NON-STATIONARY DEMAND IN A DURABLE GOODS MONOPOLY*

by

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In a context where demand for the services of a durable good changes over time, and this change may be uncertain, we show in this paper that social welfare may be higher when the monopolist seller can commit to any future price level he wishes than when he cannot. Moreover, the equilibrium under a monopolist with commitment power may Pareto-dominate the equilibrium under a monopolist without commitment ability. These results affect the desired regulation of a durable goods monopolist in this context.

1 Introduction

Demands for goods change over time and, generally, they change in an uncertain way. This work centers on an unnoticed result referred to a durable goods monopolist, when demand for the services of the durable good changes over time in an uncertain way. It is shown that welfare may be higher under a monopolist seller with commitment ability than under a monopolist seller without commitment power and, also, that the equilibrium under a monopolist seller with commitment ability may Pareto-dominate the equilibrium under a monopolist seller without commitment power. The analysis considers a monopolist who decides only on production levels. Commitment ability refers to the ability to commit, in a credible way, to a future price, and hence to sell or to buy in the future units of the durable good at that price. The results obtained ask for a specific analysis when commitment mechanisms or regulations of a durable goods monopolist under uncertain future demand are being considered.

A general result in the literature on durable goods monopolists (see Bulow, 1982; Kahn, 1986; Malueg et al., 1988; Chi, 1999) is that welfare under rentals (or under a monopolist seller with commitment ability) is lower than welfare under a monopolist seller who has no commitment power. Hence, attending to this general result, while the monopolist prefers to rent the durable good, the sale of the units of the good would be recommended.

* Manuscript received 15.2.06; final version received 20.11.06.
† I thank Ana I. Saracho for helpful suggestions. This version benefited from the remarks of an anonymous referee. Financial support from the Plan Nacional de I+D+I (projects BEC2000-0301 and BEC2003-02084) and from the UPV-EHU is gratefully acknowledged.

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from a social welfare perspective. This contradiction between producer preferences and society desires has been invoked to ask for regulation of the durable goods monopolist. However, it has also been shown in the literature that if the monopolist seller without commitment ability chooses, in addition to production levels, capacity or technology (Bulow, 1982), durability (Bulow, 1986; Malueg and Solow, 1987) or investment in cost-reducing innovations (Bond and Samuelson, 1987), he may incur inefficiencies that lower social welfare under sales below social welfare under rentals.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 analyzes the decisions of the monopolist renter, the monopolist seller with commitment ability and the monopolist seller who has no commitment power, and compares the monopolist profits in these three contexts. The main results on social welfare and Pareto-dominance are included in the last section.

2 Model

Consider a durable good produced by a monopolist and demanded by many price-taking buyers in a two-period framework. The firm is the only producer of the good, perhaps due to a patent. The analysis below will be developed under the following set of assumptions.

**Assumption 1:** Any unit of the durable good produced in period 1 may be used again in period 2, with no depreciation.

**Assumption 2:** The monopolist and the consumers have the same discount factor \( \delta = 1/(1+r) \), where \( r \) is the interest rate.

**Assumption 3:** The monopolist and the consumers:

(i) are completely informed about demand for the durable good in period 1 and production costs;
(ii) have the same beliefs in period 1 about demand in period 2;
(iii) learn at the end of period 1 what is the demand in period 2;
(iv) are risk neutral.

**Assumption 4:** The potential consumers of the durable good have perfect foresight.

**Assumption 5:** If the monopolist sells the durable good, there is a resale market in which the units of the durable good bought during the first period can be resold to other consumers in the second period.

1With some exceptions, the monopolist preference for rentals is very common (see Stokey, 1981; Bulow, 1982; Bucovetsky and Chilton, 1986; Gul et al., 1986; Kahn, 1986).

2In the USA some producers of durable goods, such as IBM and Xerox, that rented the good were required to also sell their output.

3Also, it has been proved that social welfare may be higher under rentals if the demands of potential users are interdependent (Saracho, 1997).
Assumption 6: The cost of producing the good is zero and there is free disposal of the durable good.

