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A MODEL OF DIFFUSION IN THE PRODUCTION OF AN INNOVATION

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Summary

This paper is an attempt to explain diffusion in the production of an innovation. Diffusion in production is defined as the increase in number of producers, or net entry, in the market for a new product. It is to be distinguished from the more familiar problem in the literature on technical change, namely, the diffusion among producers in the use of new products and, hence, of changes in production processes for "old" products (or services).

The empirical results confirm that a simple model -- simple in terms of number of variables -- is sufficient to explain most of diffusion in the production of an innovation. The principal variable that explains diffusion of entry is the demonstration effect. The principal variable that retards entry is the accumulated experience and goodwill of existing firms. A limiting force is the population of potential entrants. None of these variables appears to lend itself readily to influence by public policy.

The first stage in diffusion -- the interval from first commercial introduction of the product to entry by competitors -- varies greatly in duration. Institutional variables, including public policy, may have a greater impact on the length of this first stage, which is not covered by this study, than on the diffusion process in the periods examined in this paper.

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This paper is an attempt to explain the process of diffusion in the production of an innovation. Diffusion in production is defined as the increase in number of producers, or net entry, in the market for a new product. It is to be distinguished from the more familiar problem in the literature on technical change, namely, the diffusion among producers in the use of new products and, hence, of changes in production processes for "old" products (or services).

In an earlier paper, Gort and Klepper[1] showed that a typical "diffusion in production" process involves a number of stages. Phase I encompasses the interval in which the original producers of a new product remain without competitors in the market. Phase II is the interval from the "take-off" point of net entry to the time that net entry decelerates drastically. Phase III is the ensuing period of low or zero net entry and Phase IV is the subsequent period of negative net entry. Phase V represents the new equilibrium in the number of producers that coincides with the maturity of the product market and continues until some new fundamental disturbance generates a change in market structure. The present study focuses on the period from roughly the beginning of Stage II until the peak in number of producers is reached sometime in Stage III. It does not deal with the subsequent development of what may be considered a mature market, including the characteristic interval in which the number of producers declines.

Theory

For given expected prices and demand, the division of the market between existing firms and new entrants depends on V, a vector of observed attributes of the population of potential entrants, and G, a vector of observed attributes of the population of earlier entrants (and now existing firms) in the market. The average probability of entry in time t for the population of potential entrants can be written as:

$$P_t = P_t(G_t, V_t)$$

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[1] M. Gort and S. Klepper, "Time Paths in the Diffusion of Product Innovations," State University of New York at Buffalo, Economics Department, Discussion Paper No. 444.

We assume that the unobserved attributes of individual firms (which include such facotrs as the personalities and biases of managers, chance perceptions of alternative opportunities, differences in risk aversion, etc.) are randomly distributed among firms with a common set of observed characteristics.[1]

Apart from the attributes of existing firms and potential entrants, the expected returns to new entrants, discounted for risk, (and, hence, the entry rate) will depend upon a) the perceived risks associated with entry and b) the expected profit margin for the most efficient producers. Assuming a market without entry barriers and an equilibrium price at which output is greater than zero, the expected profit margin will depend upon the extent of any transitory disequilibrium between supply and demand. To be sure, profit margins will also depend upon entry barriers—that is, monopoly power. But higher entry barriers cannot, by definition, raise the rate of net entry. Consequently, an excess of actual over "normal" competitive rates of return will raise entry only to the extent that such returns arise from disequilibrium.[2]

Assuming an absence of entry barriers, we have indicated that entry will depend upon perceived risks, disequilibrium induced deviations between actual and "normal" competitive profit margins, and the attributes (mainly costs) of existing firms and of the population of potential entrants. Before specifying

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[1]For a given probability of choice taking account of the relevant variables, the observed gross number of entrants is a random number obeying a binomial distribution. This is because each firm faces a binary choice of entry or non-entry. The same principle applies to gross exits.

[2]Some entry barriers are themselves transitory in the sense that they generate incentives that lead to their destruction. Such barriers can also be classified as sources of transitory disequilibria.

the relevant (and empirically measurable) variables that control each of these elements, our model must be developed further with respect to the two components that generate the net entry rate, namely, gross entry and gross exit.

