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## **Dynamic Pricing of Genetically Modified Crop Traits**

by

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The issue considered here is the retail pricing of patented crop traits such as Roundup Ready herbicide resistance or Bt insect resistance. Our concern is not with the price of the seeds in which the traits are embodied, but rather with the implicit or explicit price for the traits themselves. Intellectual property rights are now available for traits, and while monopoly pricing of them has received some limited consideration in the economics literature<sup>1</sup>, no one has yet examined the possible implications of the durability of these traits as a factor in determining such monopolists' pricing behavior.

### **Monopoly pricing of durable goods**

The theory of monopoly pricing of durables traces to Coase (1972). He noted that when the seller of a new durable good sets a price in the first period, a fraction of potential customers will buy, but the remaining fraction still remain as potential customers in the next period. At a lower price in that next period, a fraction of the remainder will buy, and similarly for the period after that. The seller clearly has a strong incentive to exploit this kind of price discrimination through time. However, buyers will probably anticipate this behavior, and thus have an incentive to wait for next period's

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lower price. It is difficult for the seller to make a credible commitment that he will not reduce the price in the next period, given the obvious incentive to do so.

Thus Coase perceived a strategic game being played between the seller of the durable and his potential buyers. The seller's strategy for reducing future prices must be compatible with the buyers' incentives to wait for a lower price in the future. Buyers' incentive to wait can be weakened by a credible commitment that prices will not in fact fall in the future, but this credibility is difficult to establish. The outcome of the game, in terms of an equilibrium pricing strategy through time, is not obvious. Coase concluded that it is very likely that the equilibrium price will fall all the way to marginal cost (zero in the situations considered in this paper) in every period. In this case the monopolist earns no rents, let alone the "normal" monopoly rent obtainable by charging a single once-and-for-all monopoly price, or the even larger rent from intertemporal price discrimination. This conclusion has become known as the "Coase conjecture."

In this paper we first discuss the durability of crop traits and how it is determined by technological considerations and by intellectual property rights. We then consider an equilibrium pricing strategy emerging from a specific formulation of a pricing game that is dependent on the nature of intellectual property rights.

### **Technology, property rights, and the durability of crop traits**

For purposes of this analysis, a durable good is an input that provides a flow of services for more than one production cycle. When seed is purchased, the producer acquires a bundle of traits, each of which can be thought of as providing a flow of services for the current crop year, and if the flow of services of a trait extends beyond

that year, the trait may properly be considered a durable good. Varieties of crops such as soybeans and wheat are created by a recurrent selection process from which only phenotypically identical, self-replicating plants emerge. If seeds from such a crop are saved and replanted, the traits persist into subsequent years, and are thus durables. For crops such as corn, however, successful new cultivars are most often created by hybridization, produced by the crossing of two or more distinctly different genotypes. While the first generation of this cross is designed to be a highly uniform phenotypic population for the commercial crop, the traits expressed by subsequent generations can be disastrously heterogeneous. A trait expressed by a hybrid is therefore not a durable.

There are at least two other technological phenomena that may affect the durability of crop traits. The first is "terminator" technology, such as the Technology Protection System (TPS) owned jointly by Delta and Pine Land Co. and USDA. Terminator seeds either produce a crop of sterile seeds, or a crop of seeds in which the trait in question is switched off, in either case insuring that the trait at issue is not a durable. The second technology is apomyxis, currently being developed by Pioneer and CIMMYT, also not yet commercially viable. Apomyctic seeds produce a crop of viable seeds that are genetically identical to the maternal plant. Seeds saved from an apomyctic hybrid crop will replicate the commercial hybrid, thus insuring that all of the traits in the crop are durables.

However, even if a crop trait is technologically durable, the seller may be able to exclude a customer from future use of the trait. This possibility is determined by the system of intellectual property rights and enforcement mechanisms to which a technologically durable crop trait is subject. The two systems of intellectual property

rights that are relevant to crop traits are utility patents and plant breeders' rights (Plant Variety Protection or PVP in the U.S. and Union for the Protection of Varieties or UPOV in much of the rest of the world.) If a crop trait is protected by a utility patent, the seller will have the right to exclude the buyer from using the trait in subsequent years if he wishes to do so, whereas if it is protected by plant breeders' rights, the seller does not have that right (he only has the right to exclude the buyer from giving or selling the trait to other producers.) While utility patents are clearly the stronger form of property rights, they are not everywhere available, and they are more expensive to obtain. Within either system of property rights, however, the degree to which the seller is able to exclude future use of a durable trait depends on his enforcement effort and on the reliability and cost of the legal system through which enforcement takes place.