Assumption 5 assures that the different units of the durable good will be used in each period by those consumers that value it most. An alternative would be to assume that demand curves for the services of the durable good have perfect rank correlation or to admit that any unit of the durable good bought from a monopolist seller in period 1 may be sold to that monopolist in the future at the current price. Under Assumption 6 a monopolist renter may decide not to rent in period 2 some of the units of the durable good he has produced and leased in period 1. Free disposal also implies that, when the price in the resale market is not positive, consumers may not use in period 2 some of the units of the durable good they have bought in period 1 from the monopolist seller.

Let us denote by \( q_i \) and \( y_i \), respectively, the amounts of the durable good produced and used in period \( i \). The inverse demand function for the services of the durable good in period 1 is \( e(y_1) = e - fy_1 \). In that period all agents think there is a probability \( x \) that the inverse demand function in period 2 will be \( b(y_2) = b - ay_2 \) and a probability \( 1 - x \) that the inverse demand function in period 2 will be \( v(y_2) = v - zy_2 \), with \( v/z < e/f < b/a \). Thus, defining market size as the number of consumers having a positive valuation of the durable good, all agents think there is a probability \( x \) of an increase in the size of the market and a probability \( 1 - x \) of a decrease in the size of the market. Obviously, the case of a certain increase in the size of the market corresponds to \( x = 1 \) and the case of a certain decrease in the size of the market corresponds to \( x = 0 \).

In an interpretation of this model we have consumers with different willingness to pay for the services of the good in a context where each consumer uses at most one unit of the durable good. Demand varies because willingness to pay for the services of the good changes over time. The willingness to pay of some consumers may change from zero to a positive number or conversely. This interpretation is implicit in the analysis presented in this paper. A different interpretation would consider that each consumer has the same decreasing demand curve for units of the durable good. With time, this demand curve, identical for all consumers, changes.

Denote \( g(x) = xb + (1 - x)v \) and \( h(x) = xa + (1 - x)z \). Therefore, \( g(x) \) is the expected ordinate at the origin of the inverse demand curve in period 2 and \( h(x) \) is the expected slope of that curve. The ratio \( g(x)/h(x) \) will represent

\[\text{Notice that the ordinate at the origin may not change over time in the same direction as market size. Bhatt (1989) considers risk aversion in a model where the slope of the demand curve is the same in both periods, the expected level of the ordinate at the origin is unchanged and production in period 2 is positive. The main results in this paper require, however, a change over time in the expected slope of the demand curve and/or in the expected ordinate at the origin.}\]
the market size corresponding to the curve with the expected ordinate at the origin and the expected slope. Let us call this curve the expected inverse demand curve in period 2. Notice that

\[
\frac{g(0)}{h(0)} = \frac{v}{z}
\]

\[
\frac{g(1)}{h(1)} = \frac{b}{a}
\]

and

\[
\frac{dg(x)}{dh(x)} > 0
\]

Linear demands are enough to obtain the results that follow. In the rest of the paper let us use subscript \( b \) for variables referring to the case where the inverse demand function in period 2 is \( b(y_2) \) and subscript \( v \) for variables referring to the case where the inverse demand function in period 2 is \( v(y_2) \).

3 Monopolist Decisions

A monopolist renter would maximize profits in each period. Hence, he would rent \( e/2f \) in period 1, \( b/2a \) in period 2 if \( b(y_2) \) happened to be the inverse demand function in period 2 and \( v/2z \) if this function was \( v(y_2) \). Rental prices would be, respectively, \( p_1 = e/2 \), \( p_{2b} = b/2 \) and \( p_{2v} = v/2 \). The monopolist renter would dispose in period 2 of units of the good produced in period 1 if the inverse demand function in period 2 was \( v(y_2) \). Under rentals, the monopolist expected profits would be

\[
\pi^\text{rent} = \frac{e^2}{4f} + \delta x \frac{b^2}{4a} + \delta (1-x) \frac{v^2}{4z}
\]

However, rentals are often not feasible. It may be very costly to check if the good is returned in perfect condition after a rental period. Or it may be difficult to get compensation from consumers if they have damaged the good. In these situations the monopolist may prefer to sell the durable good.