Let $\overline{N}$ denote the population of potential entrants in the market for a new product. At time t, the number of potential entrants will then be $\overline{N} - n_{t-1}$ where n_{t-1} is the number that have already entered--that is, the number of producers at t-1. The number of expected entrants at time t is therefore:

$$F_t = P_t x (\overline{N} - n_{t-1}) \tag{1}$$

where F_t is the expected number of entrants in t and P_t is the choice probability of entry at t. Similarly, the expected number of gross exits is:

$$Y_t = Q_t \times n_{t-1} \tag{2}$$

where Y_t is the expected number of gross exits, Q_t is the probability of exit at time t, and n_{t-1}, the number of existing firms, represents the population from which exiting firms are drawn. Combining equations (1) and (2), we have:

$$E_t = P_t \times (\overline{N} - n_{t-1}) - Q_t \times n_{t-1} + u_t \tag{3}$$

where E_t is the actual net entry in t and u_t is a random number obeying the usual assumptions of regression.[1]

Our next task is to specify the variables on which the probability of entry and exit (P_t and Q_t) depend and to indicate an appropriate and measurable proxy variable for $\overline{N}$, the population of potential entrants. In general terms, we have already noted that P_t depends upon disequilibria between supply and demand, upon the perceived risks of entry, and on the attributes (mainly production and marketing costs) of existing firms and of the population of potential entrants. We now turn to a more concrete specification of these variables.

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[1] u_t appears in the equation since E_t is the observed actual rather than the unobserved expected net entry.

A correct measure of the magnitude of transitory disequilibrium is the difference between actual price, p_a and equilibrium, p_e. In the absence of such information, we assume that this difference is a function of the growth rate in demand and, hence, output, per firm. That is:

$$p_{a,t-1} - p_{e,t-1} = f\ ((\hat{q/n})_{t-1}) \qquad (4)$$

where the previously undefined symbol $(\hat{q/n})$ is the growth rate in output per firm, q/n, measured by $\frac{(q/n)_t - (q/n)_{t-1}}{(q/n)_{t-1}}$. The assumed functional relation stems partly from the gestation period in creating new capacity and partly from dynamic adjustment costs. The latter lead to diseconomies with high growth and such diseconomies are assumed to be an increasing function of the growth rate.[1] As a result, with a high growth rate per firm, prices can be expected to rise, thus raising the expected rate of return to entry.

We turn now to risk. We cannot, of course, measure all the forces that influence risk. However, for a given objective probability distribution of rates of return to investment in a new product market, the perceived risk to a potential entrant is a function of how many other firms made successful investments in the same market. We characterize this as the "demonstration effect" and assume it to be a function of n_{t-1}, the number of existing firms in the market.

If we assume that entry (or diffusion in use) depends exclusively on the demonstration effect, n_{t-1}, and the population of potential entrants (or users), $\overline{N}$, a familiar model of diffusion emerges. First, consider the case where $\alpha(t)$,

[1] The first explicit development of a dynamic adjustment cost theory as applied to the growth of firms is usually attributed to E. Penrose, The Theory of the Growth of the Firm, Oxford, Basil Blackwell, 1959.

the probability of entry per small interval of time, and $\beta(t)$, the probability of exit for the same small interval, are both constant and $\alpha(t) > \beta(t)$. It can be shown that:

$$n_t = \frac{\alpha \cdot \overline{N}}{\alpha+\beta} + (n_0 - \frac{\alpha\ \overline{N}}{\alpha+\beta})\ e^{-(\alpha+\beta)t} \tag{4}$$

where the only previously undefined symbols is n_0, the initial number of firms in the market. It is clear from the above that the growth path for n (the number of firms in the market) is exponential with an asymptotic maximum at $\alpha\overline{N}/(\alpha+\beta)$.

Now consider the case where $\beta(t)$ is again a constant or zero, but $\alpha(t)$ is subject to the demonstration effect and, therefore, changes over time so that $\alpha(t) = an_t$. We then have the following differential equation:

$$\dot{n}_t = an_t(\overline{N} - n_t) - \beta n_t \tag{5}$$

where $\dot{n}_t$ is the expected net entry per small interval of time, or:

$$\dot{n}_t = a^*n_t(1 - n_t/\overline{N}) - \beta n_t \tag{6}$$

where $a^* = ax\overline{N}$. It is clear from the above that if $a^* > \beta$, we have a logistic growth path for n with an asymptotic maximum of $\overline{N}(1 - \beta/a^*)$.

The above model, with a demonstration effect and a fixed number of potential users (or entrants), is precisely the model implied in Griliches seminal article on the diffusion of hybrid corn.[1] Our theoretical framework differs in that $\beta(t)$ is not assumed to be constant and $\alpha(t)$ depends critically on variables other than the demonstration effect and the number of potential users or entrants.

