

**SEQUENTIAL INNOVATION
AND MARKET STRUCTURE**

by

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and

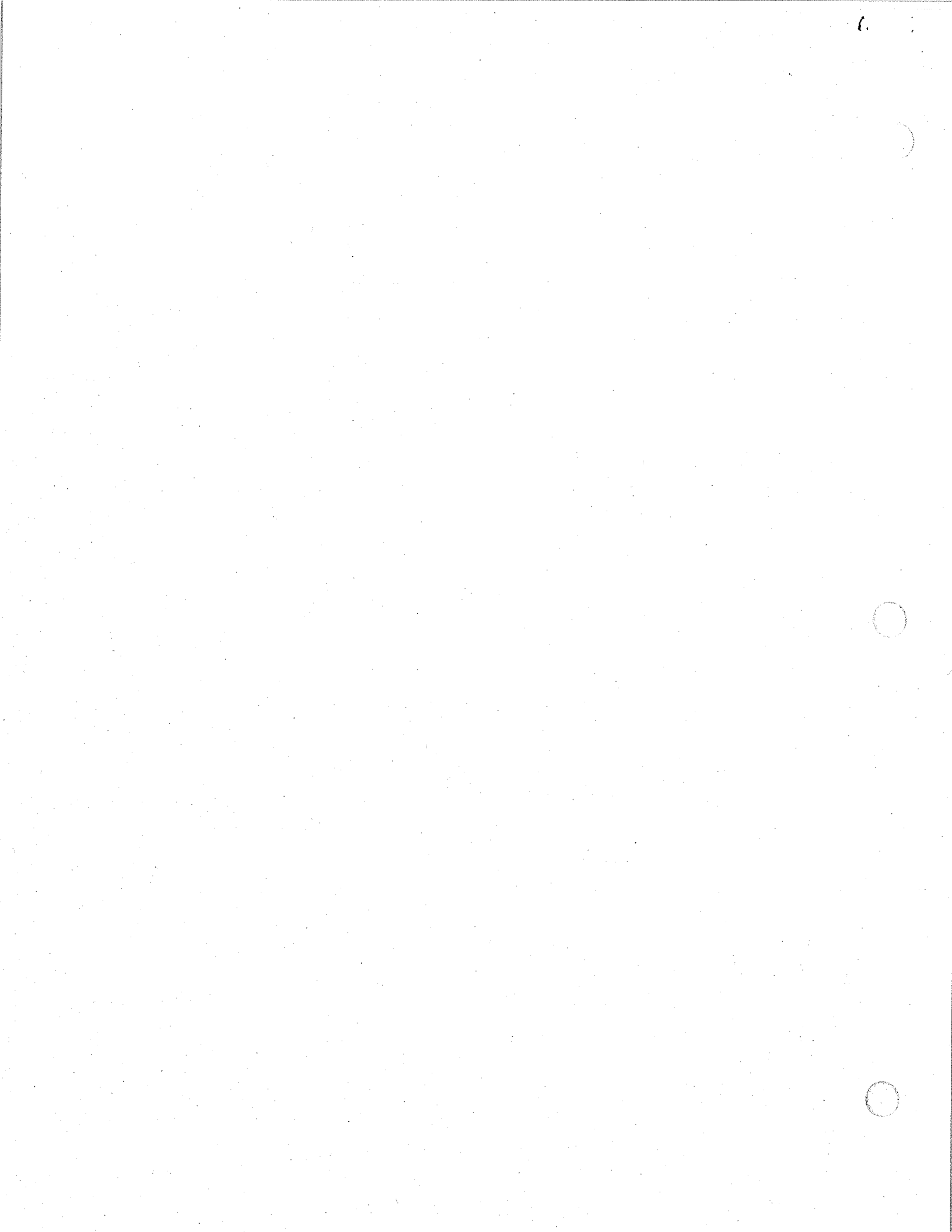
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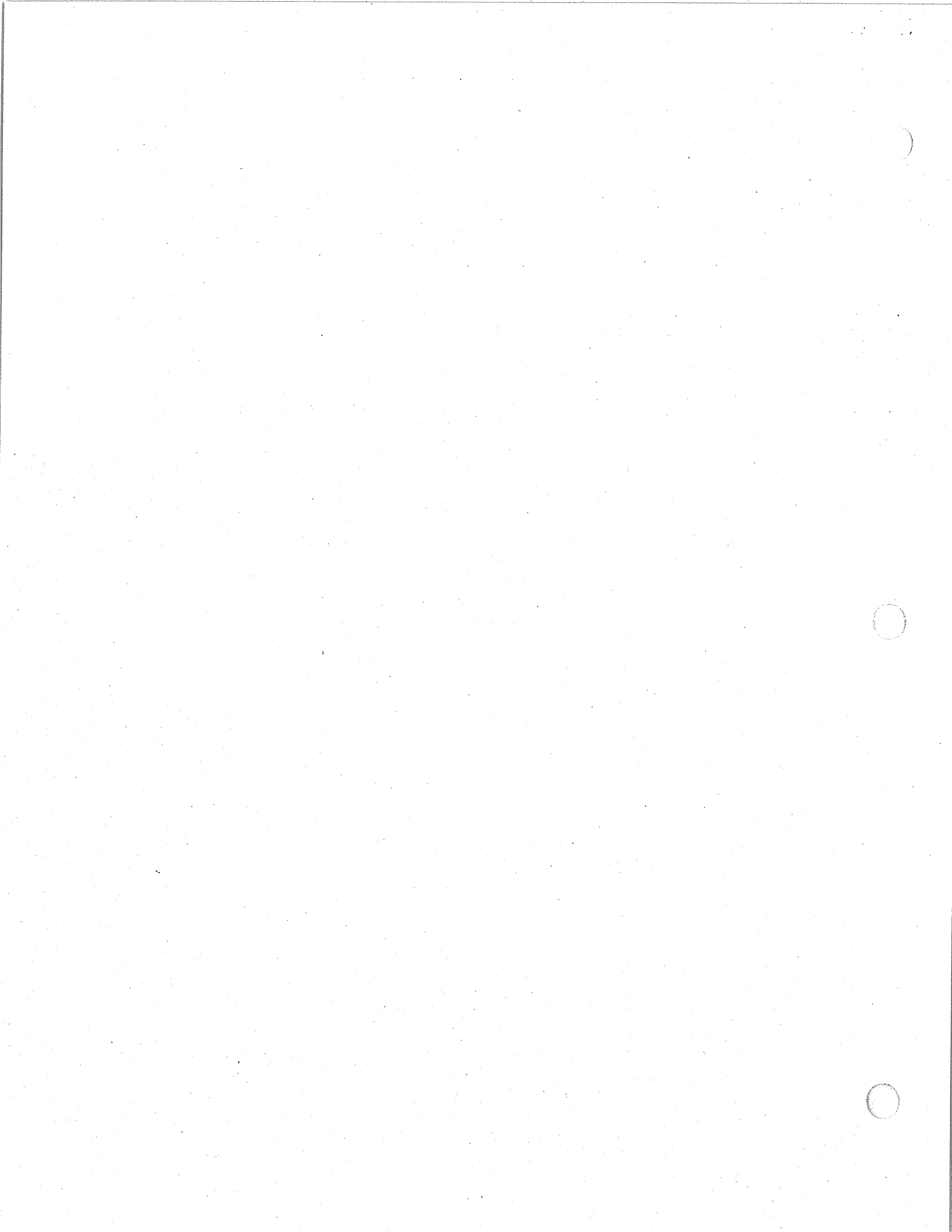
Abstract