A monopolist seller may obtain profits equal to \( \pi^\text{rent} \) if he can commit to a future price level. The ability to commit to a future production level is not enough as the size of the market may decrease. To obtain profits equal to \( \pi^\text{rent} \) the monopolist seller must be able to commit to buy in period 2, when the inverse demand function in that period happens to be \( v(y_2) \), any unit he has sold in period 1, paying a price equal to \( v/2 \) for that unit. A monopolist seller with this commitment power (from now on MC) will solve
and he will select in each period and situation the same production level as the monopolist renter. When the size of the market decreases in period 2, \( q_1 = v/2z \) units of the durable good will be resold to the monopolist in that period. 5

Consider now the decision of a monopolist seller without commitment power (from now on MNC). 6 We know that a future price is credible to the consumers in period 1 if and only if it is part of a subgame perfect equilibrium. Let us denote

\[
N(x) \equiv \frac{2e}{\sqrt{(4f + \delta x a)(4f + \delta h)}}
\]

and use superscript c for variables referring to the MC and superscript nc for variables referring to the MNC. Notice that \( N(x) \) may be increasing with \( x \), decreasing with \( x \) or increasing for some values of \( x \) and decreasing for some other values of \( x \). 7 The production decisions and profits of the latter monopolist are obtained in the following proposition.

**Proposition 1**: Production decisions and profits of a monopolist seller who has no commitment power are as follows.

(i) If \( v/z < N(x) \):

\[
q_1 = \frac{2e}{4f + \delta x a} \quad q_{2b} = \frac{b - e}{2a} \quad q_{2v} = 0
\]

\[
\pi_{nc} = \frac{e^2}{4f + \delta x a} + \delta x \frac{b^2}{4a}
\]

5Best-price provisions are not an alternative similar to this agreement as, to attain the monopolist renter profits, no sales are required in period 2 when the inverse demand function in that period happens to be \( v(y_2) \). On best-price provisions in a context where demand does not change over time see Butz (1990).

6The first-period decision of an MC is a partially flexible decision as he may undo that decision by repurchasing in period 2 units of the durable good he has sold in period 1. However, the first-period decision of an MNC is an irreversible decision as any units sold in period 1 will remain available for use by consumers in period 2. A more flexible decision leaves more alternatives available for the future and, as a consequence, permits a better adjustment to any information arriving in the future. In this work, commitment ability implies more freedom to choose in period 2. On flexibility see Jones and Ostroy (1984).

7Consider the following examples with \( \delta = 1 \): (i) \( N(x) \) is increasing with \( x \) if \( e = 2, f = 0.4, b = 4.8, a = 0.8, v = 6.2 \) and \( z = 5 \), (ii) \( N(x) \) is decreasing with \( x \) if \( e = 1, f = 0.8, b = 12, a = 9, v = 4 \) and \( z = 16 \), and (iii) \( N(x) \) is first decreasing with \( x \) and then increasing with \( x \) if \( e = 2.2, f = 0.2, b = 12, a = 1, v = 7.5 \) and \( z = 3 \).
(ii) If $v/z > N(x)$:

$$q_1 = \frac{2e}{4f + \delta h(x)}$$
$$q_{2b} = \frac{b}{2a} - \frac{e}{4f + \delta h(x)}$$
$$q_{2v} = \frac{v}{2z} - \frac{e}{4f + \delta h(x)}$$

$$\pi^{nc} = \frac{e^2}{4f + \delta h(x)} + \delta \frac{b^2}{4a} + \delta (1-x) \frac{v^2}{4}$$

Proof: See the Appendix.

