R&D Expenditure in Network Industries: Could It Be a Social Waste?

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Abstract

The existing literature suggests that an incumbent monopolist supplier of network goods can successfully deter entry by increasing its installed base, which plays a role similar to that of the commitment value of investment in capacity. In this paper we consider a market with network externality, where the consumers' utility not only depends on the network size but also on the technological quality of the product. We show that when the installed base of the incumbent fails to play its pre-emptive role to deter entry, the monopolist can deter entry, strategically by revealing its R&D expenditure on upgrading the product. The result is independent of whether the R&D project is, ex-post, successful or not. Such entry deterrence is welfare reducing.

Key Words : Network Externality, Entry Deterrence, Compatibility, Installed Base, Limit Pricing, R&D.

Introduction

Casual empiricism suggests that R&D expenditure to sales ratio is much higher in network industries, as compared to non-network industries. In computer industry the rate of R&D investment to sales has been well above 10% for many years. Major firms (e.g., Microsoft, SUN, IBM etc.) maintain huge labs and though they are extremely secretive about the R&D projects, they issue statements about their R&D expenditures in their annual reports. Firms undertake R&D either to reduce production cost or to innovate new products. In the present paper, the focus is on the type of R&D that is undertaken in order to innovate a product, which is qualitatively better than the existing products. We motivate this paper by examples of *systems*, in general, and PC operating systems, in particular. In such a context, the technological features of the

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product, which we will often refer to as the technological quality, characterize the quality of a product. So, R&D undertaken by an incumbent firm to improve the technological quality of a product is synonymous to R&D undertaken to innovate upgrades. Henceforth, we use the term R&D in this sense only.

Ellison and Fudenberg (2000), examine why a monopolist supplier of software may introduce more upgrades than is *socially optimal*. They suggest that in a market with heterogeneous consumers, excessive upgradation might take place if the upgraded versions are *backward compatible* to the earlier versions. On the other hand, Farrell and Katz (2000), suggest that in a systems market an integrated monopolist may conduct 'more' R&D than its non-integrated rivals to put 'greater' competitive pressure on the rivals. In the present paper, we suggest that a monopoly supplier of a component of a system can strategically deter entry by using R&D expenditure as a signal.

The famous anti-trust case of the *United States of America vs. Microsoft Corporation* instigated a major theoretical debate regarding *anti-competitive* behaviours in markets for network goods. The strategy, widely discussed in the literature of entry deterrence in markets with network externalities, is creation of a large installed base and keeping the product incompatible with that of the entrant. [E.g., Katz and Shapiro (1986a, b, 1992), Farrell and Saloner (1986, 1992), Klemperer (1987a, b), and Matutes and Regibeau (1989).]. The basic argument can be elaborated with the help of an example. Two competing operating systems are compatible to each other if all the programs that run on one of them and run on the other as well. In order to make the operating systems compatible to each other the firms sponsoring them will have to share source codes. So, the firms can, indeed, strategically decide whether to share the codes or to keep its product incompatible with that of the rival by *blocking* the codes. In general, when two systems are based on two incompatible technological platforms, compatibility can be achieved by the provision of a *two-way converter* and any firm can strategically keep its product incompatible to the rival's product by unilaterally blocking the converter. A one-way converter enables some network benefit for the user but does not make the products compatible and hence, does not generate externality. When the products are compatible, the entire market is the common network of the competing firms. So an incumbent can prevent the potential entrant from using its installed base by blocking the converter, and this reduces the attractiveness of the entrant's product. This, in turn, can create a pre-emptive condition for the incumbent to deter entry. The basic argument is in line with the literature on entry deterrence by investment in *capacity*, as discussed in Schelling (1960), Dixit (1979, 1980), Spence (1977, 1979) etc.

Such a mechanism may fail to deter entry, in presence of *technological progress*, if the entrant's technological edge offsets the incumbent's installed base advantage. Katz and Shapiro (1992), show that post-entry price competition can lead the entrant to capture the entire market. Fudenberg and Tirole (2000), however, emphasize on the pre-emptive role of the incumbent's installed base in entry deterrence. They show that there exists a *limit pricing Markov perfect equilibrium*, even when the entrant has a technological edge that outweighs the installed base advantage of the incumbent.

In this paper we use a static model, where post-entry the firms simultaneously choose prices. Therefore, the possibility of entry deterrence by limit pricing is ruled out. Moreover, the potential entrant is threatening to enter with a qualitatively better product. In such a context we show that strategic signalling, by publishing data on R&D expenditure, can deter entry in a world of incomplete information. We also suggest that such entry deterrence is welfare reducing. Kristiansen (1996), also considers the possibility of entry deterrence by investment in R&D. He solves a two-stage game where an incumbent and a potential entrant simultaneously choose their R&D projects in stage 1 and competes in prices in stage 2. In Kristiansen (1996), an R&D project can have two outcomes *'success'* and *'failure'*. A *risky* project (having a low probability of 'success'), if it 'succeeds', it will lead to a larger technological improvement than a *safe* project (having a high probability of 'success'). He shows that the incumbent chooses a *risky* R&D project and the entrant, in contrast, chooses a *safe* project. In presence of network externality, the incumbent's installed base discourages the entrant to choose a sufficiently risky project. If the incumbent's as well as the entrant's R&D are 'successful' or if the entrant's project is 'unsuccessful', entry is deterred. If, however, the entrant's project is 'successful' but the incumbent's one is not, then entry occurs. In contrast to Kristiansen (1996), in the present paper we show that entry is deterred irrespective of the outcome of the incumbent's R&D.

In section 2 we introduce the basic model. In section 3 we show that entry occurs in absence of R&D. In section 4 we analyse the role of R&D expenditure in entry deterrence. In section 5 we extend the analysis by endogenising the R&D expenditure. In section 6 we analyse the welfare effects of entry deterrence. Finally, in section 7, we conclude with a note on antitrust implications of the model.

The Model

The market for a network good, in period 0, is supplied by an incumbent monopolist (I). A potential entrant (E) threatens to enter the market. The technological quality of the entrant's product is better than that of the incumbent and is protected by a patent.

Confronted with the threat of entry, in the stage I of period 1, the incumbent decides whether to undertake R&D, or not. If it undertakes R&D, it will publish a statement of R&D expenditure. We assume that the incumbent cannot improve upon the technological quality of its product without undertaking R&D. We also assume that the incumbent cannot publish fraud data on R&D expenditure without actually incurring it. The incumbent's R&D project is said to be *'successful'* if it innovates an upgrade, such that the technological quality of the upgrade is better than the entrant's product. Observing the incumbent's action, the potential entrant decides whether to enter or not.

The incumbent can be either a 'high' type or of a 'low' type. Ex-ante it is uncertain whether the incumbent's R&D is successful or not. The probability of success of a 'high' type incumbent is more than that of a 'low' type. The entrant knows the probability of success for a 'high' type incumbent and that for a 'low' type incumbent. If it knows that the incumbent is a 'high' type, the *risk neutral* entrant will not enter and if it knows that the incumbent is a 'low' type, it will enter. But in a world of *incomplete information*, the entrant does not know the type of the incumbent.