This paper concerns the introduction of a sequence of new, higher-quality durable products in a market in which there already exists a lower-quality substitute. The product has the further attribute that a real resource cost is incurred at the time a higher-quality product is first used. This stylized feature of our model represents several common characteristics of commodities in evolving markets. Computers and electronic consumer durables are evident examples.

The two key features of this commodity, its exogenously improving quality and the cost incurred in first-time use, interact in interesting ways. We study the cases of a monopoly who can control the product price over time, and a sequential oligopoly in which the currently-best variety of the good is produced by only one firm, but each improvement is owned by a new potential entrant.

In the monopoly case there is a tendency for the monopolist to suppress the earlier technologically inferior varieties of the product, waiting for the better ones that will be available later, even when it would be socially optimal for the consumers to switch to the earlier innovation and switch again to the subsequent variety. The reason for this is that the monopolist can sell the subsequent innovation for a higher price if consumers do not own the earlier innovation.

In the sequential duopoly case a different phenomenon is operative. There is a tendency for the earlier innovation to be produced and sold, at a profit, when it should be suppressed in favor of waiting for the superior quality good. This is because consumers correctly believe that if they do not buy early, the subsequent innovation's producer will charge them a monopoly price and they will get no surplus.



I. Introduction

This paper concerns the introduction of a sequence of new, higher-quality durable products in a market in which there already exists a lower-quality substitute. A cost in terms of real resources is incurred in the first period that the good is used, but no cost is incurred in subsequent periods. The cost may be that incurred in the production process, or it may be a cost of first-time use incurred by consumers as they adapt to the good. This particular interpretation of the cost represents several quite common characteristics of commodities in evolving markets. Many of these commodities involve the use of auxiliary complementary goods with specific characteristics that must be standardized to insure compatibility. Newer and higher quality innovations often cause the older set of complements to become obsolete. The particular case in which the complementary input is the human capital involved in learning how to use the good provides another example of this type of fixed cost. Computers and electronic consumer durables are evident examples. Others might be the manufacturing equipment used in firms with an improving technology, or even college textbooks, where the complementary input is the instructor's familiarity with the text itself.

The two key features of this durable commodity, its exogenously improving quality and the fixed cost incurred in its first-time use, interact in interesting ways. The nature of this interaction is different according to the market structure. We study the cases of a monopoly who can control the product price over time, and a sequential oligopoly in which the currently-best variety of the good is produced by only one firm, but each improvement is owned by a new potential entrant.

In the monopoly case there is a tendency for the monopolist to suppress the earlier technologically inferior varieties of the product, waiting for the better ones that will be available later, even when it would be socially optimal for the consumers to switch to the earlier innovation and switch again to the subsequent variety. The reason for this is that the monopolist can sell the subsequent innovation for a higher price if consumers do not own the earlier innovation. Indeed, selling the two sequentially causes the fixed costs of first-time use to be incurred twice, while selling only later avoids one of these adjustments. Inefficiency can be avoided if the monopolist can rent the good in period 1. This allows him to extract all the consumers' surplus. It results in the socially efficient production because the issue of a prior sale by the firm competing against its own later sales is avoided.

In the sequential duopoly case a different phenomenon is operative. There is a tendency for the earlier innovation to be produced and sold, at a profit, when it should be suppressed in favor of waiting for the superior quality good. This is because consumers correctly believe that if they do not buy early, the subsequent innovations' producer will charge them a monopoly price and they will get no surplus. Therefore they accept a smaller sure surplus from the earlier producer. This producer can commit himself to his price at a time when the later producer is not active and therefore cannot compete, and the consumer rightly locks in any sure gains.

II. The Model

We consider a two period model of a market for a good whose quality is improving over time. The source of the quality improvement is not part of this analysis. It may be the result of research and development by the firms

that produce it, or it may be a byproduct of activities outside the firm, for example, education or training taken by the consumers. For the purposes of this paper, two facts are important: first, the quality change is exogenous, and second, the improved quality available in the second period is available only if the consumer avails himself of a newly produced good in that period. That is, although the two goods fill the same economic need, they are physically distinct. The good produced in period one can be used in period 2, but it is inferior, in the value of its service flow, to the newly produced good.