We obtain that $q_1$ decreases with $x$ when $v/z < N(x)$. The intuition for this result is that the higher is $x$ the greater is the probability that the monopolist will sell more units in period 2, and hence the incidence of the Coase problem (Coase, 1972) is greater. As a consequence, the MNC finds it profitable to reduce $q_1$ and, in this way, to make credible that in period 2 (if the inverse demand function is $b(y_2)$) the price will not be very low or the number of units in the market will not be very high. When $v/z > N(x)$, $q_1$ is even lower. In this case the MNC will sell more units in period 2 even if market size in that period decreases and, hence, the impact of the Coase problem is greater than in the case where $v/z < N(x)$ (there will always be future sales competing for consumers with present sales).

4 Welfare Analysis

Let us measure social welfare as the present value of the sum of consumer and producer surplus. Social welfare under an MC, or under a leasing monopolist, is

$$W^c = \int_0^{e/f} (e-f\theta) d\theta + \delta x \int_0^{h/2a} (b-a\theta) d\theta + \delta (1-x) \int_0^{v/z} (v-z\theta) d\theta$$

Social welfare with an MNC is

$$W^{nc} = \int_0^{2e/[(4f+\delta h(x))] (e-f\theta) d\theta + \delta x \int_0^{h/2a+e/[(4f+\delta h(x))] (b-a\theta) d\theta} + \delta (1-x) \int_0^{v/z+e/[(4f+\delta h(x))] (v-z\theta) d\theta$$

if $v/z < N(x)$, and

$$W^{nc} = \int_0^{2e/[(4f+\delta h(x))] (e-f\theta) d\theta + \delta x \int_0^{h/2a+e/[(4f+\delta h(x))] (b-a\theta) d\theta} + \delta (1-x) \int_0^{v/z+e/[(4f+\delta h(x))] (v-z\theta) d\theta$$

8 When $v/z = N(x)$ the MNC is indifferent between the decisions in (i) and in (ii).

9 Notice, however, that $q_1 = 2e/[(4f+\delta h(x))] may increase with $x$ when $v/z > N(x)$ as $dh(x)/dx = a - z$, and we have $v/z < b/a$ but it could be $a < z$. 

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if \( v/z > N(x) \). Given the results in the previous section, we can prove the following relationship between \( W^c \) and \( W^{nc} \).

**Proposition 2:**

(i) If \( v/z < N(x) \) it is \( W^c < W^{nc} \).

(ii) If \( v/z > N(x) \) it is\(^{10} \)

\[
W^c \geq W^{nc} \iff \frac{3e}{4f} \geq \frac{g(x)}{h(x)}
\]

**Proof:** See the Appendix.

Therefore, welfare under an MC may be higher than welfare under an MNC. In that case it is \( y^c_1 > y^{nc}_1 \), \( y^c_2 < y^{nc}_2 \) and \( y^c_3 < y^{nc}_3 \). However, the higher welfare under an MNC in period 2 does not outweigh the higher welfare under an MC in period 1. As a consequence of the Coase problem, the lack of commitment ability forces the monopolist to reduce production in period 1 in a way that implies a decrease in social welfare.

For some values of the parameters there may not be any \( x \) such that \( W^c > W^{nc} \). For the rest of the values of the parameters we obtain \( W^c > W^{nc} \) for \( x \) low or for intermediate values of \( x \). As \( g(x)/h(x) \) increases with \( x \) we do not obtain \( W^c > W^{nc} \) for high values of \( x \). We may obtain \( W^c > W^{nc} \) for intermediate values of \( x \) as \( N(x) \) may decrease with \( x \) or increase for low values of \( x \) and increase for high values of \( x \).

To obtain \( W^c > W^{nc} \) we need \( v/z > N(x) \). When \( v/z < N(x) \) the MNC does not sell any unit in period 2 when market size decreases. The situation is analogous to a situation where the MNC had the ability to commit to sell nothing in period 2 if market size decreased in that period. Through his first-period production, the MNC obtains this equivalence with commitment ability in the case of a decrease in market size. Hence, when \( v/z < N(x) \) it is as if the difference in commitment ability between the MC and the MNC were reduced. To obtain \( W^c > W^{nc} \) the MNC must produce new units in period 2 even if market size decreases and, thus, face the Coase problem also in that case. This requires \( v/z > N(x) \).