To summarize, if we have a trait that is technologically durable, the effect of patent protection is to allow the seller to exclude its use as a durable, while under breeders' rights the trait is a legal durable. We turn now to an analysis of how these alternatives might affect the sellers' choice of pricing strategy through time.

### **Property rights and the pricing of a non-durable crop trait**

We first consider the pricing of a non-durable trait, which is similar to the pricing problem facing any seller with a downward-sloping demand curve. Consider Fig. 1, for example, in which we present a demand curve that is derived from a schedule of heterogeneous users' valuations,  $v$ , of the expected benefit of a particular trait for one crop year on, say, one hectare. We have scaled the function so that the valuation of the highest-valuation user is set at 1.0, and the total number of users (or hectares) deriving

any benefit at all from the trait is also set at 1.0. The valuation curve  $v = 1 - q$  can reasonably be considered to be the demand curve facing the owner of the trait. We assume that the marginal cost of incorporating a trait in seed for additional crop area is essentially zero.

In this stylized case with linear demand, the trait owner maximizes profit by setting the standard monopoly price every year,  $p^* = 1/2$ , resulting in adoption (purchase) of the trait by  $q = 1/2$  of the potential users every year. The stream of monopoly rents realized is thus  $r^* = 1/4$ , with present value  $PV^* = k/4$ , where  $k$  is the capitalization rate, presumed here to be the present value of a  $T$ -year annuity starting one year from the present, or  $k = (1 - (1+i)^{-T})/i$ , where  $i$  is the discount rate.

Where property rights for the crop trait are not perfect and costless to enforce, the patent owner may not be able to exclude all pirating, or he may find it too costly to do so. The effective demand curve is not evident in this case. Deardorff (1992) and Perrin (1994) suggested that weakly-enforced property rights would result in payments only from some randomly-selected fraction  $\theta$  of potential customers. This proportional pirating model implies that the quantity demanded is fraction  $\theta$  of the quantity indicated by demand curve  $v$ , or line  $v^{pp} = 1 - q/\theta$  in Figure 2. The optimal monopolist price remains at  $p^*$ , but the optimal quantity to sell diminishes to  $\theta/2$ , the annual flow of rents falls to  $r^{pp} = \theta/4 = \theta r^*$ , and present value of rents falls to  $PV^{pp} = \theta k/4 = \theta PV^*$ .

Alternatively, Diwan and Rodrik (1991), followed by Perrin (1999), suggested that in the presence of weak property rights there is a limit royalty price, equal to some fraction  $\phi$  of the valuation for each customer, above which piracy would occur. This demand curve has height equal to fraction  $\phi$  of curve  $v$ , or line  $v^{lp} = \phi - \phi q$  in Figure 2.

The optimal monopolist price falls to  $\phi/2$ , while the optimal quantity to sell remains at  $1/2$ . The annual flow of rents is  $PV^{pp} = \phi k/4 = \phi PV^*$ , the same as for the proportional pirating case if the fractions  $\phi$  and  $\theta$  are equal. Giannakas (2000) suggests further that this limit pricing fraction  $\phi$  may be determined by the customer's expected cost of being caught pirating the trait, which is in turn determined by enforcement costs as well as by the nature of the patent system. This allows him to explore the static pricing of the trait within the framework of a regulatory game in which buyers, the monopolist, and the regulator are players.

The two theories above offer alternative explanations as to how a simple linear valuation schedule is transformed into the monopolist's derived demand curve when property rights are less than perfect. Neither is particularly persuasive, since it seems likely that potential customers' willingness to pirate is distributed in a way that is neither strictly random as implied by the first, nor strictly proportional to the expected benefit of pirating, as implied by the second. However, either approach is analytically convenient, and we will use the limit pricing approach in the analysis of durable pricing to follow.