A consumer who does not buy the good avails himself of the reservation utility x_0 . In period 1, the gross services provided by the good are worth x_1 . From this we must subtract a cost of adjustment, F , paid only when the good is used for the first time. If the consumer continues in period 2 to use the same good, the full x_1 is available to him. If he were to switch to the newly produced good, he would receive x_2 , minus the adjustment cost of F .

Now we will introduce some basic considerations that place the parameters of our model within an interesting range, from the point of view of an economic analysis. First of all, as the technology is improving, we have $x_0 < x_1 < x_2$. Beyond this restriction further constraints can be imposed by examining the four possible outcomes of this model:

- 1) The good is never introduced.
- 2) It is introduced in period 1, but the innovation in period 2 is not introduced.
- 3) It is suppressed in period 1, but in period 2 the good is introduced for the first time.

4) It is introduced in period 1, and in period 2 the new superior good is adopted to take its place.

If $x_2 - F < x_0$, then the second period is surely irrelevant as x_2 could compete neither with x_0 nor with x_1 at that time. Everyone could predict this outcome and thus x_1 would be adopted if and only if it is better than x_0 over the two period horizon.

If $x_1 - \frac{F}{2} < x_0$, then the first period's innovation is irrelevant because the fixed costs cannot be recovered even if it remains in use for both periods. The model degenerates to one where the second period good competes directly with x_0 .

Thus we restrict our analysis to the domain where

$$x_0 < x_1 < x_2$$

$$x_0 < x_2 - F$$

$$x_0 < x_1 - \frac{F}{2}$$

which encompasses all of the interesting cases where the two periods can genuinely interact.

We will analyze the performance of this system when there is a monopolist who controls production in both periods and when there are two firms, each controlling one of the goods, but with mutual knowledge of each other's strategies and of parameters of the system. These outcomes will be measured against the social optimum. It is straightforward to compute that this optimum is given by the following decision rule:

produce x_1 and not x_2 if and only if $x_2 - F < x_1$ and $x_2 < 2x_1 - x_0$

produce x_2 and not x_1 if and only if $x_1 - F < x_0$ and $x_2 > 2x_1 - x_0$

produce both x_1 and x_2 if and only if $x_1 - F > x_0$ and $x_2 - F > x_1$.

III. Sequential Innovation by a Monopolist

In this section we characterize the behavior of the system when a single monopolist controls the good in period 1 and the higher quality innovation in period 2. We derive the circumstances under which the two successive innovations will be produced and marketed, and the divergence of this monopoly solution from the socially optimal pattern of innovation. In the first subsection we treat the case of a monopoly that can sell the good at a price it can determine, but where the good, if sold in period 1, remains in the hands of the consumer without further cost in period 2. In the second subsection we consider a monopolist for whom one-period renting is possible.

A. Monopoly Selling Strategies

Let us first characterize those cases in which the monopolist will find it optimal to sell the good in both periods. To determine the monopolist's profit from this strategy, we proceed backwards. Assume that the good has been purchased by all consumers in period 1. To attract them as customers in period 2, consumers must be offered a utility of at least x_1 because they could continue to use the good in period 2 without further costs. Thus $x_2 - F - p_2 \geq x_1$, or, taking the limit where p_2 is set as high as possible,

$p_2 = x_2 - x_1 - F$. * This will be a rational decision for the monopolist only if this value of p_2 is positive. For the present, let us proceed under the further hypothesis that it is.

Now consider period 1 and assume that the monopolist offers the good at p_1 . Let each consumer believe that everyone else will purchase it and that, therefore, the period 2 equilibrium will be as described above. Under what conditions will these consumers buy in period 1?