From Proposition 2 we have that \( W^c > W^{nc} \) requires not only \( v/z > N(x) \) but also \( 3e/4f > g(x)/h(x) \). As \( v/z = g(0)/h(0) \) and \( g(x)/h(x) \) increases with \( x \), the latter condition implies a low enough probability of an increase in market size in period 2 and \( v/z \) relatively small with respect to \( elf \). Moreover, we can establish the following proposition that considers also the possibility of an increase in consumer surplus when the monopolist seller can commit.

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\(^{10}\)When \( v/z = N(x) \) we know that the MNC is indifferent between the solutions in parts (i) and (ii) of Proposition 1. If the MNC chooses the solution in part (i) it will be \( W^c < W^{nc} \). However, when the MNC decides the solution in part (ii) it will be \( W^c > W^{nc} \) if \( 3e/4f > g(x)/h(x) \).
Proposition 3: The equilibrium under a monopolist seller with commitment power may Pareto-dominate the equilibrium under a monopolist seller without commitment ability.

Proof: See the Appendix.

When the equilibrium under an MC Pareto-domines the equilibrium under an MNC, it may be advisable to establish a mechanism allowing the monopolist to get commitment ability (analogously, a regulation inducing a monopolist without commitment ability to sell the durable good may be less advisable).

APPENDIX

Proof of Proposition 1

Let \( i - jy_2 \) denote the demand function for the services of the good in the second period. The monopolist’s profits in that period will be \((i - jy_2)q_2\) where \( y_2 = \min\{q_1 + q_2, \frac{i}{j}\} \). Therefore, the production level that maximizes the monopolist’s profits in the second period will be \( q^*_2 = \max\{0, (i - jq_1)/2j\} \).

In the first period the monopolist will produce the quantity that maximizes the present value of his profits. Since consumers have rational expectations and are risk neutral, the sale price of period 1 equals the sum of the rental value for period 1 and the discounted expected sale price of period 2. Thus, the monopolist will solve the following problem:

\[
\max_{q_1} (e - fq_1)q_1 + \delta x (b - ay_2) y_2 + \delta (1 - x) (v - z y_2) y_2
\]

subject to

\[
y_2 = \min\{q_1 + q^*_2, \frac{i}{j}\} = \min\{q_1 + \max\{0, \frac{i - jq_1}{2j}\}, \frac{i}{j}\}
\]

As the quantity produced in the first period will be lower than \( b/a \) (otherwise the monopolist’s profits would be zero), we must consider two possibilities: \( q_1 \leq v/z \) and \( q_1 \geq v/z \).

(i) If \( q_1 \leq v/z \), the monopolist’s profits are

\[
(e - fq_1)q_1 + \delta \left[ x \frac{b - aq_1}{2} + (1 - x) \frac{v - zq_1}{2} \right]
\]

and the period 1 production that maximizes those profits is

\[
q_1 = \min\left\{ \frac{2e}{4f + \delta h(x)}, v/z \right\}
\]

(ii) If \( q_1 \geq v/z \), the monopolist’s profits are

\[
(e - fq_1)q_1 + \delta x \frac{b - aq_1}{2} + (1 - x) \frac{v - zq_1}{2} + \delta (1 - x) \frac{v - zq_1}{2}
\]

\[q_1 = \min\left\{ \frac{2e}{4f + \delta h(x)}, v/z \right\}
\]
and the period 1 production that maximizes those profits is

\[ q_1 = \max \left\{ \frac{2e}{4f + \delta xa}, \frac{v}{z} \right\} \]

Given that

\[ \frac{2e}{4f + \delta xa} > \frac{2e}{4f + \delta h(x)} \]

we can draw the following conclusions.