If entry occurs in stage II, the firms will decide on the provision of a two-way converter. The products can be made compatible with each other if and only if both the firms agree on the provision of a two-way converter. For simplicity, we assume that the firms do not incur any cost to provide the converter. It is important to note that any one firm can unilaterally *'block'* the converter.

Finally, in stage III, the firms simultaneously choose prices.

For simplicity we assume *zero cost of production*. Only the entrant incurs a fixed entry cost F (> 0), which is exogenous. Since the technological quality of the entrant's product is better than that of the incumbent, the entry cost F can be interpreted as the cost of acquiring (or innovating) the technology.

We consider a two-period overlapping generations model where in each period a continuum of consumers, distributed uniformly in the interval [0, 1] according to their type , arrives in the market. The period 0 consumers are alive in period 1 and hence the incumbent's sales in period 0 determine its installed base. However, the period 0 consumers make their purchase decision and get utility from consumption in period 0 only.

The type of a consumer reflects his willingness to pay for the product that is relatively better, in terms of technological quality, between two available products. If at period t, two products are available in the market and the technological quality of product i is better than that of the product j ($j \neq i$), each period t consumer, purchasing i, gets an additional benefit according to its type. The consumers get this additional benefit from relatively better technological quality only when they can compare two contemporary products and perceive that one of the products is better than the other product available in that period. If, at period t, only the product i is available in the market, or among two available products, the technological quality of product of j is better than that of the product i, the consumers of the product i do not get this additional benefit. In a sense we are considering a utility function in which the utility is derived, not from the absolute quality of the product, but from the product differential. When only one product is available, at any particular period, the consumers do not have any 'reference frame' and hence cannot perceive the product differentiation. One important underlying assumption is that the consumers do not compare between products available in the market at two different periods but compare between products of the same 'generation'. For example, if a monopolist offers an upgrade in period 1, which embodies a better technological quality, compared to the technological quality of the previous version, offered in period 0, a period 1 consumer gets the same utility as a period 0 consumer.

Each consumer has a perfectly inelastic demand, i.e., either they consume one unit of the good or they do not consume it. So, at any period the potential market size is unity. The indirect utility to a consumer of type θ, at any period t (t = 0, 1), from consumption of one unit of the product of the firm i (i = I, E), is given by,

$$V_{it} = \alpha N_{it} + \theta - P_{it}$$ if two products are available in the market, at period t, and the technological quality of i is better than that of j ($\neq i$).

$$= \alpha N_{it} - P_{it}$$ otherwise. (1)

N_{it} is the expected network size of the firm i in period t and we assume that the expectations are fulfilled in equilibrium. a is the *coefficient of network externality*, which is a measure of the network effect. Larger the a, stronger is the network effect. Since we are considering positive network externality, a is strictly positive. P_{it} is the price charged by firm i in period t. So, aN_{it} is the network benefit to the period t consumers purchasing from the firm i.

In period 0 only the incumbent is in the market. Therefore, the indirect utility to any period 0 consumer from consuming one unit of the good is given by,

$$V_{I0}=\alpha N_{I0}-P_{I0}, \qquad N_{I0}=q_{I0}, \qquad (2)$$

where q_{I0} is the sales of the incumbent in period 0. Since each of the consumers is getting the same indirect utility, in equilibrium either all the consumers purchase from the incumbent or none of them purchase the good. The incumbent can exist in the market only if all the period 0 consumers purchase from it. Therefore, q_{I0} and hence, N_{I0} is 1. In equilibrium the consumers must get non-negative indirect utility. Therefore, $P_{I0} \leq \alpha$. So, in period 0, the entire market will be covered if the incumbent charges a price $P_{I0} = \alpha$. It is irrational to charge a price less than α. Given the assumption of cost less production the period 0 profit of the incumbent is also α.

The installed base of the incumbent is thus, fixed at 1. Therefore, even when the incumbent is confronted with a threat of entry; it cannot increase the installed base by reducing the price in period 0. Since the payoff to the incumbent, in period 0, is always α, we can treat the period 1 game independently[vi].

In period 1 a continuum of 'new' consumers arrive in the market who are also distributed uniformly in the interval [0, 1] according to their type . In absence of any threat of entry the indirect utility to the period 1 consumers from consuming one unit of the product of the incumbent is given by,

$$V_{I1}=aN_{I1}-P_{I1}, \qquad N_{I1} = 1 + q_{I1} \qquad (3)$$

where q_{I1} is the sales of I in period 1. Therefore, in equilibrium, full market is covered in period 1 as well. The equilibrium price and profit are 2.

Before we proceed to analyse the period 1 game, for expositional purpose we make two assumptions.

Assumption 1: (1/6, 1/2).

Assumption 2:.

$$F \in \left(0, \min\left\{\frac{4}{9}(1-2\alpha), \frac{1}{9}\right\}\right)$$

These two assumptions ensure the existence of interior solution, post entry, except for the case where the incumbent's R&D is 'successful' and the incumbent 'blocks' the converter. Given assumption (2), it is not possible for the incumbent to deter entry, simply by blocking the converter.

Entry Occurs in Absence of R&D

In this section we consider the case where the incumbent does not undertake R&D. Since the incumbent does not undertake R&D, in period 1 it continues to sell the same product which it was selling in period 0. In stage I the entrant decides to enter or not. If it does not enter the incumbent earns a profit of 2α. entry occurs, the firms decide on the provision of the converter in stage II. Finally, in stage III, the firms simultaneously choose prices. The extensive form game is presented in figure 1.

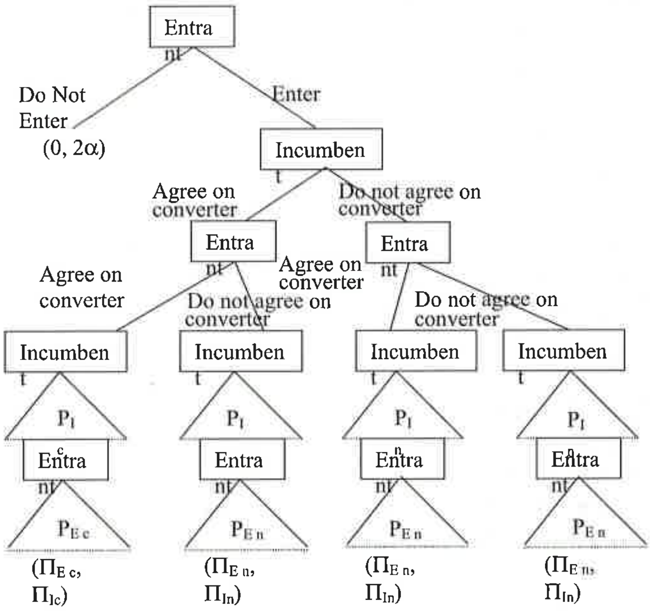


Figure I

Here P_{ic} and Π_{ic} are the price and profit of the firm i (i = E, I) when the products are compatible (i.e., both firms agree on the converter) and P_{in} and Π_{in} are the price and profit of the firm i when the products are not compatible (i.e., at least one of the firms disagrees on the converter). Since we can independently analyse the period 1 game, we are no more using any subscript to indicate time.