### **Nash equilibrium pricing of durable traits**

We now consider an explicit theoretical model of Coase's durable goods pricing theory to examine what intertemporal pricing strategies might emerge, and how they would be affected by property rights. Here we seek a Nash equilibrium solution to the game, which will insure the credibility of the resulting time path because by definition, none of the players in the game will have an incentive to behave otherwise. We convert the one-year valuation curve of Figure 1 to a valuation curve for the durable good using

the capitalization rate  $k = (1 - (1+i)^{-T})/i$ . The durable good valuation curve is  $V = kv = k - kq$ , shown in Figure 3. Given this effective demand curve, the monopolist could charge some arbitrary price  $P_1$  for the durable the first year, then in the second year charge the monopolist price for the remaining portion of the demand curve,  $k/4$ , etc., and in this manner extract most of the consumers' surplus.

However, buyers will anticipate this reduction in price, and a buyer with valuation  $kv$  and discount factor  $\delta = 1/(1+i)$  will have an incentive to wait until next year to purchase if  $(V - P_t) < \delta(V - P_{t+1}^e)$ , where  $P_{t+1}^e$  is the price he expects to be charged for the durable next year. Given this buyer incentive to wait, just how much will the seller decide to charge the first year and how fast will the price fall? A considerable number of papers have been published establishing conditions under which Coase's zero-profit conjecture would hold (see Tirole, 1988, Ch 1.) Here we adapt a relatively simple model that Tirole in turn adapted from Sobel and Takahashi.

Consider first the case of plant breeders' rights with costless enforcement. If the monopolist could credibly establish that the trait would never be sold again, a one-time price  $P^* = k/2 = kp^*$  could be charged, maximizing profits by selling only to the half of customers with the highest valuations. But it is difficult for the owner to assert credibly that the trait will never be again, and if so the initial price must be compatible with the buyer's incentive to wait for next year's lower price. We assume here that buyers' strategy is to identify an optimal limit price fraction  $\lambda$  such that they will purchase if  $V = kv > \lambda P$ . The effective demand curve is then  $P^d = V/\lambda = k(1-q)/\lambda$  in Figure 3, similar to the limit-pricing demand curve of Figure 2. At the price marked  $P_1$ , buyers would purchase quantity  $q_1$ , realizing a surplus equal to the shaded area above the line  $P_1 = \mu k$ ,

leaving the monopolist the rent below it. We assume that the seller's strategy is to identify an optimal mark-down ratio,  $\mu$ , such that if the buyers with valuations above  $V = kv = k(1-q)$  have already purchased the trait and the others have not, then he will set the price at  $P = \mu V$ . This implies that the seller follows a pricing curve such as  $P_t^s = \mu V_{t-1} = \mu k(1-q_{t-1})$  in Figure 3. This seller's behavior implies that the seller will charge an initial price  $P_1 = \mu k$ . The buyers' behavior implies that the initial quantity purchased will be  $q_1 = 1 - \mu\lambda$ , which in turn from the seller's behavior implies that  $P_2 = \mu\lambda P_1 = k\lambda\mu^2$  and  $q_2 = 1 - \lambda P_2/k = 1 - (\lambda\mu)^2$ , or in general,  $P_t = k\lambda^{t-1}\mu^t$  and  $q_t = 1 - \mu^t\lambda^t$  (here note that  $q_t$  represents the total quantity sold since the first period,  $t = 1$ .)

The seller chooses the initial price to maximize the present value of future sales,

$$PV = P_1 q_1 + \delta P_2 (q_2 - q_1) + \delta^2 P_3 (q_3 - q_2) + \dots$$

$$= P_1 (1 - \lambda P_1/k) + \delta P_2 (\lambda P_1/k - \lambda P_2/k) + \dots$$

Setting the derivative with respect to  $P_1$  equal to zero yields  $1 - 2\lambda P_1/k + \delta P_2 \lambda/k = 0$ , and since  $P_1 = \mu k$  and  $P_2 = \mu\lambda P_1$ , then  $1 - 2\lambda\mu + \delta(\lambda\mu)^2 = 0$ . Solving this for  $\mu$  we can obtain the seller's reaction curve as

$$(1) \quad \mu = [1 - (1 - \delta)^{1/2}] / \delta \lambda.$$

For the marginal buyer at any point in time,  $V = \lambda P$ , and because he is indifferent to waiting,  $V - P_t = \delta(V - P_{t+1})$ . Given that  $P_{t+1} = \mu\lambda P_t$ , the marginal buyer's reaction curve is

$$(2) \quad \lambda = (1 - \delta + \delta\mu)^{-1}.$$

A Nash equilibrium under perfect information by both parties occurs when the reaction curves are mutually consistent, which occurs with

(3)  $\mu = [(1-\delta)^{1/2} - (1-\delta)]/\delta$ , and

(4)  $\lambda = (1-\delta)^{-1/2}$ .

