Monopoly Pricing With Network Externalities

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How should a monopolist price a new durable good or technology which is subject to network externalities? In particular, should the monopolist set a low introductory price to attract a "critical mass" of adopters? In this paper, by means of a series of stylized models, we provide intuition as to when and why introductory pricing might occur in the presence of network externalities. Incomplete information about demand, asymmetric information about costs or difficulties in coordination are necessary in order for introductory pricing to occur at a subgame perfect equilibrium.

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1 Introduction

How should a monopolist price a new durable good or technology which is subject to network externalities? In particular, should the monopolist set a low introductory price to attract a “critical mass” of adopters? The economics literature focusing on these seemingly important questions is surprisingly sparse. In this paper, by means of a series of stylized models, we provide intuition as to when and why introductory pricing can occur in the presence of network externalities.

We draw from three lines of research in this paper. First is the growing literature on the adoption of innovations with network externalities. Farrell and Saloner (1985), Arthur (1989), and others examine equilibrium adoption of “unsponsored” (or nonproprietary) innovations, thus ignoring the issue of pricing. Katz and Shapiro (1985, 1986), on the other hand, consider the pricing of competing “sponsored” (or proprietary) innovations. In a two-period model they show that low first period prices might indeed be an equilibrium: however, introductory pricing results from duopoly competition, not from the monopolist’s desire to induce a critical mass of adopters.

The second line of research is the vast literature that endeavors to determine how general is the so-called “Coase conjecture,” after the seminal paper by Coase (1972) on the pricing problem facing a monopolist who sells a durable good.¹ Coase claims that, the price set by a monopolist who is unable to commit to future prices quickly converges to marginal cost as the interval between successive selling periods becomes very short. The Coase conjecture was confirmed and disconfirmed under a variety of conditions. In all cases the equilibrium solutions obey what Fudenberg and Tirole (1991) call “Coasian dynamics.” Coasian dynamics consist of two properties: (i) higher valuation adopters make their purchase no later than lower valuation adopters (*the skimming property*) and (ii) equilibrium price is nonincreasing

¹Stokey (1981); Bulow (1982); Sobel and Takahashi (1983); Fudenberg, Levine and Tirole (1985); Ausubel and Deneckere (1986); Gul, Sonnenschein and Wilson (1986); Kahn (1986); Bagnoli, Salant and Swierzbinski (1989); Von der Fehr and Kühn (1991); Karp (1992); Kühn and Padilla (1992).

over time (*the price monotonicity property*). In this paper, we show that the second property does not always hold when network externalities exist.

Third, the marketing science literature has examined pricing with “experience” or “network” effects.² In these papers, typically buyers are assumed to behave according to some rule which is not necessarily rational or they are imperfectly informed about the existence or the quality of the good. By contrast, we assume that buyers are rational agents. Furthermore, the models we present exhibit introductory pricing *only if network externalities are present*. In this way we are able to isolate the possible effects of network externalities on introductory pricing.

Specifically, we consider a rational monopolist selling a durable with network externalities to a series of rational buyers. The main question we attempt to answer is whether there exist equilibria for which prices are increasing over time. Since our main purpose is to derive possibility results, and to develop their intuition, we present our ideas in a sequence of simple examples. In each, a monopolist sells a durable good in two periods to a finite number of consumers.

In Section 2, we present two examples which assume no uncertainty about demand or costs. We construct equilibria in which a high-valuation consumer buys in the first period and low-valuation consumers buy in the second period at a higher price. We also argue why these equilibria may not be entirely compelling.

In Section 3, we assume that the monopolist is uncertain about consumers’ valuations. We find an equilibrium in which prices increase in expected value, though it is possible that prices will fall for particular demand realizations. We thus find a mixture of introductory pricing and Coasian ‘type’ intertemporal price discrimination.

Finally, in Section 4, we let the firm’s cost be unknown to buyers. Again, we find a perfect Bayesian equilibrium in which prices rise over time. In

²Bass (1980), Clarke, Darrough and Heineke (1982), Kalish (1983), Besanko and Winston (1990).

Table 1: Consumer valuations.

Buyer	Type	Number of adopters		
		1	2	3
1	H	$\bar{v}$	$\bar{v}$	$u + \bar{v}$
2	L	$\underline{v}$	$\underline{v}$	$u + \underline{v}$
3	L	$\underline{v}$	$\underline{v}$	$u + \underline{v}$

this case, introductory prices serve as a signal of low cost, in a way that is analogous to Bagwell (1985).