In period 1 each will receive $x_1 - F - p_1$ if he buys, or x_0 if he does not. In period 2 he will receive x_1 by purchasing the good at p_2 . We assume that the monopolist cannot price discriminate against such a consumer based on the fact that all other consumers have purchased the good and he has not. Implicitly we regard the fact of having purchased the good as unobservable to the monopolist. Therefore his second period utility is invariant to whether or not he purchased the good in period 1, and the decision to purchase can therefore be made by comparing the first period utilities alone. For the monopolist to sell the good, it is required that $x_1 - F - p_1 \geq x_0$, or, in the limit $p_1 = x_1 - x_0 - F$. Summing over the two periods, selling in both periods produces a total profit of

$$(1) \quad p_1 + p_2 = x_2 - x_0 - 2F$$

* To derive unique equilibria, we employ the following convention of a game theoretic nature. The price strategy chosen by firms may, in equilibrium, lead consumers to be indifferent to their purchasing decision. To arrive at a determinate equilibrium, we assume that if one firm could price slightly lower than its equilibrium price, leaving consumers with ϵ of surplus, and if the other firm could not counter this price cut without making a loss, then the customers will all go to the price cutter. In the limit, however, it does not cut its price; we use this limiting argument to determine the equilibrium buying pattern.

To see whether the monopolist would follow this strategy, we must compare this profit to what he could earn by refusing to sell in period 1, or with the strategy of selling only in period 1. Refusing to sell in period 1 would change the period 2 equilibrium because all consumers would know that none of the others had purchased the good, and hence the price that could be extracted from them would be higher. Specifically, if no one has purchased it in period 1, then $p_2 = x_2 - x_0 - F$ which is larger than (1) under our assumptions. Therefore, under all interesting circumstances, the monopolist would prefer to suppress the good in period 1 rather than to sell it.

From the point of view of social surplus maximization, the monopoly may very well be inefficient. In particular, whenever $x_1 - x_0 - F > 0$ and $x_2 - x_1 - F > 0$, the good will be sold only in the second period whereas the social optimum is for repeated innovation to take place.

The above analysis is predicated on the fact that $x_2 - x_1 - F \geq 0$. Let us now consider the case where this is negative. If the good had been sold in the first period, the firm could not sell it at a positive price in the second. This would be perfectly predictable by all consumers in the first period, and they would evaluate their two period utility from buying then to be $2x_1 - F - p_1$. If they do not buy, they know that the monopolist can hold them down to x_0 next period, because anyone in the market for the good at a positive price in period 2 must be someone who had not bought at date 1, under the maintained hypothesis $x_2 - x_1 - F < 0$. Therefore p_1 can be set so that $2x_1 - F - p_1 = 2x_0$, or $p_1 = 2x_1 - 2x_0 - F$.

The monopolist must compare this level of profit to that which could be made by selling only in period 2. As above, this is $p_2 = x_2 - x_0 - F$. Therefore he

will sell in period 1 or 2 according to the sign of $x_2 - 2x_1 - x_0$. It should be noted that, subject to the restriction that $x_2 < x_1 + F$, this is also the condition determining the social optimality of introducing the innovation in either only the first or only the second period.

A graphic summary of the comparison between the optimal innovation pattern and the monopolist's choice of innovations is given in Figure 1. The monopoly solution will be efficient except when $x_2 > x_1 + F$ and $x_1 > x_0 + F$. In this situation the monopolist will always suppress the earlier innovation and it will be socially non-optimal to do so. This is precisely the case of a rapidly evolving technology.

