Discussion Paper No. 410

Adoption and Diffusion of an Innovation under Uncertain Profitability

Richard Jensen*

December 1979; Revised February 1981

Department of Economics
The Ohio State University
Columbus, Ohio 43210

*The author has benefited substantially from discussions with John Ledyard and Glenn Loury. He also wishes to thank an anonymous referee for graciously pointing out errors in an earlier version of this paper. This work was partially supported by National Science Foundation Grant No. SOC 78-12884.

Innovation Adoption and Diffusion

Richard Jensen

Department of Economics

The Ohio State University

Columbus, Ohio 43210

1. Introduction

The argument has frequently been made that the pattern of diffusion associated with most new innovations will typically have certain characteristics. A diffusion curve for an innovation is usually defined as the proportion of its potential users who have already adopted as a function of time (measured from the first adoption). Many empirical studies by both economists and other social scientists have shown that diffusion curves nearly always have two distinct characteristics: (i) they are "S-shaped" (the proportion adopted is an increasing function of time which is initially convex but eventually becomes concave); and (ii) they tend to be right-hand skewed (the inflection point occurs at a time corresponding to a proportion adopted which is less than one half, so that the function is concave over the greatest amount of time; in fact, this skewing is occasionally severe enough to make the diffusion curve appear concave everywhere).[1]

The focus of most empirical studies of innovation diffusion has centered on identification of either the major determinants of the speed of diffusion or the characteristics of firms which determine how long they delay adoption.[2] The seminal contributions are Griliches' [6] study of hybrid corn and Mansfield's [12] study of twelve industrial innovations. These studies, and most of the similar ones following, conclude that diffusion is faster for innovations with higher profitability and that large firms tend to be the earliest adopters.

Some studies (e.g., Mansfield [12], Herregat [7]) have attempted to ascertain the effect of information and management attitude toward innovation on diffusion, an effort which seems to have been inspired by the work of the sociologist Rogers [16]. However, these attempts have been largely unsuccessful, probably due to the obvious measurement problems. The primary deficiency in this line of research is the lack of decision-theoretic models of individual firm behavior. Following Mansfield, most authors assume that the probability of adoption by a firm at a given date is positively related to the proportion of firms in the industry who have already adopted.[3] This assumption implies a differential equation whose solution yields a logistic (S-shaped) diffusion curve. Although empirically convenient, this is a description of aggregate industry behavior which sheds no light on the individual firm's adoption decision and hence fails to provide a behavioral explanation of why some firms are quicker to adopt than others.

On the other hand, the decision-theoretic approaches to individual firm adoption behavior have tended to confine themselves to explaining why and how long a firm would delay its adoption of a capital-embodied innovation. In these models a firm delays adoption while waiting either for its capital in place to deteriorate sufficiently to make adoption profitable (e.g., Fellner [3], Salter [17]), or for the innovation's profitability to increase sufficiently (e.g., Flaherty [4], Reinganum [15]), or both (e.g., Smith [19], Hinomoto [8]). The major deficiencies in these approaches are that they are limited to capital-embodied innovations, they ignore the effect of information and management attitudes on the firm's adoption decision, and they do not link firm adoption behavior to the diffusion of an innovation through an industry.

The purpose of this paper is to develop a decision-theoretic model of individual firm adoption behavior which can be used to derive an expected diffusion curve with the commonly observed characteristics mentioned above.

This analysis will therefore bridge a gap in the literature by providing a possible explanation for the most typical pattern of innovation diffusion which is based on optimal adoption behavior and certain characteristics of firms in the industry. The approach used is to view adoption as a problem of decision-making under uncertainty when learning can occur. That is, when the innovation is introduced, the firm does not know whether adoption will be profitable or not, but this uncertainty can be reduced by waiting and gathering information. In Section 2 the firm's decision problem is formalized as an optimal stopping problem in which the firm can either stop and receive the expected return from adoption or wait, take an observation, and receive the discounted expected value of this information. While waiting the firm learns about the innovation; that is, the firm starts with an original belief that the innovation is profitable (expressed as a subjective prior probability) which it adjusts each time it receives new information by applying Bayes' rule. An optimal adoption rule based on the firm's current belief that the innovation is profitable is then derived and used to show that the firm will delay adoption of a profitable innovation when its original belief is sufficiently low. This rule is also used to generate results relating the probability of adoption at or before a given date to the parameters of the model.