Proposition 1: *When the incumbent does not undertake R&D, in equilibrium, entry occurs and post-entry the firms agree on the provision of the converter.*

Proof: First let us analyse the pricing game where *both the firms agree on the provision of the converter* and hence, the products are perfectly compatible.

The effective network size is same for both the firms. Let us define a θ_c, such that the consumer of type θ_c is indifferent between the available products. By continuity of θ, there exists a θ_c. The consumers of type $\theta \geq \theta_c$;

purchase from the entrant and those of type $\theta < \theta_c$; either purchase from the incumbent or do not purchase the good. By definition, $\theta_c = P_{Ec}-P_{Ic}$. From our indirect utility function given in (1) it is apparent that all the consumers of type $\theta < \theta_c$ get the same indirect utility from consuming the product of the incumbent. Therefore, in equilibrium, either all of them purchase from the incumbent or they do not purchase the good at all. The entire market is covered if all of these consumers purchase from the incumbent. In that case the network size is 2. The fact that the consumers should get non-negative surplus in equilibrium implies that $P_{Ic} \leq 2\alpha$. Therefore, the demand function for the entrant and the incumbent are respectively given by,

$$q_{Ec} = 1-P_{Ec}+P_{Ic} \quad \text{if, } 0 \leq P_{Ec} < (1+P_{Ic}),$$
$$=0 \quad \text{otherwise.} \qquad (4)$$

and, $$q_{Ic} = P_{Ec}+P_{Ic} \quad \text{if, } 0 \leq P_{Ic} < P_{Ec} \text{ and } 0 \leq P_{Ic} \leq 2\alpha,$$
$$=0 \quad \text{otherwise.} \qquad (5)$$

The profit functions are given by,

$$\Pi_{Ec}=(1-P_{Ec}+P_{Ic})P_{Ec}-F \quad \text{if, } 0 \leq P_{Ec} < (1+P_{Ic}),$$
$$=-F \quad \text{otherwise.} \qquad (6)$$

and, $$\Pi_{Ic}=(1-P_{Ec}-P_{Ic})P_{Ic} \quad \text{if, } 0 \leq P_{Ic} < P_{Ec} \text{ and } 0 \leq P_{Ic} \leq 2\alpha,$$
$$=0 \quad \text{otherwise.} \qquad (7)$$

From the first order conditions of profit maximization we get the price reaction functions as,

$$P_{Ec} = \frac{1+P_{Ic}}{2} \quad \text{if, } P_{Ic} \geq 0, \qquad (8)$$

and, $$P_{Ic} = \frac{1+P_{Ec}}{2} \quad \text{if, } 0 \leq P_{Ec} \leq 4\alpha, \qquad (9)$$

Solving (8) and (9) we get the equilibrium prices as P^*_{Ec}=2/3 and P^*_{Ic}=1/3, the equilibrium profits are Π^*_{Ec} (4/9)-F and Π^*_{Ic}=1/9. Given our assumption (*1*), the boundary conditions, $P_{Ic} \geq 0$ and $0 \leq P_{Ec} \leq 4\alpha$, are trivially satisfied, in equilibrium. By assumptions (*2*) and (*1*), F < (4/9) (1-2α) < (4/9), and hence, both the firms earn positive profits in equilibrium. So, when the incumbent does not undertake R&D and agrees to the provision of the converter, entry occurs, in equilibrium.

Now, let us analyse the pricing games where *at least one of the firms disagrees on the provision of the converter* and hence, the products are perfectly incompatible.

The effective network size of the incumbent is determined by its installed base and its period 1 sales. The entrant's network size is simply its period 1 sales. As in the previous case, let us define θ_n, such that the consumer of type θ_n is indifferent between purchasing from the entrant and purchasing from the incumbent. By definition,

$$\theta_n = \frac{P_{En}-P_{In}}{1-2\alpha}$$

. All the consumers of type $\theta < \theta_n$ purchase from the incumbent, in equilibrium, only if they get non-negative surplus. Given that the network size of the incumbent, in period 1, is $(1+\theta_n)$ the consumers of type $\theta < \theta_n$ get non-negative surplus only if

$$P_{In} \leq \frac{\alpha(1-2\alpha)+\alpha P_{En}}{(1-\alpha)}.$$

Therefore, the demand function for the entrant and the incumbent are respectively given by,

$$q_{En} = \frac{1-2\alpha P_{En}+P_{In}}{1-2\alpha} \quad \text{if, } 0 \leq P_{En} < (1-2\alpha+P_{In}),$$
$$=0 \quad \text{otherwise.} \qquad (10)$$

and, $$q_{in} = \frac{P_{en}-P_{In}}{1-2\alpha} \quad \text{if, } 0 \leq P_{In} < P_{En} \text{ and } 0 \leq P_{In} \leq, \frac{\alpha(1-2\alpha)+\alpha P_{En}}{(1-\alpha)},$$
$$=0 \quad \text{otherwise.} \qquad (11)$$

The profit functions are given by,

$$\Pi_{En} = \frac{(1-2\alpha-P_{En}+P_{In})P_{En}}{1-2\alpha} - F \quad \text{if, } 0 \leq P_{En} < (1-2\alpha+P_{In}),$$
$$=-F \quad \text{otherwise.} \qquad (12)$$

and, $$\Pi_{In} = \frac{(P_{En}-P_{In})P_{In}}{1-2\alpha} \quad \text{if, } 0 \leq P_{In} < P_{En} \text{ and } 0 \leq P_{In} \leq \frac{\alpha(1-2\alpha)+\alpha P_{En}}{(1-\alpha)}$$
$$=0 \quad \text{otherwise.} \qquad (13)$$

From the first order conditions of profit maximization we get the price reaction functions as,

$$P_{En} = \frac{1-2\alpha+P_{In}}{2} \quad \text{if, } P_{Ic} \geq 0, \qquad (14)$$

and, $$P_{In} = \frac{P_{En}}{2} \quad \text{if, } 0 \leq P_{En} \leq \frac{2\alpha(1-2\alpha)}{(1-3\alpha)} \qquad (15)$$

Solving (14) and (15) we get the equilibrium prices as $P^*_{En} = \frac{2}{3}(1-2\alpha)$ and, $P^*_{In} = \frac{1}{3}(1-2\alpha)$, and the equilibrium profits are

$\Pi^*_{Ec} = \frac{4}{9}(1-2\alpha) - F$ and $\Pi^*_{Ic} = \frac{1}{9}(1-2\alpha)$.[vii]

Given

our assumption (*1*), the boundary conditions $P_{Ic} \geq 0$ and

$0 \leq P_{En} \leq \frac{2\alpha(1-2\alpha)}{(1-3\alpha)}$ are trivially satisfied, in equilibrium.