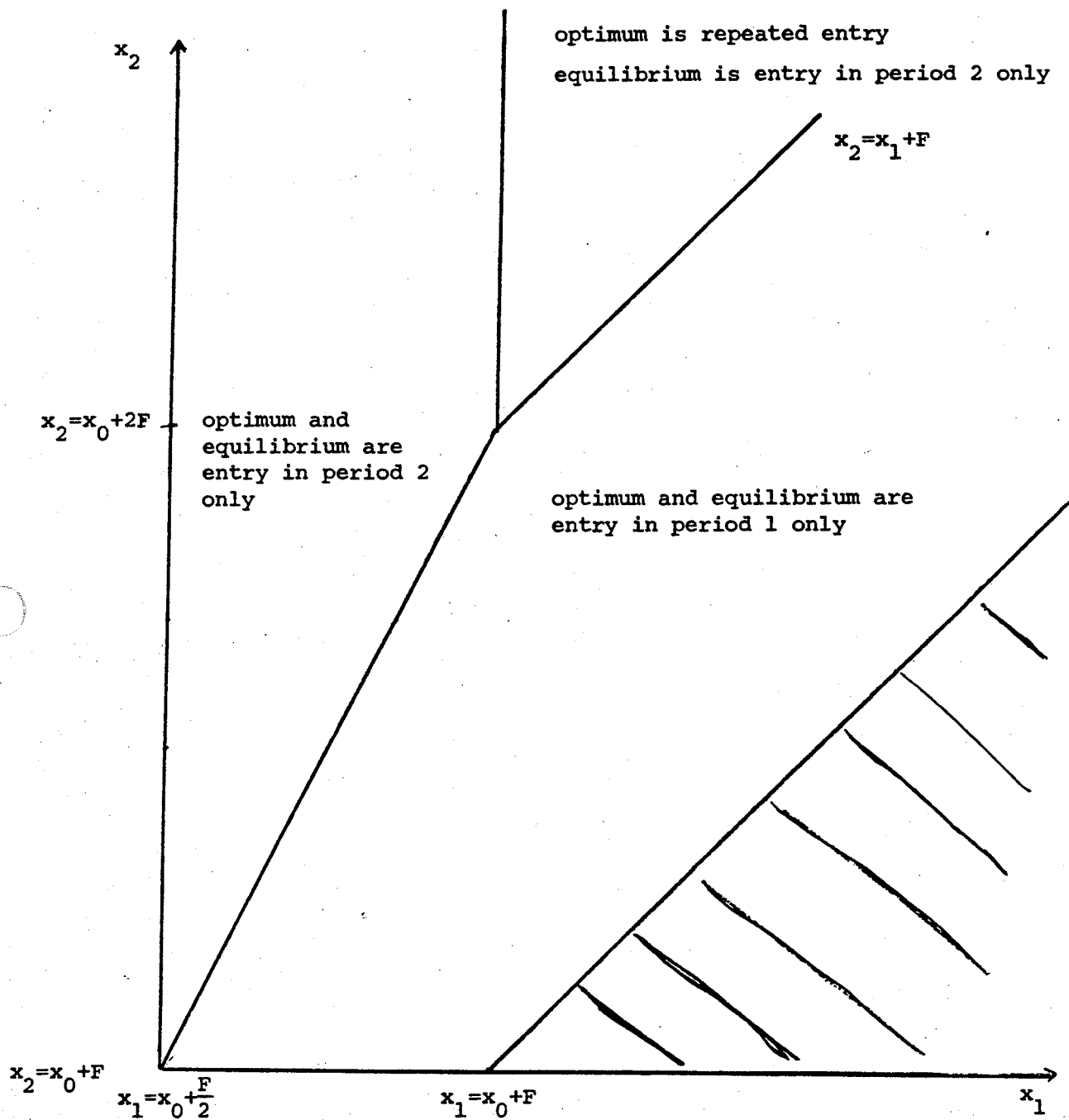


FIGURE 1

monopoly (selling strategy only)

B. Monopoly Renting Strategies

Now let us consider the possibility that the monopolist can rent the good rather than sell it. This is a strategy that is often followed by producers in rapidly evolving industries. The principal reason is probably that it protects the consumers against obsolescence when the technology is uncertain. In our model, there is another reason as well. Renting effectively eliminates the fact that the durable good sold in period 1 can compete against the better good of period 2, reducing the price that the monopolist can then charge. Recall that this factor was precisely what was responsible for the inefficiency of the equilibrium above, in the case where the monopolist would suppress the sale in the first period.

To see that renting will restore efficiency in the case where $x_2 > x_1 + F$ and $x_1 > x_0 + F$, observe that consumers can be held to their reservation utility x_0 in period 2 by the price $p_2 = x_1 - F - x_0$. Therefore, in period 1, they base their buying decision on the two period reservation utility $2x_0$, leading to $p_1 = x_1 - x_0 - F$. Two period monopoly profits from selling in both periods are therefore $x_2 + x_1 - 2x_0 - 2F$, and under our hypotheses, these exceed the profits to be made by selling in either one of the two periods alone.