In Section 3 an industry model is constructed in which firms differ only in their original beliefs that the innovation is profitable. An appropriate diffusion function is then defined and used to derive the common empirical finding that diffusion is more rapid for innovations of higher profitability. This diffusion curve is then shown to be either S-shaped or concave when it is assumed that the original beliefs are distributed uniformly and that the proportion of observations seen is equal to the true proportion (for a profitable innovation). Although these assumptions are somewhat restrictive, this is nevertheless an important and intriguing result. This is so not only because it is the first derivation of an S-shaped diffusion curve for innovations adopted by firms, but also because it shows that differences among firms in their subjective beliefs that the innovation will be profitable may be sufficient to explain the commonly observed pattern of diffusion. Section 4 then concludes the paper with a brief summary of the results and a discussion of the limitations and possible extensions of the analysis.

2. The Adoption Decision of the Firm

Consider a firm confronted by an exogenously developed innovation which, if adopted, could either increase or decrease the firm's expected present value (compared to its current level). Information about the innovation's existence comes from a source external to the firm(such as the innovation's supplier or industry trade journals) which will continue to provide information at discrete intervals as long as the firm has not adopted. It is assumed that the firm can classify each piece of information as being either favorable or unfavorable to the innovation, so that each observation can be represented by a Bernoulli random variable Z which takes on the value 1 if the information is favorable and 0 if not. Hence, if the firm does not adopt it will observe a sequence of random variables $Z_1, Z_2, \ldots,$ which are assumed to be independent and identically distributed with unknown parameter $\theta = \Pr\{Z_i=1\} \varepsilon (0,1)$. It is also assumed that θ can take on only two values, θ_1 and θ_2, where $0 < \theta_2 < \theta_1 < 1$.

Associated with each value of the random variable are certain revenues R_1 and R_0, where $R_1 > R_0$. Hence θ can be interpreted as the probability that the revenue R_1 is earned if the firm adopts and $1-\theta$ as the probability that R_0 is earned. Both R_1 and R_0 represent the present discounted value of the future stream of revenues resulting from adoption. That is, $R_i = \frac{r_i}{1-\beta}$

$(i=0,1)$, where r_i is the revenue per period earned after adoption, $r_1 > r_0$, and $\beta\varepsilon(0,1)$ is the discount rate. So if the firm adopts, it will receive r_1 in each period thereafter in which its experience is favorable and r_0 if its experience is unfavorable. There is a fixed cost $C > 0$ of adopting the innovation, so that the expected adoption return is $\theta R_1 + (1-\theta)R_0 - C$.[4] It is assumed that

$$\theta_1 R_1 + (1-\theta_1)\, R_0 - C > 0 > \theta_2 R_1 + (1-\theta_2)\, R_0 - C, \tag{1}$$

so the innovation is profitable (good) if $\theta = \theta_1$ and unprofitable (bad) if $\theta = \theta_2$.

To compute the expected values of adoption and the next observation the firm must estimate θ, which is assumed to be done in standard Bayesian fashion. That is, if p is the firm's current probabilistic belief that $\theta = \theta_1$, then θ is estimated by

$$q(p) = p\theta_1 + (1-p)\theta_2. \tag{2}$$

It is also assumed that, when the innovation appears, the firm assigns a subjective prior probability $g\varepsilon[0,1]$ to the event $\theta = \theta_1$. This initial belief that the innovation is good will depend on both the attitudes and expertise of the firm's decision-makers and their experience with similar innovations in the past. The exact assignment of g will not be dealt with explicitly, but instead will be taken as given. The firm's learning behavior is assumed to be Bayesian also. Given the current belief p that $\theta = \theta_1$, the updated belief is

$$h_1(p) = \frac{p\theta_1}{q(p)} \tag{3}$$

if the observation is favorable and

$$h_0(p) = \frac{p(1-\theta_1)}{1-q(p)} \tag{4}$$

if the observation is unfavorable. Hence, after n observations, k of which were favorable $(k \leq n)$, the firm's updated belief that $\theta = \theta_1$ will be

$$p(n,k,g) = [1 + (\frac{\theta_2}{\theta_1})^k (\frac{1-\theta_2}{1-\theta_1})^{n-k} (\frac{1-g}{g})]^{-1}. \tag{5}$$