By assumption (*2*) $F \leq \frac{4}{9}(1-2\alpha)$, and hence, both the firms earn positive profits in equilibrium. So, even when the incumbent disagrees to the provision of the converter, entry occurs in equilibrium, if it does not undertake R&D.

Once the installed base fails to deter entry, there is no incentive for the incumbent to disagree on the converter since it earns a larger profit when the products are compatible. Similarly, the entrant also earns a larger profit when the products are compatible and will agree on the converter.

It is apparent that the revenue of the entrant is smaller when the converter is blocked and hence, it becomes difficult for the entrant to enter. Suppose, $\frac{4}{9}(1-2\alpha) < F < \frac{4}{9}$. The incumbent can deter entry by threatening to disagree on the provision of the converter. When the products are incompatible the installed base of the incumbent plays a pre-emptive role in entry deterrence. By agreeing on the converter the incumbent looses its installed base advantage. But given assumption (2), the installed base of the incumbent fails to play its pre-emptive role in entry deterrence.

Role of R&D Expenditure in Entry Deterrence

In this section we consider the case where the incumbent undertakes R&D before the entrant enters, and issues a public statement about its R&D expenditure. Let R be the exogenously determined R&D expenditure.

Assumption 3: $R \in (0, 1/9]$.

This assumption allows the incumbent to earn a non-negative profit, in equilibrium, even when its R&D is 'unsuccessful'.

Proposition 2: *If the entrant knows that the incumbent's R&D project is 'unsuccessful', entry occurs and the firms agree on the provision of the converter. In equilibrium the incumbent charges a price* $P^*_{IC}=1/3$ *and earns a profit* $\Pi^*_{Ec}=(1/9)-R$. *The equilibrium price and profit of the entrant are* $P^*_{Ec}=2/3$ *and* $\Pi^*_{Ec} = (4/9)-F$ *respectively.*

Proof: When the R&D of the incumbent is 'unsuccessful' the technological quality of the entrant's product is better than that of the incumbent and the analysis is similar to that of proposition 1. When the firms agree on the provision of the converter, the equilibrium prices are $P^*_{Ec}=2/3$ and $P^*_{Ic}=1/3$, and the equilibrium profits are $\Pi^*_{Ec}=(4/9)-F$ and $\Pi^*_{Ic}=(1/9)-R$ respectively for the entrant and the incumbent.

When the firms disagree on the provision of the converter, the equilibrium prices are $P^*_{En} = \frac{2}{3}(1-2\alpha)$ and $P^*_{In} = \frac{1}{3}(1-2\alpha)$, and the equilibrium profits are $\Pi^*_{Ec} = \frac{4}{9}(1-2\alpha) - F$ and $\Pi^*_{Ic} = \frac{1}{9}(1-2\alpha) - R$ respectively for the entrant and the incumbent.

If $\frac{1}{9}(1-2\alpha) < R \leq \frac{1}{9}$, the incumbent earns a non-negative profit when the converter is provided, and a negative profit when the entrant blocks the converter. However, when the converter is not provided the incumbent will not leave the market. The R&D expenditure is already *sunk* and by leaving the market the incumbent will incur a larger loss. The entrant earns only $\Pi^*_{Ec} = \frac{4}{9}(1-2\alpha) - F$ by blocking the converter whereas by agreeing on the converter it earns a larger profit, $\Pi^*_{Ec}=(4/9)-F$. So, the threat of blocking the converter is not credible on part of the entrant. Therefore, when the incumbent's R&D is 'unsuccessful', in a world of complete and perfect information, entry occurs; and post-entry, both the firms gain from provision of the converter. Hence, in equilibrium, they will agree on the converter. Both the firms earn non-negative profits since $R \leq 1/9$.

Proposition 3: *If* $\alpha \geq (2/9)$ *and the entrant knows that the incumbent's R&D project is 'successful', the incumbent's credible threat to disagree on the converter deters entry. The equilibrium profit of the incumbent is* $2\alpha - R$. *However, if* $\alpha < (2/9)$ *entry occurs and post-entry the firms agree on the provision of the converter. In equilibrium the incumbent charges a price* $P^*_{Ic}=2/3$ *and earns a profit* $\Pi^*_{Ic}=(4/9)-R$. *The equilibrium price and profit of the entrant are* $P^*_{Ec}=1/3$ *and* $\Pi^*_{Ec}=(1/9)-F$ *respectively.*

Proof: *When the incumbent's R&D is 'successful', the technological quality of the incumbent's product is better than that of the entrant. The upgrade is perfectly compatible with its previous version and hence, the* *incumbent does not lose its installed base advantage.*

First, let us consider the case where the firms agree on the provision of the converter. We can solve this pricing sub-game in a manner similar to that done in proposition 1. Here, the technological quality of the incumbent's upgrade is better than that of the entrant's product and hence, the consumers of type $\theta \geq \theta_C$ will purchase from the incumbent and those of type $\theta < \theta_C$ will purchase from the entrant. The equilibrium prices of the entrant and the incumbent are, $P^*_{Ec}=1/3$ and $P^*_{Ic}=2/3$ respectively, and the respective profits are $\Pi^*_{Ec}=(1/9)-F$ and $\Pi^*_{Ic}=(4/9)-R$. Since, $R \leq \frac{1}{9}$ and $F \leq \min\left\{\frac{4}{9}(1-2\alpha), \frac{1}{9}\right\}$, entry will occur and both the firms will earn a positive profit.

Now, let us solve the pricing sub-games, where the firms disagree on the provision of the converter. Here, we define, θ'_n, such that the consumer of type θ'_n is indifferent between the two products. By definition, $\theta'_n = \frac{P_{In} - P_{En} - 2\alpha}{1-2\alpha}$. All the consumers of type $\theta < \theta'_n$ purchase from the entrant, in equilibrium, only if they get non-negative surplus. The consumers of type $\theta < \theta'_n$ get non-negative surplus only if $P_{En} \leq \frac{\alpha(P_{In} - 2\alpha)}{(1-\alpha)}$. Therefore, the demand function for the entrant and the incumbent are respectively given by,

$$q_{En} = \frac{P_{In} - P_{En} - 2\alpha}{1-2\alpha} \text{ if } 0 \leq P_{En} < (P_{In} - 2\alpha) \text{ and } 0 \leq P_{En} \leq \frac{\alpha(P_{In} - 2\alpha)}{(1-\alpha)}$$

$$=0 \quad \text{otherwise} \quad (16)$$

and,

$$q_{In} = \frac{1 + P_{En} - P_{In}}{1-2\alpha} \quad \text{if } 0 \leq P_{In} < 1 + P_{En}$$

$$=0 \quad \text{otherwise.} \quad (17)$$

In section 2, we found that in absence of any threat of entry, the incumbent can charge a price of 2α, in period 1. It is apparent from the demand function (16), that there does not exist a non-negative P_{En} for which $q_{En}>0$, if $P_{In} = 2\alpha$. Therefore, if the incumbent blocks the converter and charges its monopoly price 2α, entry will not occur. In equilibrium, the full market is covered and the incumbent earns a profit of 2α. The intuition is simple. In this case, the technological quality of incumbent's product is better than the entrant's product and also, given its installed base, the incumbent's network is larger. Hence, there exist no incentive for any consumer to purchase the product of the entrant.

