason is that what we defined as price is not instantaneous price but rather the discounted price over the life time of the product. Thus if the life time (i.e., durability) is increased, consumer will be willing to pay more for an additional unit of quality since this new superior quality will be used for a longer period of time. Thus we expect to see complementarity in demand. Given this assumption, we can indeed conclude that substitutability of quality and durability in production will tend to drive quality down even faster when durability declines. If, however, quality and durability are complements also in production, then the effects of declining durability on quality can be determined only by measuring its effect on the profit function, i.e., its combined effect on both revenues and costs.

5. Summary

The main results are the following:

(*a*) Unless the marginal cost with respect to durability per unit of product rises quite significantly with quantity, durability will decline over time.
(*b*) The more likely it is that quality and quantity are substitutes, either in consumption or production, the more likely it is that quality will deteriorate over time, as the market approaches the steady state.
(*c*) Substitutability of quality and durability will tend to drive quality down even faster when durability declines.

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