The firm's decision problem can now be formally stated as an optimal stopping problem, in which the stopping value is the expected return from adoption and the value from optimal continuation is the discounted expected value of the next piece of information. Since $g \varepsilon [0,1]$ it is clear that $p(n,k,g) \varepsilon [0,1]$, so the state variable for this stochastic process can be taken to be $p \varepsilon [0,1]$, the firm's current belief that the innovation is good. Let $V_t(p)$ denote the maximum expected return when the state is p and there are $t=0,1,\ldots$, decision dates remaining. Assuming that $V_0(p) = 0$ for all p, the $V_t(p)$ for $t=1,2,\ldots$ are defined recursively by

$$V_t(p) = \max\{V_t^a(p), V_t^w(p)\} \tag{6}$$

where the expected adoption return is

$$V_t^a(p) = q(p)R_1 + (1-q(p))R_0 - C \tag{7}$$

and the expected value of optimal continuation (the waiting value)[5] is

$$V_t^w(p) = \beta[q(p)V_{t-1}(h_1(p)) + (1-q(p))V_{t-1}(h_0(p))]. \tag{8}$$

Since the focus of this paper is on the case where there are an infinite number of decision dates, it is necessary to prove the existence of the dynamic programming functional equation

$$V(p) = \max\{V^a(p), V^w(p)\} \tag{9}$$

where $V^a(p)$ is given by the right-hand side of (7) and

$$V^w(p) = \beta[q(p)V(h_1(p)) + (1-q(p))V(h_0(p))]. \tag{10}$$

Because this is a familiar exercise, a formal proof will be eschewed. The existence of an optimal adoption rule for a firm facing this decision problem is given by the following theorem.[6]

Theorem 1: There exists a unique $p^* \varepsilon (0,1)$ such that $V^a(p) \gtreqless V^w(p)$ if and only if $p \gtreqless p^*$.

Proof: Standard techniques can be used to show that: (i) V(p) is continuous and convex on [0,1]; (ii) $V^w(0) \geq 0 > V^a(0) = \theta_2 R_1 + (1-\theta_2)R_0 - C$; and (iii) $V^w(1) = \beta[\theta_1 R_1 + (1-\theta_1)R_0 - C] < V^a(1) = \theta_1 R_1 + (1-\theta_1)R_0 - C$. Hence, it follows from (2) and (7) that $V^w(p) - V^a(p)$ is a continuous, convex function on [0,1] which is positive at p = 0 and negative at p = 1. Q.E.D.

The optimal adoption rule for the firm can thus be expressed as: adopt at any decision date when $p \geq p^*$ and otherwise wait. That is, the firm should adopt when its current belief the innovation is good attains a minimum reservation level. The following result about how the reservation probability p* varies with the parameters of the model will be useful in proving several additional results. The proof of this lemma is omitted because it requires several long and tedious inductions on t which would add nothing of value to the ensuing analysis.[7]

Lemma 1: p* varies directly with C and inversely with r_1, r_0, and β.

The preceding results can be used to determine how the probability of adoption at or before a given stage of the process varies with the parameters of the model.

Theorem 2: The probability of adoption at or before a given stage n varies directly with g, k, r_1, r_0, and β and inversely with C.

Proof: Theorem 1 implies that the probability of adoption at or before n can be written as $Pr\{p(n,k,g) \geq p^*\}$. Hence, the theorem's statement follows from this and from Lemma 1 and the fact that $\frac{\partial p(n,k,g)}{\partial g} > 0$ and $p(n,k+1,g) > p(n,k,g)$ for k=0,1,...,n-1. Q.E.D.

This theorem simply states that a firm is more likely to have adopted by a given stage when the discount rate is higher or the firm's estimate of the expected profitability of the innovation at that stage is higher. This is not a surprising result, of course, but it is significant to note that this result is an implication of optimal firm behavior under this model.

The final result presented in this section is also not a surprising one, but it is necessary in order to show that a diffusion can occur in an industry composed of firms facing this decision problem.

Theorem 3: Immediate adoption may not be optimal, but a good innovation will eventually be adopted with probability one if $g \neq 0$.

Proof: Theorem 1 implies that immediate adoption is not optimal if $g \epsilon [0,p^*)$. And if $g \neq 0$, then the strong law of large numbers implies $\Pr\{\lim_{n\to\infty} p(n,k,g) = 1\} = 1 > p^*$. Q.E.D

Hence, a firm will delay its adoption of a good innovation (i.e., one which it would have immediately adopted under certainty) if it is sufficiently skeptical when the innovation appears, but is willing to learn. Finally, given that delayed adoption is optimal for the firm, it is easily seen that the length of delay will tend to be shorter the more optimistic is the firm, the more favorable the information received, the higher the discount rate or period adoption returns, or the lower the cost of adoption.