So, by disagreeing to the converter the incumbent can deter entry, when its R&D is 'successful'. In equilibrium, the incumbent's profit is 2α - R. On the other hand if the incumbent accommodates entry by agreeing to the converter, its profit is (4/9)-R. Therefore, the threat to disagree on the converter is *credible* only if $\alpha \geq (2/9)$.

By allowing entry the incumbent can provide the consumers a 'reference frame' to compare the products. This increases the consumer's willingness to pay for the incumbent's upgrade, according to their type, and in turn allows the incumbent to charge a higher price. Let us call this effect, the *product differential effect*. On the other hand, when the incumbent allows entry by agreeing to the converter, it looses its *installed base advantage*. When $\alpha < (2/9)$, the network effect is 'weak'. Therefore, the *product differential effect* offsets the *installed base advantage* and the incumbent is better off by allowing entry. However, when $\alpha \geq (2/9)$, the network effect is 'strong' and the *installed base advantage* dominates over the *product differential effect*. Therefore, in the latter case, the incumbent will deter entry by credibly threatening to block the converter.

In view of proposition 3, we modify our assumption (*1*) as follows:

Assumption 1.a: $\alpha \in [2/9, 1/2)$.

Since we are interested in the issue of entry deterrence, we restrict ourselves to the interval of for which it is worthwhile to deter entry.

Proposition 2 and 3 show that the entrant will not enter if it knows that the incumbent's R&D is 'successful', and will enter if it knows that the R&D is 'unsuccessful'. However, ex-ante the outcome of the R&D is uncertain. We assume that there can be two types of incumbent. The probability of 'success' for type H incumbent is p_H and that for type L is p_L where, $p_H > p_L$. The entrant knows these probabilities. We assume that the entrant's expected payoff from entering is positive if the incumbent is a type L firm and is negative if the incumbent is type H.

Assumption 4: $\frac{4}{9}(1-p_L) > F > \frac{4}{9}(1-p_H)$

This assumption implies that the entrant will enter if it knows that the incumbent is of type L and will not enter if the incumbent is of type H. However, in a world of incomplete information, the entrant does not know the type of the incumbent.

First, *Nature* draws a type of the incumbent. Let Nature draw the type H with probability x, i.e., the prior *belief* of the entrant is that the incumbent is of type H with probability x. After Nature draws the type of the incumbent, the incumbent decides whether to undertake R&D or not. The incumbent's action gives a signal about its type. Observing the signal the entrant updates its belief by Bayes' rule and then decides to enter or not. Post-entry the game is same as that described in section 2. The extensive form representation of the reduced signalling game is shown in figure 2.

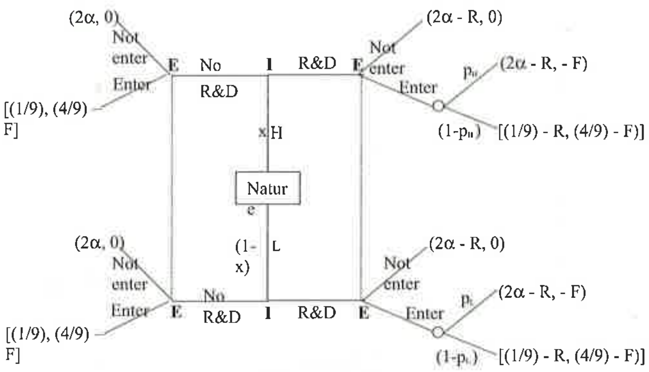


Figure II

Lemma 1: There exists a *pooling* equilibrium where the incumbent's strategy is (R&D, R&D) and the entrant's response is (Enter, Not Enter)[viii], if and only if the entrant's *prior belief* is given by $x \geq \frac{1-p_L-(9/4)F}{P_H - P_L}$

[Proof given in the appendix.]

Lemma 2: There does not exist an equilibrium, where the incumbent adopts the *pooling* strategy (No R&D, No R&D).

[Proof given in the appendix.]

Lemma 3: There does not exist any *separating* equilibrium for the above signalling game

[Proof given in the appendix.]

Applying lemma 1 3 we can write the following proposition.

Proposition 4: *If* $x \geq \frac{1-p_L-(9/4)F}{p_H - p_L}$ *there exists a unique pure-strategy perfect Bayesian equilibrium of this signalling game where both types of incumbent invest in R&D and the entrant does not enter.*

Corollary to proposition 4: *If* $x < \frac{1-p_L-(9/4)F}{p_H - p_L}$ *and* $p_L > \frac{R}{2\alpha-(1/9)}$ *there exists a unique pure-strategy perfect Bayesian equilibrium of this signalling game where the incumbent adopts the pooling strategy (R&D, R&D) and the entrant's response is (Enter, Enter).*

[Proof of this corollary is given in the appendix.]

So, irrespective of whether the incumbent's R&D is ex-post 'successful' or not, the incumbent can deter entry by undertaking R&D and publishing data on R&D expenditure if, $x \geq \frac{1-p_L-(9/4)F}{p_H - p_L}$.

An Extension: Endogenising R&D Expenditure

In our analysis in section 4 we kept the R&D expenditure exogenous. In this section we extend our analysis to endogenise it.

Assumption 5: $p_H=p_H(R)$ if $R<\bar{R}$,

$= 1$ if $R \geq \bar{R}$, where, $\bar{R}=1/9$

$p'_H(R)>0$ and $p''_H(R)<0$, for all $R<\bar{R}$ and $\lim_{R\to\bar{R}-} p_H(R)=1$

Assumption 6: $p_L=p_L(R)$ if $R<\bar{R}$,

$=\bar{p}_L$ if $R\geq\bar{R}$, where, $\bar{R}=1/9$ and $\bar{p}_L<3/4$

$p'_L(R)>0$ and $p''_L(R)<0$, for all $R<\bar{R}$ and $\lim_{R\to\bar{R}-} p_L(R)=\bar{p}_L$

$p_H(R)>p_L(R)$ for all $0<R<\bar{R}$.

We further assume the differential to be increasing in R, i.e.,

$p'_H(R)>p'_L(R)$ for all $0<R<\bar{R}$.

Assumptions (*5*) and (*6*) imply that there is no incentive for either type of the incumbent to spend more than (1/9) in R&D.