In all other cases, the profit from the optimal renting strategy is the same as that from the optimal selling strategy -- and as these coincide with the optimum we have the result that renting is efficient when the market is dominated by a single producing firm. Therefore renting should be allowed, and certainly not prohibited in these cases.

IV. Sequential Innovation in a Duopoly

In this section we assume that the evolution of technology is the same as that studied above, but that the property right to the period 2 good is owned by a different firm than that which owns the good sold in period 1. The market structure is thus a sequential duopoly. In period 1, one firm can sell x_1 and can choose its price at that time. In period 2, x_2 can be sold by the other firm. Everyone knows that the second firm cannot commit itself to any particular price until period 2 arrives. At that time, it will know the results of period 1's economic activity. That is, it can set a price dependent on the number of consumers who have bought the good in period 1. When both firms are actively seeking the same set of customers, price is determined by Bertrand competition between them. If some consumers did not buy in period 1, which can happen only if $x_1 - F < x_0$, firm 2's closest competitor will be x_0 , and firm 2's optimal price will lead consumers to have the surplus x_0 instead of x_1 in period 2.

Working backward, assume that all consumers have bought the good in period 1. Firm 2 can charge $p_2 = x_2 - x_1 - F$ and all individuals will have a utility of x_1 . It will do so if and only if p_2 is positive. Because the firm in period 2 cannot price discriminate against a consumer who has not purchased the good in period 1, even such an individual would have second period utility x_1 . Therefore, the firm in period 1 must give any consumer who purchases at least a utility of x_0 , so that their two period utility will be $x_0 + x_1$ which is the utility they could achieve by waiting until period 2 to buy. Thus $p_1 = x_1 - x_0 - F$. Hence, the equilibrium will involve a sale of the good in both periods whenever p_1 and p_2 are both positive.

Maintaining the hypothesis that all consumers have purchased the good in period 1, let us consider the case in which $x_2 - x_1 - F < 0$, so that firm 2 will not be able to earn a profit. Under what circumstances can the firm in period 1 sell to all consumers and make a profit? Whenever they do, firm 2 is expecting not to be able to sell at all, even at a price of zero. To compute the perfect equilibrium behavior of firm 2 we must imagine a deviation from the equilibrium behavior by some small set of consumers, who do not buy in period 1. In the presence of such a deviation, however small, the optimal price to be set by firm 2 is $p_2 = x_2 - x_0 - F$. Firm 2 strictly prefers selling to this very small fraction of the consumers at a positive price to competing unsuccessfully for the entire market. These deviating consumers get a utility of x_0 . Therefore, firm 1, which is a Stackelberg leader knows that it can offer the good for sale under conditions which give the consumer a two period utility of $2x_0$ -- that is, x_0 in each period. Hence $p_1 = 2(x_1 - x_0) - F$, and firm 1 will sell whenever this quantity is positive.

Observe that this will lead to an inefficient, premature, entry by firm 1 when $x_1 - x_0 - F > 2(x_1 - x_0) - F > 0 > x_2 - x_1 - F$. Firm 2 cannot enter in period 2 since firm 1 has entered in period 1 ($x_2 - x_1 - F < 0$). Firm 1 enters because its profits over the two periods are positive ($2(x_1 - x_0) - F > 0$). However, the social surplus obtained if only firm 2 had entered would have been larger ($2x_1 - F < x_2 - F + x_0$ or $x_2 - F - x_0 > 2(x_1 - x_0) - F$). Even when there is a higher social surplus from delayed entry, firm 1 can profitably enter and all individuals will buy from firm 1 because they fear that their consumers' surplus will be extracted by firm 2's monopolistic pricing strategy.

When $2(x_1 - x_0) - F < 0$, firm 1 cannot enter and efficiency will result. Firm 2 enters according to the sign of $x_2 - x_0 - F$, just as it should. (See Figure 2 for a summary.)