The time path of equilibrium prices under this solution is  $(\mu k, \lambda\mu^2 k, \lambda^2\mu^3 k, \dots)$ . For  $i=.10$ , this time path of prices is  $(0.23k, 0.18k, 0.14k, 0.11 k, 0.08 k, \dots)$  and with a five-year life cycle of the trait,  $T=5$ , this becomes  $(0.88, 0.68, 0.52, 0.40, 0.31)$ . For a discount rate of .20, the comparable numbers are  $(0.29k, 0.21k, 0.15k, 0.10 k, 0.07k, \dots)$  and  $(0.87, 0.62, 0.44, 0.31, 0.22)$ . We show in Figure 3 the first four prices in the sequence of equilibrium prices and quantities corresponding to the 20% discount rate. Buyers capture surplus equal to the shaded area, while the seller captures rent equal to the area beneath. The latter area, total revenue received, equals 0.51 for a 10% discount rate or 0.52 for a 20% rate. By comparison, the present value of returns from annual technology fees ( $kp^* = k/2$ ) would be 1.89 and 1.50 for these two discount rates. This illustrates the "problem" (from the monopolist's point of view) of the pricing of durables: he earns only about a third of the normal monopoly rent, let alone any additional gains from intertemporal price discrimination.

Now relax the assumption of perfect and costless property rights. Suppose, first, that only a randomly-determined fraction  $\theta$  of potential customers can be excluded from pirating the trait (*i.e.*, from acquiring it from a supplier other than the patent owner or his licensee.) Then the derived demand curve (analogous to  $v^{pp}$  in Figure 2) is represented by a clockwise pivoting of the valuation schedule  $V$  through the point  $(V=k, q=0)$  in Figure 3, which would result in no change at all in the time path of equilibrium prices. The seller's revenues would fall, however, to the fraction  $\theta$  of the level under perfect property rights. The seller's optimization problem would now include the amount to be

spent on enforcement, if the fraction  $\theta$  is affected by enforcement effort, but that problem is not directly relevant to questions addressed in this paper.

Suppose, alternatively, that buyers set a limit price  $\phi V$ , above which they would choose to pirate the trait rather than purchase it from the seller. This would result in a counterclockwise rotation of the valuation schedule  $V$  through the point  $(V=0, q=1.0)$ . The Nash equilibrium price path through time would fall to the fraction  $\phi$  of the level under perfect property rights.

Hence within the framework of a plant breeders' rights regime in which purchasers are permitted to re-plant the crop with the trait, this game theoretic analysis results in an initial price only one-fourth or so of the one-shot monopoly price, followed by prices that decline even further. Piracy would reduce the seller's returns proportionately below even these levels.

### **Will buyers of a durable crop trait pay for a durable?**

To this point we have concluded that under a UPOV/PVPA breeder's rights regime, it is plausible that the seller of a technologically durable trait will charge a price that declines through time as suggested by Coase's conjecture. The height of this declining price path is clearly restricted by buyers' knowledge that the seller will in the future have an incentive to lower the price. However, in the case of a crop trait, today's customers are potential competitors of the monopolist – they will have the capability of selling the trait the next year. The entire crop of the first-year adopters could be used for seed the following year. Reproductive rates in small grains are on the order of 30 or more to one, so even a 3% adoption rate in year one would provide sufficient seed for the

entire crop the following year. The price that the trait owner can charge the first marketing year therefore depends crucially on whether he can be credibly expected to exclude the future dissemination of the trait by those first-year buyers. Recall that as specified above, first-year buyers will only purchase if  $P_1 < (1-\delta)kv + \delta P_2^e = \delta v + \delta (P_2^e - \delta^T v)$ . In the extreme case that next year's price,  $P_2$ , is expected to be zero, the buyer will pay no more for the trait than  $v$ , the value of its services for the coming year alone<sup>2</sup>, the owner would charge a price equal to the optimal rent,  $P=r^*$ , and sales would cease with this first year. Only if the owner could exclude all potential customers from this pirating activity could the time path of price and sales through time be as high as that derived in the previous section.