2 The Certainty Case

We begin with an example that has no demand, cost, or quality uncertainty. The monopolist, nevertheless, is unable to distinguish different types of buyers, either because it cannot observe some individual characteristic, or because it is precluded from first-degree price discrimination.

Each buyer's valuation for the durable good depends on his type as well as on the number of other buyers who purchase the good—the essence of a network externality. In general, the benefit received by a consumer of type i during period t is given by $u_{it} = u(i, N_t)$, where N_t is the number of adopters by time t .

Suppose the monopolist sells in two periods to three potential consumers. The potential buyers' valuations are given in Table 1, where $\bar{v} \geq \underline{v} \geq 0$ and $u \geq 0$. There are two types of buyers: H-types have a uniformly higher willingness to pay than L-types. Notice that the incremental utility from the network externality, u , is the same for both types. The values correspond to total valuations; per period benefits are thus given by $(1 - \delta)$ times the value in Table 1, where δ is the discount factor; furthermore, the present value of an adoption in the second period is equal to δ times the present value of an adoption in the first period.

Throughout the paper, we will assume that the seller cannot commit to future prices. We will also assume that production costs are zero.

A useful benchmark to be first considered is the familiar case of a durable goods monopoly with no network externalities, that is, $u = 0$. Given the durability of the good, buyers anticipate that the seller will cut price in the second period should they refuse to buy in the first. In fact, one can show that, if $\bar{v} < 3\underline{v}$, then the monopolist's optimal strategy is to set the first period price at $p_1 = \delta\underline{v} + (1 - \delta)\bar{v}$ and the second period price at $p_2 = \underline{v}$ (regardless of the number of sales in the first period).³ If, on the other hand, $\bar{v} > 3\underline{v}$, then the seller's optimal strategy is to set $p_1 = \bar{v}$; and $p_2 = \bar{v}$ if no purchase was made in the first period, $p_2 = \underline{v}$ otherwise.⁴ Notice that $p_1 \geq p_2$: in the absence of network externalities, equilibrium prices decline over time.

With network externalities the patterns may change. In particular, equilibria exist in which (undiscounted) prices may rise over time.

Proposition 1 *If*

$$2\underline{v} < \bar{v} - \underline{v} < (1 - \delta)u, \quad (1)$$

then there exists a subgame perfect equilibrium such that prices increase over time.

Proof: We prove the proposition by choosing strategies for the H-type consumer, the two L-types, and the monopolist, which together constitute an equilibrium:

- The H-type buys in period 1 if and only if $p_1 \leq \bar{v} + \delta u$. In period 2, he makes a purchase if one of the following is true:⁵

³In the case we consider, and if $\bar{v} < 3\underline{v}$, the Coase conjecture holds, in the sense that $p_1 \rightarrow \underline{v}$ as $\delta \rightarrow 1$.

⁴Since we are dealing with a finite number of types, if the monopolist could set prices for an indefinite number of periods and were able to discriminate between consumers, then he would optimally set $p = \bar{v}$ until one sale was made (to the highest value consumer), and set $p = \underline{v}$ thereafter, thus extracting all of the buyers's surplus (this strategy is optimal regardless of the relation between $\underline{v}$ and $\bar{v}$). This corresponds to the "Pacman" strategy, in the words of Bagnoli, Salant and Swierzbinski (1989).

⁵Since we assume that each adopter makes at most one purchase, an additional condition for a purchase in period 2 by some given agent is that the same agent made no purchase in period 1. For simplicity, this condition is assumed to be satisfied throughout.

- no purchase was made in period 1 and $p_2 \leq \bar{v}$;
 - one purchase was made in period 1 and $p_2 \leq u + \underline{v}$;
 - two purchases were made in period 1 and $p_2 \leq u + \bar{v}$.
- The L-types buy in period 1 if and only if $p_1 \leq \delta u + \underline{v}$. In period 2, they make a purchase if one of the following is true:
 - one or more purchases were made in the first period and $p_2 \leq u + \underline{v}$;
 - no purchase was made in the first period and $p_2 \leq \underline{v}$;
 - The seller sets $p_1 = \delta u + \bar{v}$ and
 - if one or more purchases were made in period 1, sets $p_2 = u + \underline{v}$;
 - if no purchase was made in period 1, sets $p_2 = \bar{v}$.

