ELSEVIER

Research in Economics 59 (2005) 59–66

RESEARCH IN ECONOMICS

www.elsevier.com/locate/yreec

Durable goods monopoly and quality choice

Gregory E. Goering*

Department of Economics, University of Alaska, P.O. Box 756080, Fairbanks, AK 99775-6080, USA

Received 28 July 2004; accepted 26 November 2004

Abstract

A simple two-period durable goods monopoly model with quality choice is examined. It is shown that a seller tends to offer durable output with a lower quality than a renter who in turn offers lower quality than the socially efficient level. These results are contrasted to earlier works on durability and quality. It is shown that the impact of product durability on the optimal quality chosen depends critically upon the interrelationship between durability and quality costs at the margin and quality's impact on the durable goods stream of service flows.

Keywords: Durable goods; Monopoly; Product quality

JEL classification: D4; L12; L15

1. Introduction

Durable goods models have generated a great deal of interest in the past several decades due to their prevalence in real-world economies and also the classic conjecture of Coase (1972). Coase argued that a monopolist selling a durable good faces a commitment problem with initial buyers. Buyers rationally recognize the selling firm will have an incentive to lower the price in future periods, which will decrease the value of any durable units buyers still hold. The selling firm has no incentive to take this capital loss of current buyers into account in the future since it *does not* own these units. Unless the firm can credible commit itself this Coase 'problem' tends to decrease the firm's profit. Obviously,

* Tel.: +1 907 474 5572; fax: +1 907 474 5219.
E-mail address: ffgeg@uaf.edu

1090-9443/$ - see front matter © 2005 University of Venice. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.rie.2004.12.004

if the firm rents or leases all units it internalizes this problem, hence the dichotomy between rentals and sales markets in durable goods industries.

There are a large number of studies that explore this rental/sales issue, e.g. Goering (1993), Purohit (1995), Saggi and Vettas (2000) and Hoppe and Lee (2003). However, the interrelationship between durability and the larger issue of product quality has to a large extent been ignored. An interesting exception is Chi (1999) who correctly notes durability is only one aspect of a larger issue about the quality choice of firms. In a two-period dichotomous high and low quality setting Chi finds that a uncommitted perfectly durable goods monopolist tends to select a higher quality than a committed seller (renter) will.

The current analysis recasts the quality and durability relationship in more general two-period setting where the demand and cost relationships between product durability and quality can be examined. In essence durability can be thought of as the *length* of the product's service flow while quality is the value of the service flow in this setting. The monopolist can select any product quality for the parametrically specified durability level. The model allows for the explicit linkage of durability and quality on both the cost and demand side. Interestingly, the model shows in contrast to Chi (1999) a uncommitted seller may well provide a lower quality than either a renter or the socially optimum depending upon the interrelationship between durability and quality costs at the margin and quality's impact on the durable goods stream of service flows. This shows that the assumptions one makes about the interrelationship between durability and quality have an extremely large impact on the predicted results. Thus, even the simple two-period model analyzed here can yield a large array of expected outcomes.

2. A basic durable goods and quality-choice model

In a simple two-period world let a monopolist's product's durability be given by $\delta \in [0, 1]$, where δ is exogenously determined fraction of first period units that are available for use in the second period.[1] Hence, if δ equals zero the good is non-durable and if it equals one the good is perfectly durable. Clearly, in many situations the firm may be able to influence their product's durability. However, to focus on the firm's quality choice the analysis uses a parametric specification for durability.[2] Note that in this setting durability δ determines the length of the service flow of the good.

As is standard the service (rental) demand for durables is dependent upon the stock in circulation. Additionally, it is assumed that the quality q selected in the first period tends to increase the level of the service flows in the two periods. Assuming a linear specification the service demands in period one and two are thus

$$p_1 = a + \alpha_1 q - bx_1 \quad \text{and} \quad p_2 = a + \alpha_2 q - b(\delta x_1 + x_2), \tag{1}$$

[1] See Bulow (1982, 1986) for the basic two-period durable goods monopoly framework.
[2] Note that Chi (1999) restricts his attention to perfectly durable goods.

where x_1 and x_2 are the monopolist's output in period one and two, respectively.[3] The simple specification in (1) allows, among other things, for a varying impact of quality over time. For example, if $\alpha_1 = 0$ with $\alpha_2 > 0$ the quality chosen will only impact the level of future demand, but not current demand.