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[1]Z. Griliches, "Hybrid Corn: An Exploration in the Economics of Technological Change," Econometrica, October 1957. A similar though more complex model was subsequently presented in E. Mansfield, "Technological Change and the Rate of Imitation," Econometrica, October 1961.

We have now specified the demonstration effect as controlling perceptions of risk and we have specified our proxy for transitory disequilibrium. Next, consider the attributes of existing firms in the market and of the population of potential entrants. As a simplification, and in the absence of contrary information, we assume that both sets of firms are drawn from a common universe except with respect to one class of attributes. Existing firms will have accumulated over the period they have been in the market a stock of knowledge and experience, of human capital that is not rapidly reproducible, and of goodwill in the market. Consequently, they have an advantage over new entrants which is an increasing function of the accumulated volume of past production (and sales). We approximate the effect of such accumulated experience by $\Sigma q_{t-1}/\Sigma q_T$ where Σq_{t-1} is the accumulated aggregate output from the initial introduction of the product to t-1. It is deflated by Σq_T, the accumulated aggregate output to the end of the interval covered by our data to permit the use of pooled cross-section as well as time-series data.

The effect of accumulated experience will, *ceteris paribus*, steadily increase over time until it becomes a prohibitive barrier to entry for most firms. However the faster the rate of technical change in production processes or products, the less is the relevance of past experience for the future, and the higher the technical change in products the smaller is the effect of accumulated goodwill. A proxy for technical change should therefore have a positive sign in our model.

To conclude the discussion of gross entry, we specify that the population of potential entrants, $\overline{N}$, is proportional to the number of firms in the host industry of the product innovation. Implicit in this is the assumption there are technological and marketing linkages among product markets in the same industry. It further assumes the size of the population of firms technically equipped to enter an industry (though not already in it) is related to the number of firms in the industry. Obviously these assumptions are viewed only as approximations to reality. How good such approximations are is an empirical question as is our compromise with theory in defining the boundaries of industries in accordance with the 4-digit SIC classification.

Turning now to Q_t, the probability of exit, we must once again, in the context of limited information, start with simplifying assumptions. Specifically, we start with the premise that existing firms have valid engineering forecasts of their costs, and that the principal surprises and disappointments leading to exit result from errors in forecasting prices and market demand (or output). Obviously, there will be instances of exit arising from unique historical circumstances such as the retirement of an owner-manager, or the inability of some firms to produce a product that appeals to end users. But how important these special circumstances are is an empirical question to be tested indirectly by the adequacy of the general variables as explanations of the relevant phenomenon.

To test our hypotheses on exit, we employed a method first developed by Solow.[1] Namely, we constructed a number of hypothetical series of expected output and price by the model of adaptive expectations. The model specifies that $x^e_{t+1} = x^e_t + \lambda(x_t - x^e_t)$ where x^e_t and x_t are, respectively, the expected and the actual values of the variable under consideration at time t, and λ is the speed of adjustment with values between zero and one. For a given λ, a time series of the expected output and price can be constructed by iteration, starting with a single initial value and using the observed time series of output and price as elements. We created hypothetical time series of the expected output and price for $\lambda = 0.1$, 0.5 and 0.9, representing a slow, moderate, and fast adjustment process.

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[1] R.M. Solow, Price Expectations and the Behavior of the Price Level, Manchester University Press, 1969.

Assuming that the expected and actual values are the same at some initial point in time, a time series of error rates in expectations can be generated, $(x_t - x_t^e)/x_t$, t = 1,2,...,T, based on the differences between the actual and expected values.

Using the time series of error rates in expectations of output and price, we took two-year averages of the error rates in expectations as well as the annual estimates. This was done partly because of the arbitrariness of a one-year interval in assessing the effects of disappointments and surprises on exit decisions, but partly also to differentiate between immediate (short-run) and lagged (long-run) effects. Accordingly we used q_t^* for output (or p_t^* for price) and $\bar{q}_{t-1}$ for output (or $\bar{p}_{t-1}$ for price) in our equation where q_t^* (or p_t^*) is the current year error rate in expectations of output (or price) and $\bar{q}_{t-1} = \frac{q_{t-1}^* + q_{t-2}^*}{2}$. (or $\bar{p}_{t-1} = \frac{p_{t-1}^* + p_{t-2}^*}{2}$) .