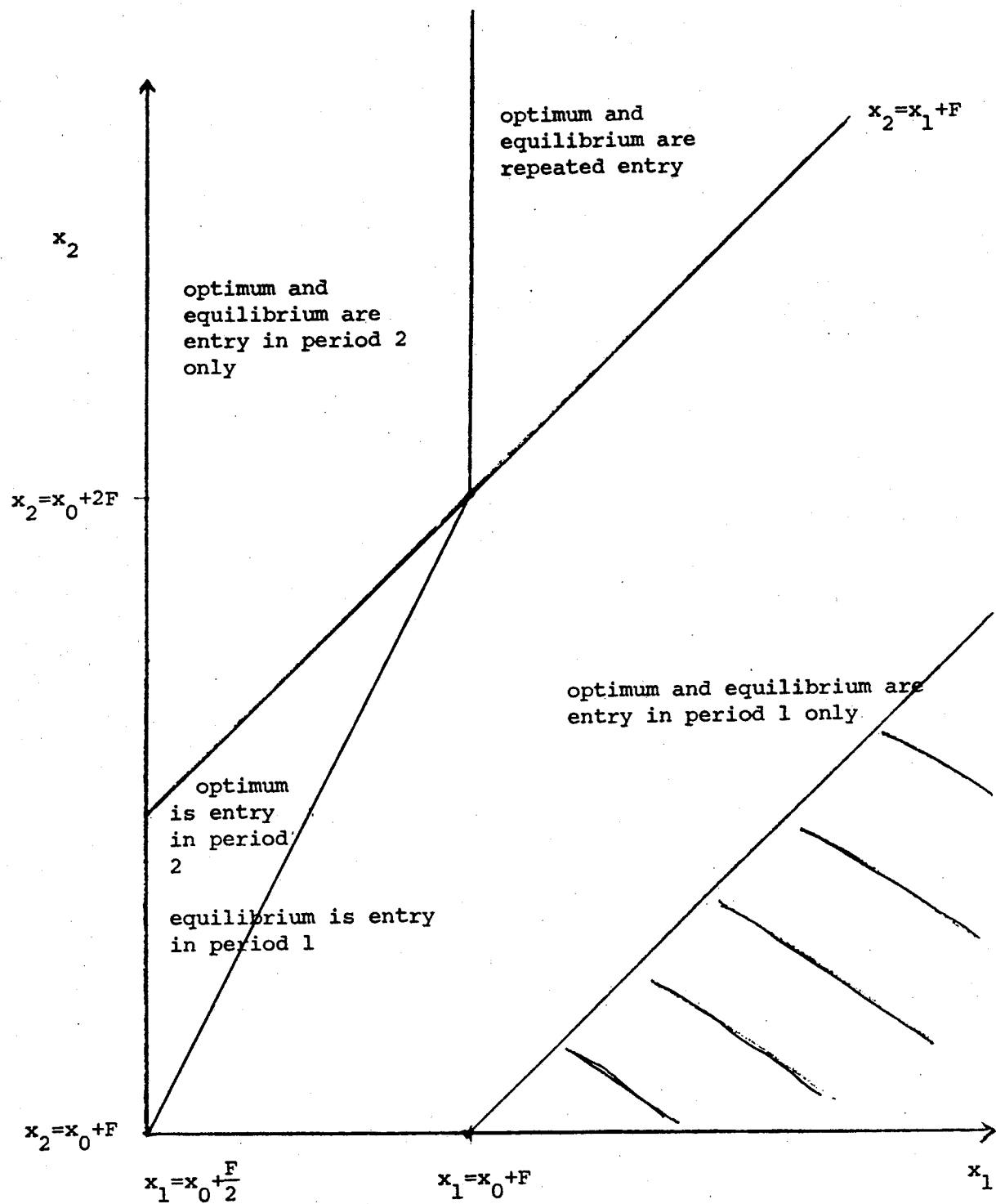


FIGURE 2

sequential duopoly