## Conclusions

Crop traits are technologically durable if they are embodied in the seed of a true-breeding variety as opposed to a hybrid seed. If the trait is protected by a utility patent, the owner can be expected to charge the monopoly rental rate, or technology fee, each and every year for use of that trait. This rental rate should be in the vicinity of the median level of customers' valuations of the service of the trait for one year, with approximately half of the potential adopters choosing to adopt. However, if the trait is protected only by breeders' rights, the buyer retains the right to use the trait in the future, and the owner is selling a durable good to that buyer. Using an explicit game-theoretic model of trait pricing, we find that the Nash equilibrium path of prices through time is in accord with Coase's conjecture about the pricing of durable goods. The price charged for the initial release of five-year durable trait can be expected to be about 75% larger than

the annual monopoly rental rate, but the present value of revenues would be only about 25% of those from annual monopoly prices. While this result holds for a trait protected by breeders' rights, a similar result could occur under utility patent protection, if enforcement costs under the legal system are sufficiently high.

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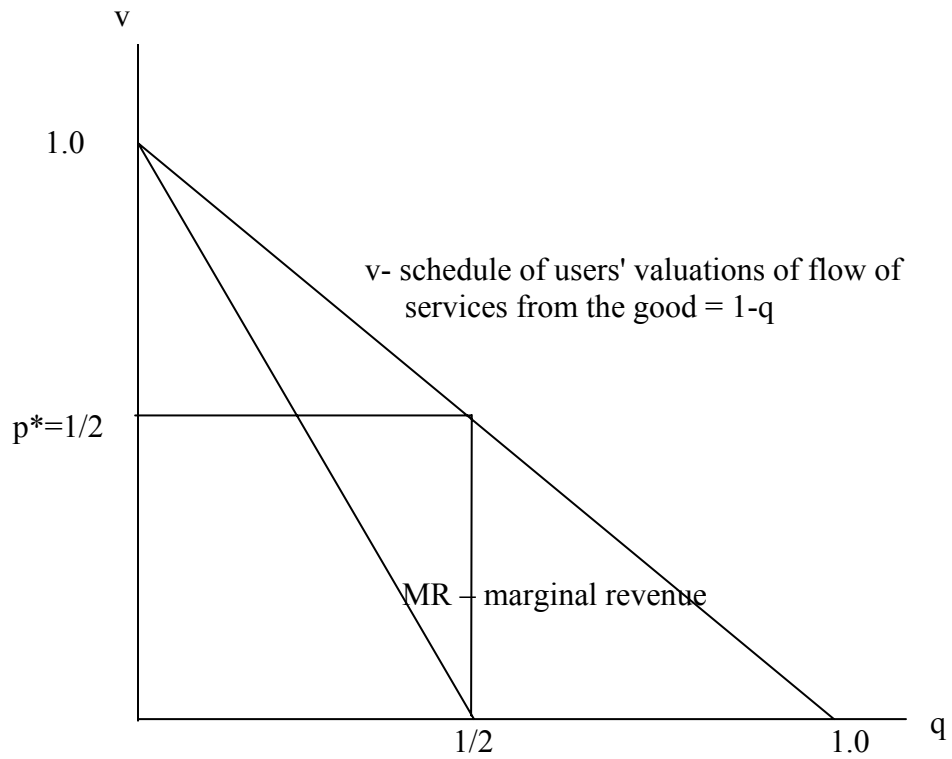