Before turning to empirical tests, a review of some of the economic issues raised by our model may be helpful. First, can a general model devoid of the unique institutional aspects of each product market explain the observed phenomenon? For example, we have said nothing about the role of a small number of critical patents as entry barriers even though patents are commonly believed to have had a role in some of the product markets with which we dealt. Second, though diseconomies of scale have often been proposed by economists as explanations for entry instead of faster growth by existing firms, we have excluded this variable from our model. Since the average size of firm normally continues to grow long after net entry approaches zero, diseconomies of scale are viable explanations of the history of diffusion in production only if special assumptions are made about shifts over time in the minimum and maximum efficient size of firms. Such assumptions tend to be ad hoc and are difficult to fit into a general model.

A third basic issue is our assumption that there is a definable and measurable population of potential entrants as distinct from the universe of business firms. And finally, there is the question of the power of several variables, in terms of their effect on entry. In particular, what is the influence of the demonstration effect, of accumulated experience and goodwill, and of dynamic adjustment costs ?

Estimation Procedure

The estimating procedure that was appropriate differed from ordinary least squares because of the need to impose inequality constraints on the parameters. Since the probability of entry or of exit cannot be less than zero or greater than 1, and since OLS estimates do not guarantee parameters that fall within these limits, a constraint needs to be imposed. The imposition of constraints, as the section on statistical results will show, considerably improved our results in terms of consistency of estimates with theory.

We may specify our model for E_t, actual net entry, as follows:

$$E_t = \sum_{j=1}^{s} w_{jt}\theta_j + u_t, \quad t=1,2,\ldots,T \tag{7}$$

where

$$w_{jt} = \begin{cases} x_{jt} \times (\bar{N}-\eta_{t-1}), & j=1,2,\ldots,\ell \\ -x_{jt} \times \eta_{t-1} & j=\ell+1,\ldots,s \end{cases}$$

and x_{jt} $(j=1,2,\ldots,\ell)$ is an explanatory variable of the probability of entry at time t or p_t. x_{jt} $(j=\ell+1,\ldots,s)$ is an explanatory variable of the probability of exit at time t, or Q_t. θ_j's are parameters associated with the explanatory variables, x_j's.

We may write our linear inequality constraints in the form

$$0 \leq \sum_{i=1}^{\ell} w_{jt}\theta_j \leq (\bar{N} - \eta_{t-1}) \tag{8}$$

$$-\eta_{t-1} \leq \sum_{\ell+1}^{s} w_{jt}\theta_j \leq 0 \qquad t=1,2,\ldots,T \tag{9}$$

We assume that the error term u_t satisfies the usual Gauss-Markov conditions. The above procedure can be formulated as a quadratic programming problem and solved by a finite computational routine such as the Lemke algorithm. The resulting estimates of θ will be asymptotically unbiased, consistent, and efficient, provided the specification is correct.[1]

Data

The sample of product innovations was selected from a set of forty-six product histories developed in connection with a related research project.[2] Of the forty-six, only six had data on output, prices, number of firms, and patents, over the entire period necessary for our analysis. Our method of analysis involves the pooling of cross-section and time-series data so that complete, or almost complete, histories were essential.

Information on number of firms was obtained from Thomas' Register of American Manufactures, supplemented by correspondence with industry experts and by a variety of other trade sources. Annual data on the number of patents issued for each product were obtained from the United States Patent Office. Data on prices and output were derived from a variety of government and private sources, including trade publications and information provided by companies in the relevant product markets. Counts of product and process improvements subsequent to the initial introduction of each of the six products were also derived from a wide variety of published and unpublished sources, including product histories provided by individual companies. $\bar{N}$ was based on data from the Census of Manufactures for 1947, 1954, 1958, and 1963.

[1]For an extensive discussion of inequality constrained least-squares estimation, see Chong Kiew Liew, "Inequality Constrained Least-Square Estimation", Journal of the American Statistical Association, September 1976.

[2]See M. Gort and S. Klepper, op. cit.

As previously noted, the period chosen for each of the six products, encompassed the interval from take-off in entry or the time when the complete data became available to the time when the number of firms in the market reached its historical peak. The products and relevant time intervals are listed below.