To see that these strategies form a Nash equilibrium, notice first that The H-type consumer gets an equilibrium payoff of zero. If he were not to purchase in the first period, then the period 2 price would be set to $p_2 = \bar{v}$ and his would be the only purchase, so he wouldn't be able to get better than a zero payoff.

Now consider the L-types' strategy at any period 2 subgame. Although the designated strategies are not the only strategies that constitute an equilibrium (because of network externalities), they certainly do constitute an equilibrium. As to the L-types' strategy in period 1, we can see that a deviation would imply buying at price $p_1 = \delta u + \bar{v}$. This would yield a net utility of $\delta u + \underline{v} - (\delta u + \bar{v})$, which is negative, whereas the equilibrium payoff is zero.

Finally, let us check that the monopolist's strategy is optimal. If no purchase was made previously, then the first inequality in (1) implies that it is more profitable to set $p_2 = \bar{v}$ (yielding $\Pi = \bar{v}$) in the second period than it is to set $p_2 = \underline{v}$ (yielding $\Pi = 3\underline{v}$). In the first period, the only possible alternative price would be $p_1 = \delta u + \underline{v}$, yielding $\Pi = 3(\delta u + \underline{v})$. In equilibrium, however, the seller gets $\Pi = \delta u + \bar{v} + \delta 2(u + \underline{v})$, which is greater

than $3\delta u + \bar{v}$, which in turn is greater than the optimal deviation profit, by the first part of (1).

To conclude, we note that the second inequality in (1) implies that the second period price is greater than the first period price. ■

A closer examination of the strategies which support the equilibrium reveal the importance of network externalities. Due to these externalities, it is in the interest of the two L-type consumers to coordinate their purchases. This desire for coordination implies the existence of multiple equilibria. Specifically, in the case considered, the L-type strategies call for selecting the “good” equilibrium (making a purchase) in period 2 but not in the period 1.⁶

Notice that in this example, although undiscounted prices are increasing, discounted prices are decreasing. Nevertheless, the multiplicity of subgame equilibria under network externalities is sufficiently broad to include equilibria with increasing discounted prices. A minimum of four potential adopters is needed for this purpose. The idea is that one adopter buys in the first period and three in the second period. Increasing discounted prices constitutes an equilibrium because if a period-2 buyer deviates (by anticipating purchase) the remaining two adopters punish him by choosing the “bad” period-2 subgame equilibrium.

Thus, we now assume there are four potential adopters, one A type and three B types. The A-type adopter has a positive stand-alone valuation but gains nothing from network externalities; the B-type adopters have no stand-alone valuation but receive positive network benefits. It is crucial for the result that, unlike the previous example, different types derive different utility from the network effect. Valuations are given in Table 2.

Proposition 2 *If $v < \delta u$, then there exists a subgame perfect equilibrium such that discounted prices increase over time.*

⁶Although we are considering time-dependent strategies, the result would also hold under Markov strategies in an infinite horizon game with a state defined by the cumulative number of adopters—whether or not their identities matter.

Table 2: Consumer valuations.

Buyer	Type	No. adopters	
		1 to 3	4
1	A	v	v
2	B	0	u
3	B	0	u
4	B	0	u

Proof: We prove the proposition by choosing strategies for the A-type consumer, the three B-types, and the monopolist which together constitute an equilibrium:

- The A-type buys as soon as price is lower than v .
- The B-types buy in period 1 if and only if $p_1 \leq 0$. In period 2, they make a purchase if and only if either of the following is true:
 - the A-type alone or the A-type and two B-types made a purchase in period 1 and $p_2 \leq u$;
 - some other pattern of purchases occurred during period 1 and $p_2 \leq 0$;
- The seller sets $p_1 = v$ and
 - $p_2 = u$ if the A-type made a purchase in period 1,
 - $p_2 = v$ if the A-type did not make a purchase in period 1.

The equilibrium outcome resulting from the play of these strategies is that the A-type buys in period 1 at $p_1 = v$ and the B-types all buy in period 2 at price $p_2 = u$. The condition of the proposition ensures that $p_1 < \delta p_2$.