Figure 1. User evaluations of annual benefit of a trait

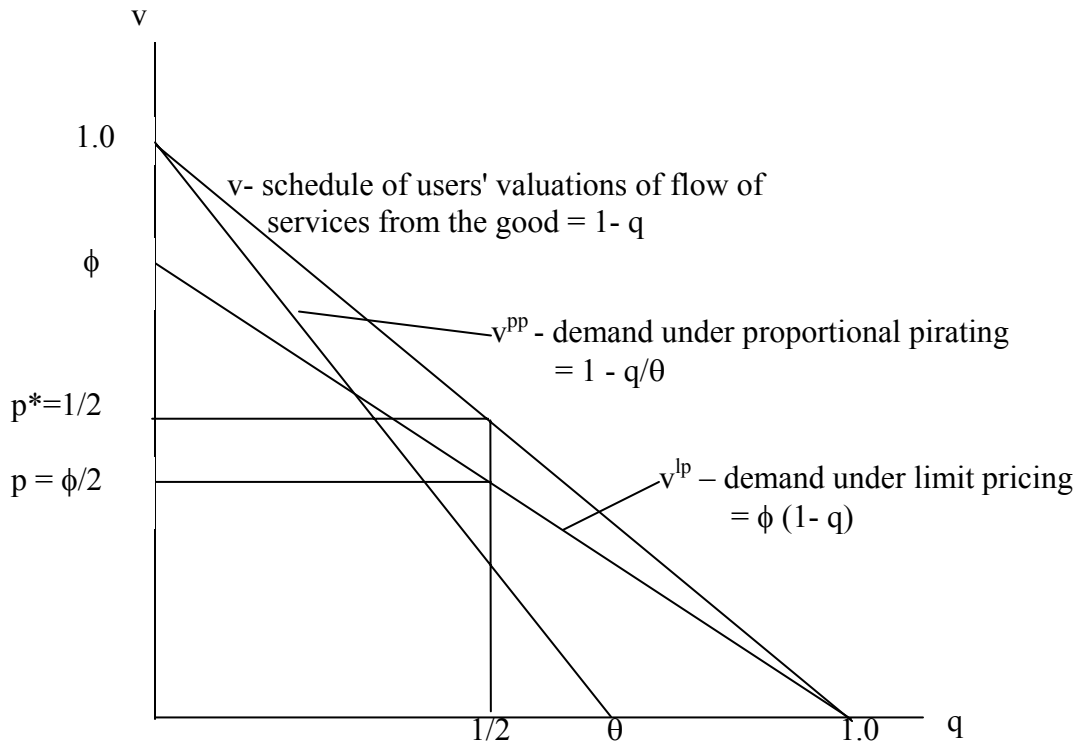


Figure 2. Effective demand with imperfect property rights.

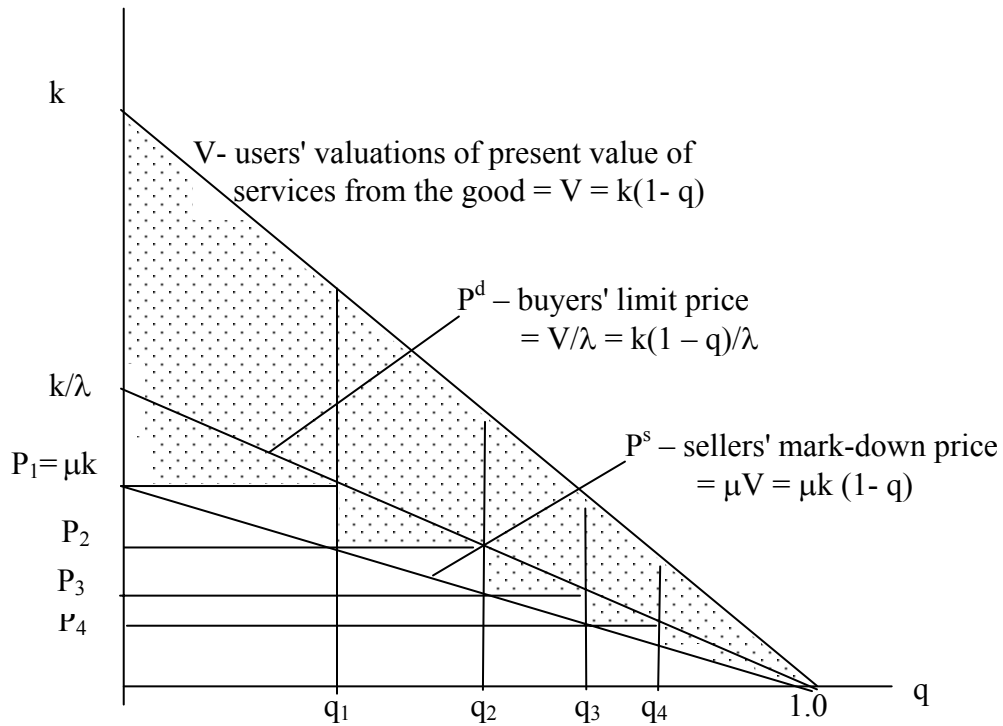


Figure 3. Nash equilibrium pricing of a durable trait.

<sup>1</sup> See Perrin, Moschini and Lapan, Giannakas.

<sup>2</sup> This would be technically true only for an asset with infinite life, which is effectively the case if a new asset can be acquired for free any time in the future. Given a T-year asset life as in the inequality here, the buyer expecting a zero price next year would pay even less than the value of current services, by the amount of the present value of services he would obtain in year T+1 if he postponed purchase.