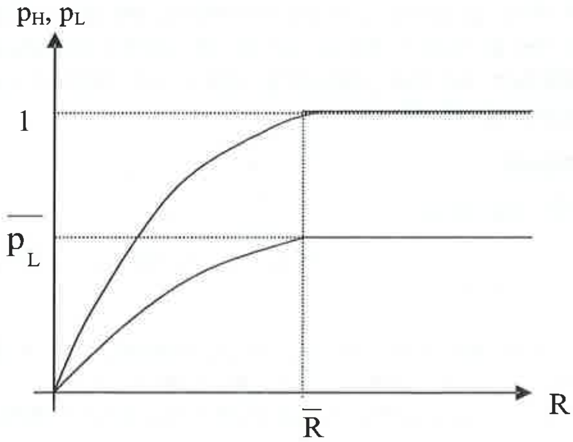


Figure III

Therefore, when entry occurs, the expected profit of the type H incumbent is given by,

$$E(\Pi_H) = p_H(R)2\alpha + (1 - p_H(R))\frac{1}{9} - R \qquad \text{if } R < \bar{R}$$

$$= 2\alpha - R \qquad \text{if } R \geq \bar{R} \qquad (18)$$

The expected profit of the type L incumbent is given by,

$$E(\Pi_L) = p_L(R)2\alpha + (1 - p_L(R))\frac{1}{9} - R \qquad \text{if } R < \bar{R}$$

$$= (2\alpha - \frac{1}{9})\bar{p}_L - (R - \frac{1}{9}) \qquad \text{if } R \geq \bar{R} \qquad (19)$$

Since, $p_H(R) > p_L(R)$ for all $0 < R \leq \bar{R}$, $E(\Pi_H) < E(\Pi_L)$. Also, since p_H and p_L are strictly concave, it can be easily shown that the expected profit functions are also concave, for $0 < R \leq \bar{R}$.

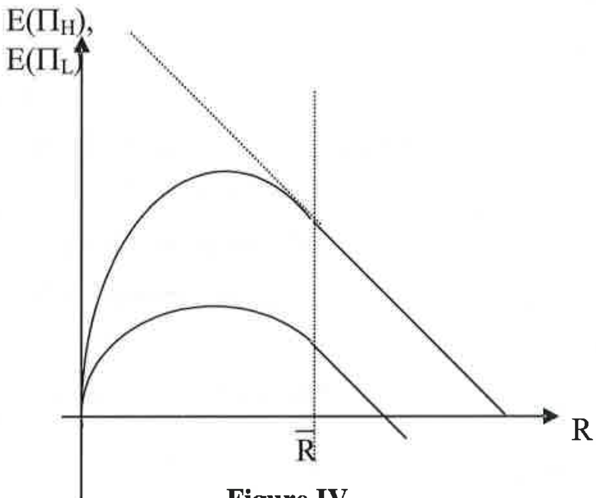


Figure IV

Given the above specifications, neither type of incumbent will spend more than $\bar{R}$ on R&D, since, for all $R > \bar{R}$, the expected profits are monotonically decreasing in R. So to check the existence of perfect Bayesian equilibrium for the signalling game we restrict our analysis to $0 < R \leq \bar{R}$.

Lemma 4:

$\exists$ a $\hat{R} \in (0, \bar{R}]$, such that $x = \frac{1 - p_L(\hat{R}) - (9/4)F}{p_H(\hat{R}) - p_L(\hat{R})}$ if, $x \geq \frac{1 - p_L(\bar{R}) - (9/4)F}{p_H(\bar{R}) - p_L(\bar{R})}$. [Proof given in the appendix.]

If the incumbent adopts a pooling strategy, i.e., both types choose the same R, given the entrant's prior belief x, from lemma 1 we know that it will not enter if and only if, $x \geq \frac{1 - p_L(R) - (9/4)F}{p_H(R) - p_L(R)}$ Now if there exists a R, for all R<R, $x < \frac{1 - p_L(R) - (9/4)F}{p_H(R) - p_L(R)}$ and for all R≥R, $x \geq \frac{1 - p_L(R) - (9/4)F}{p_H(R) - p_L(R)}$. Therefore, if the incumbent adopts a pooling strategy, the entrant will enter only if $R < \hat{R}$.

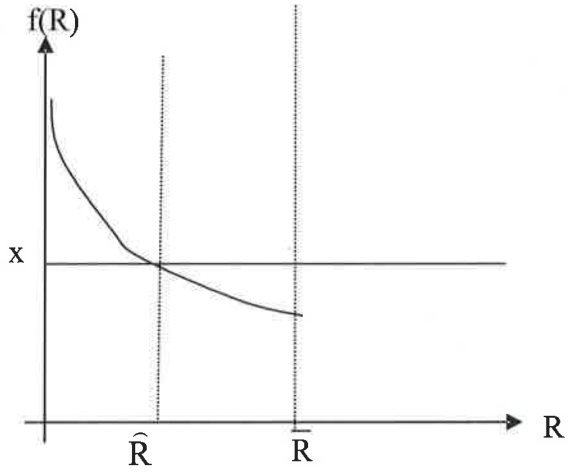


Figure V

Lemma 5: $\exists\, 0 < \tilde{R}_H < \bar{R}$ such that $\frac{4}{9}(1 - p_H(\tilde{R}_H)) = F$.

[Proof given in the appendix.]

If the incumbent adopts a separating strategy, i.e., different types choose different R, the entrant's belief is updated and it can correctly infer the type of the incumbent. From our analysis in the previous section, we know that the entrant, confronting a type H incumbent, does not enter only if $F \geq 4/9(1 - p_H(R))$. Since, there exist $0 < \tilde{R}_H < \bar{R}$, the entrant, confronting a type H incumbent, does not enter if $R \geq \tilde{R}_H$.

Lemma 6: Since $\bar{p}_L < 3/4$, for all $0 < R \leq \bar{R}$ and for all

$$F \leq \min\{\frac{25}{81}(1 - 2\alpha), \frac{1}{9}\}, \quad F < \frac{1}{9}(1 - p_L(R))$$

[Proof given in the appendix.]

From our analysis in the previous section, we know that in a separating equilibrium, the entrant, confronting a type L incumbent, does not enter only if $F \geq \frac{1}{9}(1 - p_L(R))$.

From lemma 6 we conclude that the entrant confronting a type L incumbent will always enter since, $\bar{p}_L < 3/4$.

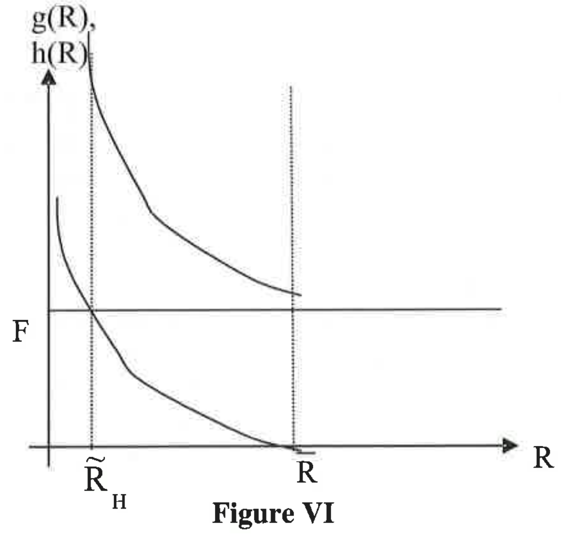


Figure VI

Lemma 7: If there exists a $\hat{R} \in (0, \bar{R}]$, then $\tilde{R}_H < \hat{R}$.