To see that the designated strategies form a subgame perfect Nash equilibrium, notice first that the A-type gets a zero equilibrium payoff, the same he would get if he were to deviate ($p_2 = p_1$ if he does not make a purchase in period 1).

The B-types' strategies at any period-2 subgame clearly constitute a Nash equilibrium: either all adopt, and the willingness to pay is u , or not all adopt, and the willingness to pay is zero. Notice that the multiplicity derived from network externalities plays here a very important role. Now consider the B-types' strategy in period 1. A deviation would imply buying at price $p_1 = v$. However, given the equilibrium strategies, and given that this would be a unilateral deviation, no additional purchases would be made in period 2, and thus the deviation payoff would be $-v$, whereas the equilibrium payoff is zero.

Finally, let us check that the monopolist's strategy is optimal. In period 2, and assuming that the A-type did not purchase in period 1, $p_2 = v$ extracts the most surplus the monopolist can get from the A-type; to attract additional buyers, he'd have to set $p_2 \leq 0$, which would clearly result in a lower payoff. A similar reasoning applies to the various possibilities that include a purchase by the A-type in period 1.

Similarly, in period 1, $p_1 = v$ extracts the most surplus the monopolist can get from the A-type; and to get more buyers, he'd have to set $p_2 \leq 0$, which would clearly result in a lower payoff. ■

As we stated above, most of the power of the increasing-prices examples is derived from multiplicity of equilibria, which, in turn, is a consequence of network externalities. In fact, it can be shown that for *any* positive value of u there exists a continuum of equilibria. To see why, consider a simple model with one period only and two potential adopters. Each potential adopter has a valuation v if he is the sole adopter and $u + v$ if both adopt. Now suppose each buyer selects the strategy "buy if and only if price is less than or equal to $\hat{p}$." Suppose the seller sets $p = \hat{p}$. One can easily see that, for every $v \leq \hat{p} < u + v$, these strategies form an equilibrium, in fact, a subgame perfect Nash equilibrium.

There are several ways one might reduce this multiplicity of equilibria. One is to consider an equilibrium refinement. For example, if we consider

the concept of strong equilibrium (Aumann, 1959) or that of coalition-proof equilibrium (Bernheim, Peleg and Whinston, 1987), then a single equilibrium would arise: $p = u + v$ and both consumers buy the product.⁷ Applying the Harsanyi and Selten (1988) concept of risk-dominance we would, again, select a single equilibrium, this time with $p = u/2 + v$ and both consumers making a purchase.⁸

A more interesting way of reducing the multiplicity of equilibria is to change the structure of the game. Again, suppose there are two potential buyers, with valuations as in the previous paragraphs. But now suppose the seller is allowed not only to offer a simple sale contract but also a price schedule, $p(n)$, in which price is contingent on the number of purchases, n . Then one can easily check that there exists an (essentially) unique Nash equilibrium: the seller sets the price schedule, $p(1) = u + v$ and $p(0) < v$; each buyer makes a purchase.⁹

Whichever criterion is used, it can be shown that all surviving equilibria exhibit the usual properties of Coasian dynamics, namely that of decreasing prices. This reinforces the idea that, if there is no demand or cost uncertainty, increasing prices can only occur under somewhat unreasonable equilibria. In the remainder of the paper, we will consider only "reasonable" equilibria, and focus on the issues of demand and cost uncertainty.

3 Incomplete information about demand

In this section, we examine the possibility of introductory pricing in the context of a model with incomplete information.

Once again, consider a monopolist selling in two periods. There are two potential buyers. Each buyer's valuation depends on his type (of which there can be three) and on the number of other buyers, according to the values

⁷The concepts of strong equilibrium and coalition-proof equilibrium coincide in the case of symmetric two-player games. This is not generally the case, however.

⁸ $p = u/2 + v$ is the highest price such that each consumer (weakly) prefers to make a purchase given the expectation that the other consumer will make a purchase with a 50% probability.

⁹See Dybvig and Spatt (1983) for a closely related approach.

Table 3: Consumer's valuations.

buyer type	probability	Number of adopters	
		1	2
H	1/3	$\bar{v}$	$u + \bar{v}$
M	1/3	$\underline{v}$	$u + \underline{v}$
L	1/3	0	u

in Table 3. The buyer's type is private information. The monopolist's prior distribution has equal weight on each type, and this is common knowledge.