3. The Rate of Diffusion and an Expected Diffusion Curve for an Innovation

The optimal adoption rule derived in Section 2 will now be used to analyze the diffusion of a good innovation in a simple industry model. Consider an industry composed of a continuum of firms who become aware of the innovation at the same time, receive the same information about it (if they wait), and are identical in every way except for their original beliefs that the innovation is good. The assumption of common knowledge about the innovation is a reasonable one since the observations arise from an external source in this model. The assumption of different original beliefs is also reasonable since both the expertise and attitudes of decision-makers and previous experience with similar innovations is bound to vary among firms. The approach will be to determine what kind of diffusion curve could be expected to be observed when the innovation is good (and therefore will eventually be adopted by all firms).

Given these assumptions, firms will adopt at different dates if and only if their original beliefs differ. Hence it will be useful to rewrite the optimal adoption rule in terms of the firm's original belief, the information received, and the reservation probability.

Lemma 2: For any triple (n,k,p^*), where $k,n=0,1,\ldots$ $(k \leq n)$ and $p^* \epsilon (0,1)$, there exists a unique $g^*(n,k,p^*) \epsilon (0,1)$ such that $p(n,k,g) \gtreqless p^*$ if and only if $g \gtreqless g^*(n,k,p^*)$.

Proof: Using (5), $p(n,k,g) = p^*$ can be solved directly for g to obtain

$$g^*(n,k,p^*) = [1 + (\frac{1-p^*}{p^*}) (\frac{\theta_1}{\theta_2})^k (\frac{1-\theta_1}{1-\theta_2})^{n-k}]^{-1}. \tag{11}$$

This expression obviously belongs to (0,1) for given (n,k,p^*). Noting that $\frac{\partial p(n,k,g)}{\partial g} > 0$ completes the proof.

The optimal adoption rule can thus be restated as follows: If the reservation probability is p^*, then the firm will adopt at any stage n when $k \leq n$ favorable observations have been seen if $g \geq g^*(n,k,p^*)$, and otherwise wait. So $g^*(n,k,p^*)$ represents the minimum original belief which the firm could have had if it adopted at stage n after seeing k favorable observations when the reservation probability was p^*. Let $s_j = (j, \sum_{i=1}^{j} Z_i)$ for $j=1,2,\ldots$, and $s_0=(0,0)$, so that $g^*(n,k,p^*)$ can be rewritten as $g^*(s_n,p^*)$, and let

$$g_m(s_n,p^*) = \min\{p^*,g^*(s_1,p^*),\ldots,g^*(s_n,p^*)\}. \tag{12}$$

Then $g_m(s_n,p^*)$ is the smallest value that $g^*(s_j,p^*)$ has attained over the initial value $g^*(s_0,p^*) = p^*$ and the first n observations. Because the adoption decision is irreversible, after n observations all firms with $g \geq g_m(s_n,p^*)$ will have adopted at or before stage n. If the original beliefs of firms in the industry are distributed on [0,1] according to the cumulative distribution function F(g), then the proportion of firms which have adopted by stage n for a given sequence of observations $s_1,\ldots,s_n$ and given reservation probability p* is

$$d(s_n,p^*) = \int_{g_m(s_n,p^*)}^{1} dF(g) \qquad (13)$$

Defining the diffusion function in this way insures that it will be nondecreasing in n since $g_m(s_{n+1},p^*) \leq g_m(s_n,p^*)$ for all n. Moreover, $d(s_0,p^*) = \int_{p^*}^{1} dF(g) \geq 0$ and $\lim_{n\to\infty} d(s_n,p^*) = 1$ almost surely when $\theta = \theta_1$, so the diffusion function defined by (13) satisfies the basic requirements for the diffusion curve of a good innovation.

Before addressing the question of the shape of this diffusion curve, the following result relating the parameters of the model to the rate of diffusion in the industry will be presented. Conventionally, diffusion of an innovation is said to be faster when the proportion of firms which have adopted by a given stage n is at least as great for all n and strictly greater for some n.

<u>Theorem 4</u>: Diffusion of a good innovation will be faster (slower) when C is smaller (larger) and r_1, r_0, or β are larger (smaller).