On the cost side we suppose that there is a constant positive marginal cost of production in each period c_1 and c_2. However, there is a one time cost associated with durability δ and quality q given by $\theta(q,\delta)$ where $\theta(q,\delta)$ is twice continuously differentiable and strictly increasing and convex in δ and q. This cost specification allows for the exploration of the linkage between durability and quality without the complicating impacts of these on the marginal production costs. Durability and quality effectively determine the level of 'fixed' manufacturing costs in the model, implying the total cost in each period is given by:

$$\mathrm{TC}_1 = c_1 x_1 + \theta(q,\delta) \quad \text{and} \quad \mathrm{TC}_2 = c_2 x_2. \tag{2}$$

The cost specification in (2) can be rationalized by the somewhat standard 'fixed cost of innovation' modeling assumption which suggests that the choice of improved product quality in some cases may be fixed in nature and not dependent upon output levels. In our case this cost depends upon the characteristics of the product δ and q, the latter of which is determined in period one endogenously.

Note that the cost specifications in (2) differs from the earlier treatments of quality which have not included a cost for durability (in part because of the simplifying assumption that output is perfectly durable) and have assumed that quality impacts the marginal production costs (which are constant with respect to output). A full general cost function where durability, quality, and output are specified jointly in period t as $c_t(q_t,x_t,\delta_t)$ would be ideal, but this, unfortunately, is not tractable. However, it is shown the model is still sufficiently rich with the cost specification in (2) to yield a large array of results. Indeed, even with the simple cost structure in (2), the model will show that there likely is no overarching general result capturing the linkage between durability and quality choices. Instead this relationship is complicated enough that most results will not be robust to changes in modeling assumptions such as costs and service flows.

With the demand and cost assumptions in (1) and (2), the monopolist's discounted profit stream is

$$\begin{aligned}\pi = {} & (a + \alpha_1 q - b x_1 - c_1) x_1 - \theta(q,\delta) + \beta[(\delta x_1 + x_2)(a + \alpha_2 q \\ & - b(\delta x_1 + x_2)) - c_2 x_2],\end{aligned} \tag{3}$$

where $\beta \in [0, 1]$, is the one period discount factor.

Although (3) is the objective function for the monopolist it would not be the objective function of a social planner. Instead the planner seeks to maximize the discounted stream

[3] Note that although the service flow (rental price) in period one is not influenced by the durability parameter δ, the sales price in period one is dependent upon the product's durability, i.e. $p_1^s = a + \alpha_1 q^s - b x_1^s + \beta\delta(a + \alpha_2 q^s - b(\delta x_1^s + x_2^s))$. The sales price in period one p_1^s is the discounted stream of the service (rental) prices and therefore does integrally depend upon product durability δ (where $\beta \in [0, 1]$ is the one period discount factor).

of net surplus (firm profits plus consumer surplus), which is given by (4)

$$S = \int_0^{x_1^*} (a + \alpha_1 q - b x_1) dx_1 - c_1 x_1 - \theta(q, \delta) + \beta \left[\int_0^{X_2^*} (a + \alpha_2 q - b X_2) dX_2 - c_2 x_2 \right], \tag{4}$$

where $X_2 = \delta x_1 + x_2$ is the stock of durable output in the second period. The maximizing solution to (4) in terms of x_1, x_2, and q will yield the socially optimal benchmark to which we can compare to the monopolist's maximizing solutions to (3).

In terms of the timing of the moves by the monopolist or social planner, it is assumed that in period one the quality level q and period one output x_1 are selected simultaneously. Then in period two the second period output is chosen. In this setting potential period one buyer will purchase the good at a known quality level. This, of course, provides the decision maker with commitment ability with these early buyers since quality (and first period output) cannot subsequently be modified.