Let p_1 be the monopolist's first-period price and p_2^n the second-period price given that n purchases were made in period one. Since there are only two potential adopters, we only have to concern ourselves with p_2^0 and p_2^1 . We showed in the last section that network externalities create the possibility of multiple equilibria which can, in turn, give rise to equilibria with introductory pricing. Since we now want to concentrate on the effect of demand uncertainty, we assume that the Pareto superior equilibrium is chosen in any subgame which has multiple equilibria. From the last section, one can see that this assumption implies that equilibrium prices must decline in the absence of demand uncertainty. With demand uncertainty, however, introductory pricing may reappear.

Proposition 3 *If $\underline{v} > \frac{3}{2}u$ and $\delta \approx 1$, then there exists a Perfect Bayesian equilibrium such that*

$$p_2^0 < p_1 < p_2^1. \quad (2)$$

The first inequality is price-skimming and the second one is introductory pricing. Furthermore,

$$p_1 < E(p_2^i \mid i < 2), \quad (3)$$

that is, the first-period price is lower than the expected second-period price (conditional on fewer than two sales having occurred in the first period), so that introductory pricing occurs in expected value.

Proof: We make the equilibrium hypothesis that there is separation, specifically, that, in equilibrium, only the high types buy in the first period.

If one adoption occurs in the first period, then the optimal price in period two is either $p_2^1 = u + \underline{v}$ or $p_2^1 = u$. Since the posterior probability that the buyer is of medium and low type is $1/2$ each, expected profits are given by $u + \underline{v}$ and $2u$, respectively. Since $\underline{v} > u$, by hypothesis, we conclude that the first alternative is better, that is, $p_2^1 = u + \underline{v}$.

Consider now the case when no adoption occurs in the first period. The candidate prices are $p_2^0 = u/2 + \underline{v}$ and $p_2^0 = u$. By a similar reasoning, we conclude that $p_2^0 = u/2 + \underline{v}$.

Now consider the optimal price in the first period, p_1 . Since we have assumed separation, this price should be such that the high-valuation type is indifferent between purchasing in the first period and purchasing in the second period. This implies

$$\bar{v} + \frac{1}{3}u + \frac{1}{3}\delta u - p_1 = \delta\bar{v} + \frac{1}{3}\delta u + \frac{1}{3}\delta u - \frac{1}{3}\delta p_2^1 - \frac{1}{3}\delta p_2^0. \quad (4)$$

For $\delta \approx 1$, we get

$$p_1 \approx \frac{1}{3}p_2^1 + \frac{2}{3}p_2^0. \quad (5)$$

Since $p_2^0 < p_2^1$, it follows that $p_2^0 < p_1 < p_2^1$. Furthermore, given that, conditional on less than two sales occurring in the first period, p_2^0 and p_2^1 occur each with probability $1/2$, we conclude that

$$p_1 < \frac{1}{2}p_2^0 + \frac{1}{2}p_2^1 = E(p_2^i | i < 2). \quad (6)$$

Finally, we have to check that the candidate equilibrium strategy is optimal from the monopolist's perspective. Along the equilibrium path, the monopolist's profits are given by

$$\frac{1}{9}2p_1 + \frac{1}{9}2\delta p_2^0 + \frac{1}{9}0 + \frac{2}{9}(p_1 + \delta p_2^1) + \frac{2}{9}p_1 + \frac{2}{9}\delta p_2^0 \quad (7)$$

or simply

$$\frac{6}{9}p_1 + \frac{2}{9}\delta p_2^1 + \frac{4}{9}\delta p_2^0. \quad (8)$$

If $\delta \approx 1$, then, substituting the expressions above, we get that profits are approximately equal to

$$\frac{12\underline{v} + 8u}{9}. \quad (9)$$

It is easy to see that the best potential alternative from the monopolist's perspective is to set a price schedule such that medium-valuation types prefer to buy in the first period.¹⁰ If that happens, it will always be the case (in equilibrium) that the remaining types in the second period are low-valuation types. Therefore, $p_2^0 = p_2^1 = u$ is the subgame-perfect strategy. The most the monopolist can charge in the first period is then given by the indifference condition for a medium-valuation buyer

$$\underline{v} + \frac{2}{3}u + \frac{1}{3}\delta u - p_1 = \delta(u + \underline{v} - u). \quad (10)$$