Proof: It follows from Lemma 2 and (13) that showing $g_m(s_n,p^*+\delta) > g_m(s_n,p^*)$ for any arbitrarily small $\delta > 0$ will be sufficient to prove the claim of the theorem. Recall from Lemma 3 that $p(n,k,g^*(n,k,p^*+\delta)) = p^*+\delta$ and $p(n,k,g^*(n,k,p^*)) = p^*$. Since $\frac{\partial p(n,k,g)}{\partial g} > 0$, it follows that $g^*(n,k,p^*+\delta) > g^*(n,k,p^*)$ for all $\delta > 0$. Q.E.D.

This result confirms empirical results showing that diffusion of a good innovation will be faster (slower) when its expected profitability is higher (lower) for all firms in the industry. Although this is not surprising, it is worthwhile to note that this result is an implication of optimal firm behavior and obtains for any measurable distribution of original beliefs.

In order to determine the shape of the expected diffusion curve for a good innovation implied by this model, the behavior of the second difference of $d(s_n,p^*)$ with respect to n will be examined under specific assumptions on the information received by the firms and the distribution of original beliefs. The second difference of $d(s_n,p^*)$ is

$$\Delta^2 d(s_n,p^*) = -F(g_m(s_{n+2},p^*)) + 2F(g_m(s_{n+1},p^*)) - F(g_m(s_n,p^*)). \qquad (14)$$

The assumptions on information and beliefs are:

(A1) $s_n = (n, n\theta_1)$ for $n=0,1,\ldots$

(A2) $$F(g) = \begin{cases} 0 & \text{for } 0 \leq g < a \\ \frac{g-a}{b-a} & \text{for } g \varepsilon [a,b] \\ 1 & \text{for } b < g \leq 1 \end{cases}$$

Since $E(\sum_{i=1}^{n} Z_i | \theta = \theta_1) = n\theta_1$, (A1) requires that the proportion of observations seen which are favorable be equal to the proportion expected when the innovation is good at every decision date. (A2) distributes the original beliefs of firms in the industry uniformly over a subset of [0,1]. These additional assumptions allow the following result to be proved.

<u>Theorem 5</u>: Let $\tilde{p} = [\,1 + (\frac{\theta_2}{\theta_1})^{\theta_1} (\frac{1-\theta_2}{1-\theta_1})^{1-\theta_1}]^{-1}$. Then under (A1) and (A2):

(i) if $p^* > \tilde{p}$, then there exists a unique, positive integer $\tilde{n}$ such that $\Delta^2 d(s_n,p^*) > 0$ for all $n < \tilde{n}$ and $\Delta^2 d(s_n,p^*) < 0$ for all $n > \tilde{n}$.

(ii) if $p^* \leq \tilde{p}$, then $\Delta^2 d(s_n,p^*) < 0$ for all n.

Proof: Under (A1), $g^*(s_n,p^*) = \{1 + (\frac{1-p^*}{p^*})[(\frac{\theta_1}{\theta_2})^{\theta_1}(\frac{1-\theta_1}{1-\theta_2})^{1-\theta_1}]^n\}^{-1}$.

Let $\Delta g^*(s_n,p^*) = g^*(s_{n+1},p^*) - g^*(s_n,p^*)$ and $\Delta^2 g^*(s_n,p^*) = \Delta g^*(s_{n+1},p^*) - \Delta g^*(s_n,p^*)$ for n = 0,1,... . Then simple algebraic manipulations yield:

$$\Delta g^*(s_n,p^*) < 0 \text{ for all } n \tag{15}$$

$$\Delta^2 g^*(s_n,p^*) \gtreqless 0 \text{ if and only if } g^*(s_n,p^*) \lesseqgtr \tilde{p}. \tag{16}$$

Hence, $g_m(s_n,p^*) = g^*(s_n,p^*)$ for all n under (A1). Now let $\hat{n}$ be the value of n which solves $g^*(s_n,p^*) = \tilde{p}$ when n is treated as a continuous variable (simple algebra can be used to find $\hat{n}$ explicitly and show that $\hat{n} \geq 1$). If $\frac{\hat{n}}{b-a}$ is an integer, define $\tilde{n} = \hat{n}$; if not, define $\tilde{n}$ to be the smallest integer greater than or equal to $\frac{\hat{n}}{b-a}$. Then since (15) implies that $g^*(s_0,p^*) = p^* > g^*(s_1,p^*) > \ldots$, results (i) and (ii) follow directly from (16) and the fact that, under (A2), $\Delta^2 d(s_n,p^*) = -\frac{\Delta^2 g^*(s_n,p^*)}{b-a}$ for all n. Q.E.D.