Note that alternatively a more extensive form of the game could be specified where quality is set before the output level in the initial period. In this formulation the quality level would still provide commitment ability for the decision maker with potential period one buyer (since the quality choice is simply set an even earlier stage) and thus would not materially influence the general results. Thus, the simpler simultaneous choice is explored here. However, as was pointed out by an anonymous referee and the Associate Editor in earlier draft of the paper, this conclusion would likely change in an oligopolistic setting. With competition among firms the commitment value of an earlier stage choice of quality is not necessarily non-zero. In this setting the firms may gain commitment ability (credibility) amongst each other at each stage of the game and one would expect quality to be used in a strategic fashion with rivals (likely causing an increase in quality). In a broader sense oligopolistic rivalry among firms in sales markets would undoubtedly reveal other strategic effects, such as the use of period one output to 'capture' future (period two) market share or demand. Thus in a richer oligopolistic setting these firm strategic aspects, which are lacking in the current model, could be explored.

3. Optimal quality choice with durable production

To calculate socially optimal benchmark, Eq. (4) is differentiated with respect x_1, x_2, and q. The first-order condition on second period production x_2 can be used to reduce the number of governing equations to two (which will ease comparisons to the monopoly solutions)[4]

[4] Since demand is linear and the marginal manufacturing cost is constant the second-order condition for x_2 is always satisfied, implying $\frac{\partial S}{\partial x_2} = a + \alpha_2 q - b(\delta x_1 + x_2) - c_2 = 0$ is indeed optimal.

$$\frac{\partial S}{\partial x_1} = a + \alpha_1 q - b x_1 - c_1 + \beta\delta c_2 = 0, \tag{5}$$

$$\frac{\partial S}{\partial q} = \alpha_1 x_1 + \frac{\beta\alpha_2(a + \alpha_2 q - c_2)}{b} - \theta_q(q, \delta) = 0. \tag{6}$$

From (5) it is apparent that the value of a unit with durability δ is simply the standard price equals marginal cost condition adjusted for the discounted cost savings a durable unit provides (i.e. a second period unit does not have to be manufactured to provided second period service if $\delta > 0$). Similarly, (6) shows the revenue at the margin from quality must equal the marginal cost at the social optimum.[5] Note the parameterization of the model α_1, α_2 and δ in (6) captures the discounted time path of these revenues as well as the impact of durability on the marginal cost of quality in a simple fashion.

To ascertain the impact of durability on product quality in the socially optimal case, (5) and (6) can be totally differentiated with respect to durability, quality, and period one output, yielding[6]

$$\frac{\partial q^*}{\partial \delta} = \frac{\beta\alpha_1 c_2 - b\theta_{q\delta}(q, \delta)}{|H_2|}, \tag{7}$$

where $|H_2| > 0$ by the second-order condition. Even in our highly stylized model the impact of durability has an ambiguous impact on optimal quality. Intuitively durability may impact the marginal cost of quality directly $\theta_{q\delta}(q,\delta)$. It also indirectly impacts the benefits of quality through period one output if quality affect the current demand ($\alpha_1 > 0$). As the product becomes more durable the planner has an incentive to increase period one output which in turn will increase the value of quality when $\alpha_1 > 0$. If quality only tends to impact future service demands then (7) shows $\partial q^*/\partial\delta$ is solely determined by the effect of durability on the marginal cost of quality. If, for example, the product's durability tends to increase the marginal cost of providing quality ($\theta_{q\delta}(q,\delta) > 0$) Eq. (7) is necessarily negative. On the other hand, if there is a synergy between durability and quality at the margin ($\theta_{q\delta}(q,\delta) < 0$) and quality does impact the current demand ($\alpha_1 > 0$) than (7) is unambiguously positive. Proposition one summarizes these findings.

Proposition 1. *The impact of durability on the socially optimal product quality depends upon the interrelationship between durability and quality costs at the margin and quality's impact on the durable goods stream of service flows.*

We can now compare the social optimum in (5) and (6) to the monopoly solutions and show that the monopolists tends to offer a lower product quality than socially optimal in contrast to Chi (1999).

Although the monopolist seeks to maximize the discounted stream of rental profits in (3) through their choice of outputs x_1 and x_2 and quality q, it can only do so unconstrained

[5] The analysis supposes that parameters and costs are such that the second-order conditions are satisfied in all cases for (5) and (6), i.e. the bordered Hessian is negative definite ($|H_2| > 0$).

[6] For brevity we focus on the impact of durability on the optimal quality choice.

if rents all period one output or has commitment power as a seller. In other words, the resultant solution will only be time-consistent with commitment power or rentals. Otherwise, the Coase conjecture comes into play and initial buyers rationally recognize a seller without commitment ability will have an incentive to lower the price in future periods (i.e. re-maximize) at the buyers' expense. We calculate unconstrained the rental (committed seller) solution first.