As $\delta \approx 1$, we see that $p_1 \approx u$. Therefore, equilibrium profits are approximately equal to $2u$. But, given that we assume $\underline{v} > 3/2u$, we see that this is less than the value given by (9). ■

There is an interesting similarity between the equilibrium just described and the equilibrium presented in Farrell and Saloner's (1985) game of adoption with network externalities. In both cases, medium-valuation adopters play "bandwagon" strategies: to adopt (or buy) in the second period if and only if an adoption (purchase) was made in the first period. The main difference between the two models is that in Farrell and Saloner (1985) there is an unsponsored new technology, whereas we consider a monopolist selling that new technology.

¹⁰The other alternative would be to set $p_1 = u$ which would lead all types to purchase in the first period and yield a profit $\Pi = 2u$ to the monopolist. As we will see below, this is lower than what the monopolist can get by discriminating between buyers.

Table 4: Consumer's willingness to pay.

buyer type	probability	Number of adopters	
		1	2
H	α	v	$u + v$
L	$1 - \alpha$	0	u

4 Asymmetric information about cost

Our last example considered asymmetric information about production costs. Here we suppose consumers are not perfectly informed about the seller's costs. Since we want to concentrate on the effects of asymmetric information, we avoid the issue of consumer's timing of purchases by assuming that the monopolist is selling to two consumers who arrive sequentially. Each consumer can be of two types, high valuation and low valuation, with probability α and $1 - \alpha$, respectively. A high valuation consumer has a utility of v if he is the only one to buy the product and $u + v$ if both consumers buy the product. A low valuation consumer has zero utility if he is the only one to buy the product and u if both consumers buy the product (cf Table 4). Utilities are realized after both adoption decisions have been made. (Again, this simplification is made with the sole purpose of isolating the effect of asymmetric information about cost.)

Finally, the seller can be of two types, high cost (c) and low cost (zero). The seller's cost is unknown to buyers.¹¹

Proposition 4 *Suppose that*

$$\frac{u - c}{u + v - c} < \alpha < \frac{u}{u + v} \quad (11)$$

and that

$$\alpha u < \alpha(2\alpha - 1)u + \alpha v + (1 - \alpha)c < u. \quad (12)$$

¹¹Since we consider equilibria with separation, the probability that the seller's cost is low is irrelevant (so long as it is positive).

Then, there exists at least one Perfect Bayesian Equilibrium with separation (i.e., different types of firms setting different prices in the first period). Furthermore, every equilibrium with separation has the property that the low-cost firm sets an introductory price.

Before proceeding with the proof, it is worth noting that the set of parameter values determined by (11-12) is non-empty. To do so, it suffices to check that $u = c = 2, v = 1, \alpha = 1/2$ satisfy all conditions.

Proof: Since we are interested in finding Perfect Bayesian Equilibria, we will begin by considering the monopolist's problem in the second period. Suppose that the first-period consumer has bought the good. Then, expected profits in the second period for the high-cost monopolist will be $\alpha(u + v - c)$ if he sets a high price ($p_2 = u + v$), and $u - c$ if he sets a low price ($p_2 = u$). (One can easily check that no other price can be optimal for the seller.) By the first part of (11), we conclude that it is optimal for the high cost monopolist to set a high price in the second period, so that a second adoption occurs with probability α conditional on a first adoption having occurred.

A similar problem arises for the low-cost firm, with the difference that production cost is zero. Given the second part of (11), we conclude that it is optimal for a low cost firm to set price equal to u in the second period, so that a second adoption occurs with probability one conditional on a first adoption having occurred.

Finally, if no purchase has occurred in the first period, then both types of firms set $p_2 = v$.¹²

Condition (11) is crucial for the equilibrium which we will derive. If the first-period consumer believes the firm to be of low cost, then he will expect a low price to be set in the second period, and a second adoption to occur with probability one. This implies that his expected valuation (and willingness

¹²If $v < c$, then the high-cost firm sets $p_2 = c$. In what follows, we will assume that $v > c$. The result does not depend on this condition, although (11-12) would appear somewhat different.

to pay) equals $u + v$ (or simply u , if he is a low-valuation type). If, on the contrary, the consumer believes the seller to be of a high-cost type, then his expected valuation is only $\alpha u + v$ (or αu , if he is a low-valuation type).