[Proof given in the appendix.]

If $x \geq \frac{1 - p_L(\bar{R}) - (9/4)F}{p_H(\bar{R}) - p_L(\bar{R})}$, $\tilde{R}_H < \hat{R} \leq \bar{R}$. Clearly the entrant's strategy is to enter if $R < \hat{R}$ and not to enter otherwise. For all $0 < R \leq \bar{R}$, $E(\Pi_i) \leq (2\alpha - R)$, i = {H, L}. Therefore, spending $R < \hat{R}$ becomes a dominated strategy for the incumbent. Again, $(2\alpha - R)$ is monotonically decreasing in R. Therefore, the best response for the incumbent of both types is to spend $\hat{R}$. Now we can write the following proposition.

Proposition 5: *If*, $x \geq \frac{1 - p_L(\bar{R}) - (9/4)F}{p_H(\bar{R}) - p_L(\bar{R})}$ *there exists a unique pure strategy perfect Bayesian equilibrium where the incumbent chooses the pooling strategy* $(\hat{R}, \hat{R})$ *and the strategy of the entrant is (Enter if* $R < \hat{R}$*, Not Enter otherwise).*

It is apparent from the above discussion that there does not exist a separating equilibrium.

An Example: *Let* $\alpha = 4/9$, $F = 2/81$ and $x = 5/6$. Therefore, $\alpha \in (2/9, 1/2)$, $F \leq \min\{4/9(1-2\alpha), 1/9\}$.

Let, $p_H = \left(\frac{R}{\bar{R}}\right)^{\frac{1}{2}}$ if $R < \bar{R}$,

= 1 if, $R \geq \bar{R}$ where, $\bar{R} = 1/9$

and, $p_L = \bar{p}_L \left(\frac{R}{\bar{R}}\right)^{\frac{1}{2}}$ if $R < \bar{R}$,

$= \bar{p}_L$ if $R \geq \bar{R}$, where $\bar{R} = 1/9$, and $\bar{p}_L = 11/16$

Clearly, p_H and p_L are monotonically increasing and strictly concave in R, for $0 < R \leq \bar{R}$. Also, for the given values, $x \geq \frac{1 - p_L(\bar{R}) - (9/4)F}{p_H(\bar{R}) - p_L(\bar{R})}$. Therefore, there exists a $\hat{R} \in (0, \bar{R}]$, such that $x = \frac{1 - p_L(\hat{R}) - (9/4)F}{p_H(\hat{R}) - p_L(\hat{R})}$. Solving for $\hat{R}$, we get $\hat{R} = 0.1102$. In equilibrium, both types of incumbent spend $\hat{R} = 0.1102$ and the entrant does not enter. In the following section, we analyse the welfare implications of entry deterrence by R&D investment.

Welfare Implications:

When the incumbent does not undertake R&D it accommodates entry and, in equilibrium, agrees to the converter. The equilibrium profits are $\Pi^*_{Ec} = (4/9) - F$ and $\Pi^*_{Ic} = 1/9$. The consumers of type $\theta \geq \theta_C$ purchase from the entrant and those of type $\theta < \theta_C$ purchase from the incumbent. In equilibrium, $\theta_c = P_{Ec} - P_{Ic} = (1/3)$. The aggregate consumers' surplus is given by,

$$CS = \int_0^{(1/3)} (2\alpha - \frac{1}{3})d\theta + \int_{(1/3)}^{1} (2\alpha + \theta - \frac{2}{3})d\theta = (2\alpha - \frac{1}{9}).$$

Therefore, the aggregate welfare under entry accommodation is given by,

$$W_A = 2\alpha + \frac{4}{9} - F \quad (20)$$

When the incumbent deters entry by strategically spending on R&D it earns a monopoly profit given by $(2\alpha - R)$. Since, the monopoly price 2 is exactly equal to the network benefit to the consumers, there is no consumer's surplus. Therefore(,) the aggregate welfare under entry deterrence is given by,

$$W_D = 2\alpha - R \quad (21)$$

Since, $F \leq \min\{\frac{4}{9}(1-2\alpha), \frac{1}{9}\}$ comparing (20) and (21), we conclude that entry deterrence is welfare reducing.

Conclusion:

The majority of the existing literature, on entry deterrence in network markets, suggests that an incumbent can deter entry simply by keeping its product incompatible with the product of the entrant. The installed base of the incumbent plays a pre-emptive role in such entry deterrence. However, it is possible that the installed base advantage of the incumbent is not enough to deter entry, simply by keeping the product incompatible with the product of the entrant. In such a circumstance, it is possible for the entrant to deter entry by using R&D expenditure as a strategic signal. The result is independent of the outcome of the R&D project. We also show that such entry deterrence is welfare reducing. The implication of this result is very important in the context of anti-trust laws. A monopolist can spend on R&D with the sole motivation of entry deterrence. In that case the outcome of the R&D project is immaterial to the firm conducting the R&D. Such behaviour is certainly anti-competitive and should be taken into account while designing the anti-trust laws.

Appendix

- *Proof of Lemma 1:* Given the prior belief x and the incumbent's strategy (R&D, R&D), the entrant's best response is (Enter, Not Enter) if and only if

  $$\{x(1-p_H)+(1-x)(1-p_L)\}(4/9)-F<0 \Rightarrow x \geq \frac{1-pL-(9/4)F}{p_H-p_L}.$$

  Both types of incumbent gains from investing in R&D if (2 α- R) > (1/9). Given that R≤1/9, (2α - R) > (1/9) is trivially true.

- *Proof of Lemma 2:* Consider the incumbent's strategy (No R&D, No R&D). From lemma 1 we know that the entrant's response is (Enter, Not Enter) if $x \geq \frac{1-p_L-(9/4)F}{p_H-p_L}$ and (Enter, Enter) otherwise. In the former case both types gain from deviation. In the later case type H incumbent gains by deviating if the expected payoff to the type H from investing in R&D is larger that the payoff from not investing in R&D, i.e., if $\{p_H(2\alpha)+(1-p_H)(1/9\}-R>(1/9)$. Given our assumptions this is always true.

- *Proof of Lemma 3:* First let us consider the separating strategy (No R&D, R&D). Since the entrant's belief is determined by Bayes' rule, the entrant's response is (Enter, Enter). Type H gains from deviation if $\{p_H(2\alpha)+(1-p_H)(1/9\}-R>(1/9)$ which is always true.