The maximization of (3) with respect to x_1, x_2, and q gives[7]

$$\frac{\partial \pi^{\mathrm{r}}}{\partial x_1^{\mathrm{r}}} = a + \alpha_1 q^{\mathrm{r}} - 2bx_1^{\mathrm{r}} - c_1 + \beta\delta c_2 = 0, \tag{8}$$

$$\frac{\partial \pi^{\mathrm{r}}}{\partial q^{\mathrm{r}}} = \alpha_1 x_1^{\mathrm{r}} + \frac{\beta\alpha_2(a + \alpha_2 q^{\mathrm{r}} - c_2)}{2b} - \theta_q(q^{\mathrm{r}}, \delta) = 0, \tag{9}$$

where the superscript r denotes the rental (or equivalently the committed sales) solution.

If we compare the monopolistic durable goods renter's (9) with the socially optimal quality condition (6) it is immediately apparent that the monopolist renter will offer a lower product quality than is efficient. The simple logic is that a monopolist tends to offer less output, both in the current period as well in the future, so the benefit of product quality is less in (9) than (6). In other words, the standard result that the monopolist sets marginal revenue equal to marginal cost rather than price implies not only lower output but a lower product quality as well in this setting.

Proposition 2. *A durable goods monopoly renter or committed seller will offer durable output with a lower quality than what is efficient*.

Proposition 2 can be contrasted to Chi (1999) who finds the opposite result. The difference in results, of course, is due to the different modeling assumption, in particular the assumption that quality impacts the level of the service demands in the current setting. If this is the case optimal quality will in part be dependent upon sales volume and therefore will tend to be lower in situations where output is lower.

In terms of the impact of durability on the monopolist's optimal quality choice it is easy to show an analogous equation to (7) still holds. Thus, whether or not a more highly durable good causes a renting monopolist to offer more or less quality depends upon the impact of durability on the marginal cost of providing quality and quality's effect on the goods current service flow.[8]

If the monopolist sells with no credible commitment ability then the solution found in (8) and (9) is dynamically inconsistent, since the firm will wish to deviate (re-maximize) in the second period at the initial buyers expense (Coase conjecture). In other words, the seller will wish to set a lower second period price than the one announced in the first period. Hence, although the firm still seeks to maximize (3) it must do so with

---

[7] As in the social planner case, the first-order condition on second period output $x_2^{\mathrm{r}} = \frac{a+\alpha_2 q^{\mathrm{r}} - c_2}{2b} - \delta x_1^{\mathrm{r}}$ is used to reduce the number of governing equations to two.

[8] The renting monopolist's analog to (7) is $\frac{\partial q^{\mathrm{r}^*}}{\partial \delta} = \frac{\beta\alpha_1 c_2 - 2b\theta_{q\delta}(q^{\mathrm{r}}, \delta)}{|H_2^{\mathrm{r}}|}$ where $|H_2^{\mathrm{r}}| > 0$ by the second-order condition. As in (7) the sign is once ambiguous without very specific knowledge. Thus, proposition one can be extended to durable goods monopoly renters (or committed sellers).

an expectational constraint placed on it by rational period one buyers. These buyers know the firm will maximize (10) in the second period

$$\pi_2^s = (a + \alpha_2 q^s - b(\delta x_1^s + x_2^s) - c_2)x_2^s, \tag{10}$$

where the superscript s denotes an uncommitted seller's values. If we compare (10) to the discounted portion of (3) it is apparent that the seller in this case has no incentive (ability) to take into account the loss in value of period one buyers on their existing stock δx_1^s since the firm does not own these units. The maximization of (10) with respect to x_2^s gives:

$$x_2^s = \frac{a + \alpha_2 q^s - c_2}{2b} - \frac{\delta x_1^s}{2}. \tag{11}$$

Hence, initial buyers know that the firm will set period two output according to (11). Implying that (11) becomes a constraint on the firm's behavior. In other words, the dynamically consistent solution to the uncommitted seller's problem is found by maximizing (3) subject to (11) which gives:

$$\frac{\partial \pi^s}{\partial x_1^s} = a + \alpha_1 q^s - 2bx_1^s - c_1 + \beta\delta c_2 - \frac{\beta b \delta^2 x_1^s}{2} = 0, \tag{12}$$

$$\frac{\partial \pi^s}{\partial q^s} = \alpha_1 x_1^s + \frac{\beta\alpha_2(a + \alpha_2 q^s - c_2)}{2b} - \theta_q(q^s, \delta) = 0. \tag{13}$$