1. DDT, 1944-52 (9 years)
2. Streptomycin, 1946-53 (8 years)
3. Styrene, 1955-65 (11 years)
4. Television receivers, 1946-55 (10 years)
5. Transistors, 1954-61 (8 years)
6. Cathode ray tubes, 1948-1959 (12 years)

Results

Table 1 summarizes the principal statistical results. The equation tested with, however, variations in the inclusion of selected variables (see Table 1), was:

$$E_t = [\alpha_0+\alpha_1 n_{t-1}+\alpha_2(\hat{q/n})_{t-1}+\alpha_3(\Sigma q_{t-1}/\Sigma q_T)+\alpha_4 v_{t-1}+\alpha_5 w_{t-1}] \times (\bar{N}_{t-1}-n_{t-1})$$
$$- [(\beta_0+\beta_1\bar{q}^*_t+\beta_2 q_{t-1}+\beta_3\bar{p}^*_t+\beta_4 p_{t-1}) \times n_{t-1}] + u_{t-1} \qquad (10)$$

where

E_t = net entry

n_{t-1} = number of existing firms in t-1

$\Sigma q_{t-1}/\Sigma q_T$ = accumulated output to t-1 divided by the accumulated output at the end of the period studies

v_{t-1} = the number of patents issued in t-1

w_{t-1} = the number of product and production process improvements recorded in t-1

q^*_t = the rate of expectation error in output per firm in time t $\left(\frac{(q/n)_t-(q/n)^e_t}{(q/n)_t}\right)$

Table 1

Regression Coefficients, t-statistics, and correlations for explanations of net entry[1]

	OLS[2]	ICLS[3]	OLS[2]	ICLS[3]	OLS[2]	ICLS[3]	OLS[2]	ICLS[3]
α_0	0.0321 (3.374)	0.0276 (3.306)	0.0275 (2.801)	0.0268 (3.231)	0.0379 (3.333)	0.0321 (2.957)	0.0328 (2.794)	0.0312 (2.894)
α_1	0.0005 (2.311)	0.0008 (6.155)	0.0005 (2.471)	0.0008 (6.547)	0.0004 (1.968)	0.0008 (6.070)	0.0004 (2.161)	0.0008 (6.466)
α_2	-0.0061 (-1.673)	-0.0056 (-1.754)	-0.0054 (-1.463)	-0.0054 (-1.749)	-0.0047 (-1.239)	-0.0050 (-1.896)	-0.0039 (-1.001)	-0.0049 (-1.880)
α_3	-0.0518 (-2.731)	-0.0411 (-4.021)	-0.0474 (-2.499)	-0.0402 (-3.970)	-0.0611 (-2.463)	-0.0499 (-4.718)	-0.0585 (-2.373)	-0.0492 (-4.771)
α_4	--	--	--	--	0.0001 (0.1007)	0.0001 (0.1511)	0.0002 (0.2105)	0.0001 (0.1633)
α_5	--	--	--	--	-0.0035 (-1.275)	-0.0025 (-1.222)	-0.0035 (-1.242)	-0.0025 (-1.233)
β_0	-0.0222 (-0.3754)	0.0943 (4.474)	0.0328 (0.4764)	0.1040 (4.710)	-0.0372 (-0.6130)	0.0905 (4.358)	0.0210 (0.2993)	0.1001 (4.589)
β_1	--	--	-0.0104 (-0.1550)	0.0084 (1.630)	--	--	0.0019 (0.0269)	0.0080 (1.579)
β_2	-0.1964 (-3.847)	-0.1238 (-3.766)	-0.1836 (-3.497)	-0.1331 (-4.122)	-0.1978 (-3.838)	-0.1192 (-3.622)	-0.1866 (-3.492)	-0.1283 (-3.970)
β_3	--	--	0.3048 (1.644)	0.0778 (4.672)	--	--	0.3096 (1.662)	0.0749 (4.569)
β_4	-0.8638 (-2.487)	-0.9269 (-2.468)	-0.5966 (-1.439)	-0.9113 (-2.533)	-0.7911 (-2.030)	-0.8808 (-2.397)	-0.5197 (-1.237)	-0.8734 (-2.475)
$\hat{R}^2$		0.7548		0.7637		0.7608		0.7697
$\hat{\bar{R}}^2$		0.7214		0.7187		0.7152		0.7121

[1] The symbols are identified in the text in the discussion of equation (10). t-statistics are shown in parentheses. A dash signifies that the variables was excluded in the specific version of the equation. The speed of adjustment coefficients $\hat{\lambda}$, was .5 for expected output and .9 for expected price. $\bar{R}^2$ is the correlation adjusted for degrees of freedom.

[2] Ordinary least squares estimation.

[3] Inequality constrained least squares estimation.