If there is no uncertainty about the firm's costs, then the optimal price for the first period is easy to derive. A low-cost firm will set a price equal to u , whereas a high-cost firm will set a price equal to $\alpha u + v$. Notice that the first-period price set by a low-cost firm is equal to its second period price, that is, introductory pricing does *not* occur. Also, the *expected* second-period price set by a high-cost firm is equal to the price set in the first period.

We construct equilibria with separation, that is, equilibria in which different types of sellers set different first-period prices. In equilibrium, if each seller sets the designated price, consumers will form a posterior belief which assigns probability one to the respective type. If any out-of-equilibrium price is set, then —we assume— consumers believe the probability that the firm has high cost is one.

Given this, the conditions for an equilibrium include: (i) A high-cost firm has no incentive to imitate a low cost firm by setting price at the level a low cost firm would choose, nor would a high cost firm set any other price which consumers would interpret as indicating the firm has high costs; (ii) A low-cost firm has no incentive to set any price different from the designated price, given that it would then be believed to be a high-cost type.

Suppose that, in the first period, the high-cost firm sets a price $p^H = \alpha u + v$, and let p^L denote the first-period price set by the low-cost firm at the equilibrium we construct.

To check condition (i), we have to consider two possible deviation prices for the high-cost firm. One is for it to set a price equal to the low-cost firm's equilibrium price. The equilibrium condition then becomes

$$\alpha(\alpha u + v - c + \alpha(u + v - c)) + (1 - \alpha)\alpha(v - c) \geq p^L - c + \alpha(u + v - c), \quad (13)$$

assuming that $p^L < u$. The left-hand side of (13) gives the expected profit for a high-cost firm which follows the designated equilibrium strategy, whereas

the right-hand side represents expected profit from imitating the low-cost firm: by setting a price equal to p^L , the high-cost firm is believed to be of low cost; and, if $p^L < u$, then both types will buy at this price *if they believe the seller to have low costs*, as they do in equilibrium.

Specifically, let p^L be such that (13) holds as an equality.¹³ Simplifying, one gets

$$p^L = \alpha(2\alpha - 1)u + \alpha v + (1 - \alpha)c, \quad (14)$$

so that the second part of (12) implies the equilibrium hypothesis $p^L < u$.

The second possible deviation price for the high-cost firm is αu . At this price, both types of consumers will buy in the first period. However, the first part of (12), together with (13), implies that this is not optimal. Intuitively, the idea is that, in equilibrium, the high-cost firm is following its first-best action. Therefore, if it is to deviate, it must be that the buyers' posterior is affected by the seller's deviation, which only occurs if price is set equal to p^L .

To check Condition (ii), it suffices to consider two possible values for the first-period price set by the high-cost firm: $p^H = \alpha u + v$ and $p^H = \alpha u$. The first possibility leads to the condition

$$p^L + u \geq \alpha(\alpha u + v + u) + (1 - \alpha)v, \quad (15)$$

which is implied by the second part of (12). The second possibility leads to

$$p^L + u \geq \alpha u + u, \quad (16)$$

which is equivalent to the first part of (12). ■

We should note that this equilibrium is very similar to that which appears in Bagwell (1989). In both cases the first-period price is lower than the

¹³There exists a continuum of separation equilibria with different low-cost-firm prices p less or equal to $\bar{p}$. The one we are considering is the unique separation equilibrium which survives Cho and Kreps' (1987) "intuitive" criterion. Note, however, that introductory pricing occurs in *any* separating equilibrium.

second-period price because firms want to signal their low cost. In both cases first-period consumers care about the seller's cost to the extent that their expectations about cost influence their expectations about future prices. However, in Bagwell's (1989) model, first-period consumers care about future prices because they plan to purchase from the same seller in the second period (repeat business), whereas in our model first-period consumers care about future prices to the extent that the probability of future purchases by *other* consumers depends on future prices.

5 Conclusion

We have constructed examples in which the pricing of a durable good possessing network externalities, or of access to a growing network, can exhibit penetration or introductory pricing. Coasian dynamics fail in that price can rise over time. Despite the stylized simplicity of the examples, we feel that this logic can be applied to explain promotional pricing in a wide variety of settings where network externalities are important.