If we compare (13) the renter's (9) we see that the form of the equations is the same. However, by comparing (12) with (8) it is apparent that an uncommitted seller will produce a lower amount of period one durable output than a renter, i.e. $x_1^s < x_1^r$. This is due to the seller's commitment problem with first-period buyers. By lowering the amount sold to these consumers it tends to mitigate the firm's commitment problem with them. This in turn implies that as long as quality has an impact on current demand levels ($\alpha_1 > 0$) a seller will offer quality that is lower than that of a renter. Once again this can be contrasted to Chi (1999) who obtained the opposite result. Since we have already shown a renter will offer lower quality than what is socially efficient in (6) we have:

Proposition 3. *A durable goods monopoly seller will offer durable output with a lower quality than a renter who in turn offers lower quality than the socially efficient level when quality impacts current demand.*

Note that if the quality choice primarily impacts future output ($\alpha_1 = 0$) than the seller's reduction in initial output to mitigate commitment problems has no impact on the quality choice. Consequently, the seller and renter would offer the same product quality in this case albeit still at a lower than socially efficient level of (6). Thus, if quality is really more of an improvement in future service flows a durable goods seller and renter may select similar quality levels.

Finally, as in the renter's and socially optimal case whether or not a more highly durable good induces the monopolistic seller to manufacturer a higher quality product

depends upon on the specific costs and service flow relationships between quality and durability.[9]

4. Conclusion

The simple two-period monopoly model shows that quality choice and product durability are linked quite closely as one would expect. Depending upon durability's impact on the marginal cost of quality and the time path of the quality enhanced service flows a variety of results are possible. These results are summarized in the three propositions.

More broadly the current analysis and the previous work of Chi (1999), indicate that there likely is no overarching general result that exists capturing the linkage between durability and quality choices. Instead this relationship is complicated enough that most results will not be robust to changes in modeling assumptions such as costs and service flows. For example, the current model finds uncommitted sales monopolist will offer the lowest quality while Chi (1999) shows the opposite is true utilizing a different two period setting. Undoubtedly, product durability and quality decisions are highly firm specific and quite detailed knowledge of the cost and service demand functions are necessary to make behavioral predictions

Acknowledgements

The author gratefully acknowledges the helpful comments and suggestions of an anonymous referee and the Associate Editor on an earlier draft of the paper. Of course, any remaining errors are the author's sole responsibility.

References

Bulow, J., 1982. Durable goods monopolists. Journal of Political Economy 90, 314–332.
Bulow, J., 1986. An economic theory of planned obsolescence. Quarterly Journal of Economics 101, 729–749.
Chi, W., 1999. Quality choice and the coase problem. Economics Letters 64, 107–115.
Coase, R., 1972. Durability and monopoly. Journal of Law and Economics 15, 143–149.
Goering, G., 1993. Durability choice under demand uncertainty. Economica 60, 397–411.
Hoppe, H., Lee, I., 2003. Entry deterrence and innovation in durable-goods monopoly. European Economic Review 47, 1011–1036.
Purohit, D., 1995. Marketing channels and the durable goods monopolist: renting versus selling reconsidered. Journal of Economics and Management Strategy 4, 69–84.
Saggi, K., Vettas, N., 2000. Leasing versus selling and firm efficiency in oligopoly. Economics Letters 66, 361–368.

[9] By implicit differentiation it can shown selling monopolist's comparative static derivative is

$$\frac{\partial q^{s^*}}{\partial \delta} = \frac{\beta\alpha_1(c_2 - b\delta x_1^s) - (2b + \beta b\delta^2/2)\theta_{q\delta}(q^s, \delta)}{|H_2^s|}$$

where $|H_2^s| > 0$ by the second-order condition. Without specific cost and service flow knowledge the sign here is ambiguous once again. Hence, proposition one can be generalized to durable goods monopoly renters, committed sellers and uncommitted sellers.