$\overline{q}_{t-1}$ = the average rate of expectation error in output in t-2 and t-1

p^*_t = the rate of expectation error in price in time t $(\frac{P_t - P^e_t}{P_t})$

$\overline{p}_{t-1}$ = the average rate of expectation error in price in t-2 and t-1

$\overline{N}_{t-1}$ = the population of potential entrants in time t-1[1]

Table 1 shows that our hypotheses with respect to the role of the demonstration effect (the coefficient α_1) and the accumulated experience and goodwill (α_2) are strongly confirmed as judged both by the signs of the coefficients and the t statistic. The elasticities measured at the means, and averaged for the six products[2] are quite high. A one percent increase in the variable that measures the demonstration effect leads to a 1.87 percent increase in entry. A one percent increase in the variable that measures accumulated experience leads to a 2.88 percent decrease in entry.

Our assumption that the population of potential entrants can be roughly approximated by $\overline{N}_{t-1}$, where $\overline{N}_{t-1}$ is measured by the number of firms in the host industry, is also strongly confirmed. An alternative specification in which the size of the population of potential entrants was assumed to equal $2\overline{N}_{t-1} - n_{t-1}$ reduced R^2 materially.

Our results indicate also that n_{t-1} effectively measures the population of potential exits. It appears unnecessary to distinguish between earlier and later entrants—that is, to devise a measure that takes account of the extent to which n_{t-1} consists of recent or of old entrants—in measuring potential

[1]Any point in time preceding a census year was given the value of the observation for the previous census year.

[2]Since the absolute values of the relevant variables vary across the six products, the elasticities vary accordingly.

gross exit. Disappointments in output and in price expectations came through as strong explanatory variables and with the correct signs for the lagged variables. Our best results were with a moderate speed of adjustment coefficient, $\lambda = .5$, for errors in output expectations and a much faster adjustment, $\lambda = .9$, for errors in price expectations. The reversal of signs on current and lagged errors in expectations is, a priori, plausible. Greater expected than realized values reflect optimism and, in the short run, should not lead to exit. It takes time for disappointments to take their effect on decisions to leave the market.

Among the negative results, dynamic adjustment costs leading to disequilibria--at least to the extent that this variable can be measured by the growth rate in output per firm--did not have a statistically significant effect on entry. Neither did the proxies for rate of technical change. In the case of the annual volume of patenting, the deficiency is in the choice of proxy. The number of patents does not capture technological change for two reasons: first, important patents are not distinguished from trivial ones and, second, it is in any event an index of the input of innovative effort rather than of the output of innovations. We employed this proxy only because it has been widely used in economic literature (we believe, incorrectly) as an index of technical change. Our second index of technical change, the number of product and production process improvements failed to contribute to explaining the phenomenon perhaps because the information is too thin to be used in the context of a model tested against annual data. Too many of the annual observations were zeros.[1]

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[1]The results obtained by M. Gort and S. Klepper, op. cit., show that if the entry history is decomposed into stages each consisting of a number of years, the frequency of product and production process innovations is much higher during periods of high than of low entry.

The positive results appear to be quite robust in the sense that minor changes in either the list of variables (as indicated in Table 1) or the choice of a lag (to conserve space, results using alternative lags are not shown) do not markedly change th . α's and β's. Similarly, the use of alternative speed of adjustment coefficients for expectation errors, while it reduces the R^2, does not, in most instances, change the signs or the statistical significance of the key variables. In contrast, if inequality constrained least squares is substituted by ordinary least squares estimation--a procedure we have indicated is inappropriate--the results are materially affected.

Finally, a question might be raised whether, because of unidentified structural changes, net entry declines simply as the time approaches the point at which the number of producers is at a historical peak. Using T as the symbol for that point, we added T-t to the list of variables in the model specified by equation (10). The additional variable contributed nothing to explaining net entry and, in fact, R^2 adjusted for degrees of freedom declined.

Conclusions

The empirical results confirm that a simple model--simple in terms of number of variables--is sufficient to explain most of the phenomenon of diffusion in the production of an innovation. The principal variable that explains diffusion of entry is the demonstration effect. The principal variable that retards entry and finally brings it to an end is the accumulated experience and goodwill of existing firms, operating as a barrier to entry. A limiting force is the population of potential entrants approximated by the number of firms in the host industry of a product innovation (minus, of course, the number that have already entered). None of these variables appears to lend itself readily to influence by public policy.

Our study begins with the point in time corresponding to entry by the first competitors of the initial innovators. The first stage--the interval from first commercial introduction of the product to entry by competitors--varies greatly in duration. It may well be that institutional variables, including public policy, have a greater impact on the length of this first stage than on the diffusion process in the periods examined in this paper.

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