  Now let us consider the separating strategy (R&D, No R&D). The entrant's belief is determined by Bayes' rule and its response is (Enter, Not Enter). Therefore, type L incumbent gains from deviation if (2α - R) > (1/9) which is trivially true.

- *Proof of the corollary to proposition 4:* First let us consider the pooling strategy (R&D, R&D). Given the entrant's prior belief $x<\frac{1-p_L-(9/4)F}{p_H-p_L}$, the entrant's response is (Enter, Enter). Type H incumbent does not gain by deviating if the expected payoff to the type H from investing in R&D is larger that the payoff from not investing in R&D, i.e., if $\{p_H(2\alpha)+(1-p_H)(1/9)\}-R>(1/9)$, which is always true. Type L also does not gain from deviation if $\{p_L(2\alpha)+(1-p_L)(1/9)-R>(1/9)$, i.e., if $p_L>\frac{R}{2\alpha-(1/9)}$, . Therefore, there exists a pooling equilibrium where both types of the incumbent invest in R&D and the entrant enters. Now let us consider the pooling strategy (No R&D, No R&D). The entrant's response is (Enter, Enter). Since, $p_L>\frac{R}{2\alpha-(1/9)}$, both types of incumbent gain from deviation. Now let us consider the separating strategy (No R&D, R&D). Entrant's response is (Enter, Enter). It follows from lemma 3 that the type H gains from deviation. Finally, let us consider the separating strategy (R&D, No R&D). Type L incumbent gains from deviation since,

  $$p_L>\frac{R}{2\alpha-(1/9)},$$

- *Proof of Lemma 4:* Let $f(R)=\frac{1-p_L(R)-(9/4)F}{p_H(R)-p_L(R)}$. Since $p'_L(R)>0$ and $p_H(R)-p_L(R)$ is increasing in R, f(R) is defined for all $0<R\leq\bar{R}$ and is monotonically decreasing in R. By continuity of f(R) there exists a $\hat{R}\leq\bar{R}$ only if, $x\geq\frac{1-p_L(\bar{R})-(9/4)F}{p_H(\bar{R})-p_L(\bar{R})}$

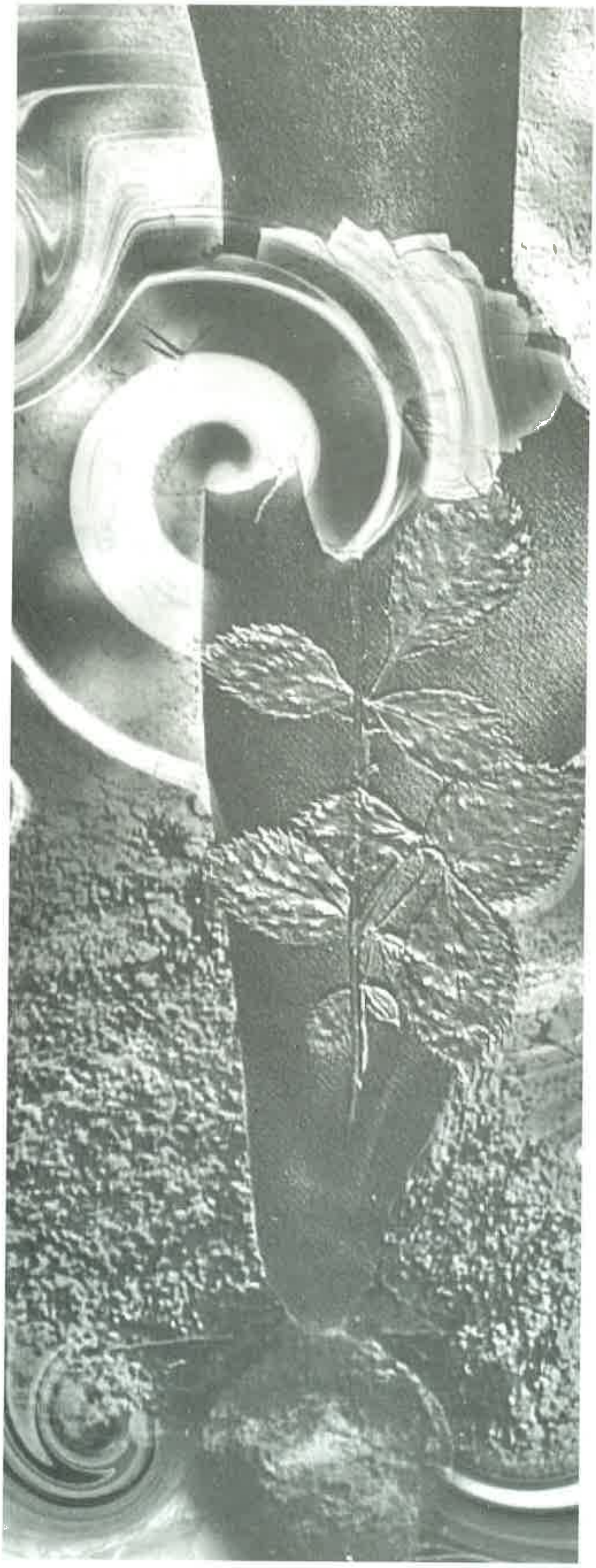
- *Proof of Lemma 5:* Let, $h(R)=4/9(1-p_H(R))$. Since, and $p'_H(R)>0$, h(R) is monotonically decreasing in R. $p_H(\bar{R})=1$ implies $h(\bar{R})=0$. Now, since F > 0, by continuity of h(R) there exists $\tilde{R}_H<\bar{R}$.

- *Proof of Lemma 6:* Let $g(R)=4/9(1-p_L(R))$. Now, $g(\bar{R})=4/9(1-\bar{p}_L)$. Given that $F\leq\min\{4/9(1-2\alpha),1/9\}$ and $\bar{p}_L<3/4$, for all $0<R\leq\bar{R}$, $F<g(\bar{R})$. Since, $p'_L(R)>0$, g(R) is monotonically decreasing in R and hence min. $g(R)=g(\bar{R})>F$. Therefore, $g(R)>F$ for all $0<R\leq\bar{R}$.

- *Proof of Lemma 7:* If, $x\geq\frac{1-p_L(\bar{R})-(9/4)F}{p_H(\bar{R})-p_L(\bar{R})}$ there exists a $\hat{R}\in(0,\ \bar{R}]$, by definition of $\hat{R}$, $x=\frac{1-p_L(\hat{R})-(9/4)F}{p_H(\hat{R})-p_L(\hat{R})}$. By definition of $\tilde{R}$, $4/9(1-P_H(\tilde{R}_H))=F$. Therefore, $(1-P_H(\tilde{R}_H))=9/4F$ and hence,

  $$x=\frac{p_H(\tilde{R}_H)-p_L(\hat{R})}{p_H(\hat{R})-p_L(\hat{R})}$$

  Since, x < 1, $p_H(\tilde{R}_H)<p_H(\hat{R})$ and hence, $\tilde{R}_H<\hat{R}$.



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