This theorem shows that under (A1) and (A2) the diffusion curve found by approximating $d(s_n,p^*)$ by a smooth curve through the points $\{(n,d(s_n,p^*))|n=0,1,\ldots\}$ will be either S-shaped or concave. Although (A1) and (A2) are rather restrictive assumptions, this is an intriguing result because it predicts diffusion curves of the same type as those most often observed. Moreover, this result shows that the pattern of diffusion which is believed to be characteristic of many new innovations can be explained solely by differences in the subjective beliefs of firms about the likelihood that the innovation will be good.

Finally, the effects of a change in the mean or variance of the uniform distribution on the rate of diffusion will be examined. A variance-preserving change in the mean is interpreted as a change in the industry's average original optimism about the innovation, and a mean-preserving change in the variance is interpreted as a change in the precision of the industry's average original optimism.

Theorem 6: Under (A1) and (A2), diffusion of a good innovation will be:

(i) faster (slower) when the industry's average original optimism about the innovation is higher (lower);

(ii) faster (slower) in the initial stage of diffusion and slower (faster) in the concluding stage when the industry's original beliefs are less (more) precise.

Proof: The mean and variance of the distribution given by (A1) are $\mu = \frac{a+b}{2}$ and $\sigma^2 = \frac{(b-a)^2}{12}$. A variance-preserving change in μ corresponds to equal changes in both a and b. Since $d(s_n,p^*) = \frac{b-g^*(s_n,p^*)}{b-a}$ under (A1) and (A2), result (i) follows from the fact that $\frac{\partial d}{\partial a} > 0$ and $\frac{\partial d}{\partial b} > 0$. A mean-preserving change in σ^2 corresponds to changes in a and b of equal size and opposite sign. Result (ii) then follows from the fact that, for any small $\delta > 0$,

$$\frac{b+\delta-g^*}{(b+\delta)-(a+\delta)} \gtreqless \frac{b-g^*}{b-a} \text{ if and only if } g^* \gtreqless \mu \text{ and}$$

$$\frac{b-\delta-g^*}{(b-\delta)-(a+\delta)} \gtreqless \frac{b-g^*}{b-a} \text{ if and only if } g^* \lesseqgtr \mu.$$

Q.E.D.

It is evident that an innovation will diffuse more rapidly when the industry is more optimistic that the innovation is good. The ambiguity in the effect of a change in variance arises from the fact that a change in varaince is equivalent to adding (or subtracting) both more optimistic and more pessimistic firms to the industry. Hence, the duration of diffusion will be longer (shorter) in an industry whose beliefs about the innovation are more (less) diverse.

4. Concluding Remarks

The main conclusion of this paper can be briefly summarized as follows. Firms may delay adoption of an innovation if they do not know whether it is good (profitable) or not in order to gather information and reduce this uncertainty. In such a situation firms have subjective beliefs that the innovation will be good when it appears which will differ due to differences in the expertise and attitudes of decision-makers about innovation and differences in previous experiences with similar innovations. Those firms who do not adopt immediately will revise their beliefs upward as they learn that the innovation is good (from the information gathered) until they become optimistic enough to adopt. The commonly observed pattern of diffusion (the S-shaped diffusion curve) can then be explained solely by the difference among firms in the original beliefs that the innovation will be good.

It is, of course, necessary to recognize that this result is limited by the special assumptions made to obtain it. Although there are several of these, the two which deserve the most attention are the assumption of a uniform distribution of original beliefs in the industry and the assumption that a firm which never adopts can continue to earn its pre-innovation return (made implicitly in the assumption $V_0(p) = 0$ for all p). There is no reason, a priori, to assume that the original beliefs in an industry will have any particular distribution. On the other hand, since this result holds for at least one type of distribution, it might be possible to derive the same result for a more general class of distributions. It would also be interesting (and more realistic) to incorporate rivalry by allowing a firm which never adopts to gain (lose) relative to its pre-innovation position when a rival firm adopts an innovation which is bad (good). A first effort at such an analysis has already been made by this author [10], but the results have not yet been as interesting as expected.[8]

Although extensions along these lines will help to broaden the applicability of the results of this analysis, a final comment in its defense should be made. It does provide a much-needed explanation of a pattern of diffusion characteristic of many innovations which derives from the optimizing behavior of individual firms. Hence, viewing adoption and diffusion of an innovation as a problem of decision-making under uncertainty when learning can occur would seem to be an approach which is not only appropriate, but also holds promise for more general explanations.