Several issues remain to be answered. In particular, whether the Coase conjecture itself fails with network externalities is a question requiring further work. Although price can rise initially, it might still necessarily fall to marginal cost "in the twinkling of an eye" as the monopolist's commitment period becomes arbitrarily small.

References

- Arthur, B., "Competing Technologies, Increasing Returns, and Lock-In by Historical Events," *Economic Journal* 99 (1989), 116-131.
- Aumann, R., "Acceptable Points in General Cooperative n -person Games," in *Contributions to the Theory of Games IV*, Princeton: Princeton University Press, 1959.
- Ausubel, L., and R. Deneckere, "Reputation and Bargaining and Durable Goods Monopoly," *Econometrica* 57 (1989), 511-531.
- Bagnoli, M., S. Salant, and J. Swierzbinski, "Durable Goods Monopoly with Discrete Demand," *Journal of Political Economy* 97 (1989), 1459-78.
- Bagwell, K., "Introductory Price as a Signal of Cost in a Model of Repeat Business," *Review of Economic Studies* 54 (1989), 365-84.
- Bass, F., "The Relationship Between Diffusion Rates, Experience Curves, and Demand Elasticities for Consumer Durable Technological Innovations," *Journal of Business* 53:2 (1980), S51-S67.
- Besanko, D., and W. Winston, "Optimal Price Skimming by a Monopolist Facing Rational Consumers," *Management Science* 36:5 (1990), 555-67.
- Bernheim, D., D. Peleg, and M. Whinston, "Coalition-proof Nash Equilibria. I: Concepts," *Journal of Economic Theory* 42 (1987), 1-12.
- Bulow, J., "Durable-Goods Monopolies," *Journal of Political Economy* 90:2 (1982), 314-32.
- Cho, I.-K., and D. Kreps, "Signaling Games and Stable Equilibria," *Quarterly Journal of Economics* 102 (1987), 179-221.
- Clarke, F., M. Darrough, and J. Heineke, "Optimal Pricing Policy in the Presence of Experience Effects," *Journal of Business* 55:4 (1982), 517-31.

Coase, R., "Durability and Monopoly," *Journal of Law and Economics* 15 (1972), 143-149.

Dybvig, P.H., and C.S. Spatt, "Adoption Externalities as Public Goods," *Journal of Public Economics* 20 (1983), 231-247.

Farrell, J., and G. Saloner, "Standardization, Compatibility, and Innovation," *Rand Journal of Economics* 16 (1985), 70-83.

von der Fehr, Nils-Henrik Morch, "Coase vs. Pacman: Who Eats Whom in the Durable Goods Monopoly?" mimeo, March, 1991.

Fudenberg, D., D. Levine, and J. Tirole, "Infinite Horizon Models of Bargaining with One-Sided Incomplete Information," in A. Roth (Ed.), *Game-Theoretic Models of Bargaining*, Cambridge University Press, 1985.

Fudenberg, D., and J. Tirole, *Game Theory*, Cambridge, Mass.: MIT Press, 1991.

Gul, F., H. Sonnenschein, and R. Wilson, "Foundations of Dynamic Monopoly and the Coase Conjecture," *Journal of Economic Theory* 39 (1986), 155-190.

Harsanyi, J., and R. Selten, *A General Theory of Equilibrium Selection in Games*, Cambridge, Mass.: MIT Press, 1988.

Kahn, C., "The Durable Goods Monopolist and Consistency with Increasing Cost," *Econometrica* 54 (1986), 275-294.

Kalish, S. "Monopolistic Pricing with Dynamic Demand and Production Costs," *Marketing Science* 2 (1983), 135-59.

Katz, M., and C. Shapiro, "Network Externalities, Competition, and Compatibility," *American Economic Review* 75 (1985), 424-440.

Katz, M., and C. Shapiro, "Technology Adoption in the Presence of Network Externalities," *Journal of Political Economy* 94 (1986), 822-841.

Kuhn, K and J. Padilla, "Product Line Decisions and the Coase Conjecture,"

mimeo, 1992.

Sobel, J., and I. Takahashi, "A Multi-Stage Model of Bargaining," *Review of Economic Studies* 50 (1983), 411-426.

Stokey, N., "Intertemporal Price Discrimination," *Quarterly Journal of Economics* 94 (1979), 355-71.

Stokey, N., "Rational Expectations and Durable Goods Pricing," *Bell Journal of Economics* 12 (1981), 112-28.