(a) If

\[ \min \left\{ \frac{2e}{4f + \delta h(x)}, \frac{v}{z} \right\} = \frac{v}{z} \]

then \( q_1 = 2e/(4f + \delta xa) \) and the monopolist’s profits will be

\[ \pi^{nc} = \frac{e^2}{4f + \delta xa} + \delta x \frac{b^2}{4a} \]

(b) If

\[ \max \left\{ \frac{2e}{4f + \delta xa}, \frac{v}{z} \right\} = \frac{v}{z} \]

then \( q_1 = 2e/[4f + \delta h(x)] \) and the monopolist’s profits will be

\[ \pi^{nc} = \frac{e^2}{4f + \delta h(x)} + \delta x \frac{b^2}{4a} + \delta (1 - x) \frac{v^2}{4z} \]

(c) If

\[ \frac{2e}{4f + \delta xa} > \frac{v}{z} > \frac{2e}{4f + \delta h(x)} \]

by comparing

\[ \frac{e^2}{4f + \delta xa} + \delta x \frac{b^2}{4a} \]

and

\[ \frac{e^2}{4f + \delta h(x)} + \delta x \frac{b^2}{4a} + \delta (1 - x) \frac{v^2}{4z} \]

we may conclude that if

\[ \frac{v}{z} < \frac{2e}{\sqrt{(4f + \delta xa)[4f + \delta h(x)]}} \]

then

\[ q_1 = \frac{2e}{4f + \delta xa} \quad \text{and} \quad \pi^{nc} = \frac{e^2}{4f + \delta xa} + \delta x \frac{b^2}{4a} \]
whereas if
\[
\frac{\nu}{z} > \frac{2e}{\sqrt{(4f + \delta xa)(4f + \delta h(x))}}
\]
then
\[
q_i = \frac{2e}{4f + \delta h(x)} \quad \text{and} \quad \pi_c = \frac{e^2}{4f + \delta h(x)} + \delta x \left(\frac{b^2}{4a} + \delta (1 - x)\right) \frac{v^2}{4z}
\]
As
\[
\frac{2e}{4f + \delta xa} > \frac{2e}{\sqrt{(4f + \delta xa)(4f + \delta h(x))}} > \frac{2e}{4f + \delta h(x)}
\]
the proposition follows.

**Proof of Proposition 2**

We have
\[
W^c = \frac{3e^2}{8f} + \delta x \left(\frac{3h^2}{8a} + \delta (1 - x) \frac{3v^2}{8z}\right)
\]
and

if \(v/z < N(x)\):
\[
W^{nc} = \frac{1}{8}\left(12e^2 + 4\delta x be\right) + \delta x \left(\frac{3h^2}{8a} + \delta (1 - x) \frac{4v^2}{8z}\right)
\]
if \(N(x) < v/z\):
\[
W^{nc} = \frac{1}{8}\left[12e^2 + 4\delta eg(x)\right] + \delta x \left(\frac{3h^2}{8a} + \delta (1 - x) \frac{3v^2}{8z}\right)
\]

From the expressions above it is clear that \(W^c < W^{nc}\) if \(v/z < N(x)\) as
\[
W^{nc} - W^c = \frac{\delta x e (4hf - 3ea)}{8 f (4f + \delta xa)} + \delta (1 - x) \frac{v^2}{8z} > 0
\]
To compare \(W^c\) and \(W^{nc}\) when \(N(x) < v/z\) we have
\[
W^{nc} - W^c = \frac{-3\delta e^2 h(x) + 4\delta ef g(x)}{8 f [4f + \delta h(x)]}
\]
Hence, we have
\[
W^c \equiv W^{nc} \iff \frac{3e}{4f} \geq \frac{g(x)}{h(x)}
\]

**Proof of Proposition 3**

When \(N(x) < v/z\) and \(3e/4f \geq g(x)/h(x)\) we have \(W^c > W^{nc}\) and
Therefore,

$$\text{CS}^e \equiv \text{CS}^\infty \iff e \leq \frac{g(x)}{4f} \leq \frac{h(x)}{h(x)}$$

As we always have $\pi^e > \pi^\infty$, the equilibrium under an MC will Pareto-dominate the equilibrium under an MNC when $\forall z > N(x)$ and $e/4f > g(x)/h(x)$.

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