Footnotes

1. See Lekvall and Wahlbin [11], Mansfield [12,13], Nasbeth and Ray [14], or Rogers and Shoemaker [16] for examples of these diffusion curves.
2. See Davies [1] or Mansfield [12] for excellent discussions, and Gold [5] for a sweeping criticism, of this approach to the study of diffusion.
3. The rationale for this assumption is generally Schumpeter's imitation hypothesis (perceptions of profit opportunities are positively related to the successful experience of others in the market). However, in practice models based upon this assumption are merely applications of the medical theory of epidemics. See Davies [1] for an interesting demonstration of the relationship between these models.
4. The decision to adopt is thus an irreversible one.
5. It is assumed that there is no explicit cost to taking an observation. This is somewhat restrictive since it precludes the possibility that a firm may stop (or never start) taking observations when it is sufficiently skeptical, and therefore may skip a good innovation. Nevertheless, the central results of this paper could still be obtained if there was an explicit cost of observation, although additional assumptions would be required to prevent this possibility.
6. This theorem is proved under much more general learning rules than those implied by Bayes Theorem in Jensen [9].
7. This proof can be found in [9].
8. One result obtained which is interesting is that adoption by one firm may reduce the probability of adoption by the firm still waiting. Both Flaherty [4] and Reinganum [15] have analyzed adoption behavior in duopolies under certainty when the supply price of the innovation declines through time. Even in this case there is a diffusion since the firms in general will not adopt at the same date.

References

1. S. Davies, "The Diffusion of Process Innovations," Cambridge University Press, Cambridge, England, 1979.

2. M.H. DeGroot, "Optimal Statistical Decisions," McGraw-Hill, New York, N.Y., 1970.

3. W. Fellner, The Influence of Market Structure on Technological Progress, Quarterly Journal of Economics, 65, (1951), 556-577.

4. M.T. Flaherty, Timing Patterns of New Technology Adoption in Duopolistic Industries, Unpublished Manuscript, June, 1977.

5. B. Gold (Ed.), "Research, Technological Change, and Economic Analysis," Lexington Books, Lexington, Mass., 1977.

6. Z. Griliches, Hybrid Corn: An Exploration in the Economics of Technological Change, Econometrica 25 (1957), 501-522

7. G. Herregat, "Managerial Profiles and Investment Patterns," Universite Catholique de Louvain, Louvain, France, 1972.

8. H. Hinomoto, Capacity Expansion with Facilities Under Technological Improvement, Man. Sci. 11 (1965), 581-592.

9. R. Jensen, On the Adoption and Diffusion of Innovations Under Uncertainty, Discussion Paper 410, Center for Mathematical Studies in Economics and Management Science, Northwestern University, December, 1979.

10. R. Jensen, A Duopoly Model of the Adoption of an Innovation of Uncertain Profitability, Discussion Paper 434, Center for Mathematical Studies in Economics and Management Science, Northwestern University, July, 1980.

11. P. Lekvall and C. Wahlbin, A Study of Some Assumptions Underlying Innovation Diffusion Functions, Swed. J. Econ. 75 (1973), 362-377.

12. E. Mansfield, "The Economics of Technological Change," W.W. Norton, New York, N.Y., 1968.

13. E. Mansfield et al., "The Production and Application of New Industrial Technology," W.W. Norton, New York, N.Y., 1977.

14. L. Nasbeth and G.F. Ray (Eds.), "The Diffusion of New Industrial Processes," Cambridge University Press, Cambridge, England, 1974.

15. J.F. Reinganum, On the Diffusion of New Technology: A Game Theoretic Approach, Social Science Working Paper 312, California Institute of Technology, 1980.

16. E. Rogers and F.F. Shoemaker, "Communication of Innovations," Free Press, New York, N.Y., 1971.

17. W.E.G. Salter, "Productivity and Technical Change," Cambridge University Press, Cambridge, England, 1960.

18. J.A. Schumpeter, "Capitalism, Socialism, and Democracy," Harper and Row, New York, N.Y., 1942.

19. V.L. Smith, "Investment and Production," Harvard University Press, Cambridge, Mass., 1966.