TIME PATHS IN THE DIFFUSION
OF PRODUCT INNOVATIONS*

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This study attempts to measure and analyse the diffusion of product inno-
vations. Diffusion is defined as the spread in the number of producers engaged
in manufacturing a new product. Thus, the term refers to the net entry rate in
the market for a new product. We trace the history of diffusion for 46 new
products and examine the inter-relations among diffusion, other aspects of
technological change, price, output, and certain attributes of the relevant
markets.

To explain the 46 product histories, we construct a theory of the develop-
ment of industries for new products. Our theory combines elements of tradi-
tional, neoclassical models with what Nelson and Winter (1974) have termed
an evolutionary theory. A novel feature is that the historical sequence, or time
path, of events is viewed as a critical determinant of the ultimate structure of
new product markets. Thus the time path of events determines not only the
course traversed in reaching the end result but the ultimate market structure
itself.

The paper is organised in four sections. In Section I we present our theory.
In Section II we construct a series of alternative theories of the development
of industries for new products based on approaches to be found in received
literature. The evidence from the 46 new product histories is examined in
Section III. Finally, a brief summary of principal findings follows in Section IV.

I. AN EVOLUTIONARY THEORY OF DIFFUSION OF INNOVATIONS

A product innovation is composed of two steps: the technical development of
a new product and the introduction of the new product into the market. The
length of the interval between the two steps varies substantially across new
products, ranging from several months to several decades. Our analysis begins
with the second step when the new product is introduced into the market.

Beginning with the first commercial introduction of the product, we hypo-
thesise five stages in the evolution of the market with respect to the number of
producers in it. These five stages represent a prototype of the life-cycle of the
market from its beginning up to, but not including, the period of eventual
decay or contraction in absolute market size.[1] In specifying a prototype, we do
not argue that each stage must be present for every product – merely that the

[1] We did not examine the contraction stage because our data generally do not extend to this stage.

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five stages represent a general pattern. Moreover, the identification of stages in the history of a continuously changing phenomenon is, essentially, an analytical convenience. Other scholars who focus on other aspects of this phenomenon may appropriately identify a larger or a smaller number of stages. The five periods, however, capture the major transitions in the forces that we believe determine the number of producers in a market during most of its life-cycle.

We specify the five stages seriatim. Stage I begins with the commercial introduction of a new product by its first producer (though in rare instances there is a concurrent introduction of the product by more than one producer) and ends with a sharp increase in the rate of entry of new competitors into the industry. We hypothesise that the length of this stage is related to the ease of copying the initial innovator(s), the size of the market for the new product soon after it is first introduced, and the number of potential entrants into the market. In addition, the speed with which technological information is communicated in the economy is an important factor affecting the length of Stage I. We speculate that there has been a historical increase in the rate of diffusion of technological information and that this has contributed to a decrease in the length of Stage I over time.

Stage II is the period of sharp increase in the number of producers. The existence of this stage cannot be doubted; in virtually all new product markets there is a period of rapid growth in the number of producers. The important questions concern why entry occurs at all – that is, why the market is not captured entirely by existing producers – and what ultimately brings about an end to the rapid growth in the number of producers.

Stage III is the period in which the number of entrants is roughly balanced by the number of exiting firms, leaving net entry approximately zero. Zero net entry does not, however, reflect an equilibrium but rather is associated with structural changes in the market (discussed later) which, when they mature, precipitate the ensuing Stage IV. The sharp decline in the gross entry rate in Stage III (to a point where gross entry roughly equals gross exit) arises from forces that have their origin in Stage II. In a sense, therefore, Stage III could be viewed, alternatively, as the final segment of Stage II.

Stage IV is the period of negative net entry. It represents a culmination of the structural changes under way in Stage III. These are discussed later in some detail. The conclusion of the period of negative net entry brings the beginning of Stage V – a second period of approximately zero net entry. The approximate absence of net entry or exit does not result, however, from equality of the number of producers with a unique equilibrium level defined by market size and economies of scale. Stage V continues until the eventual shrinkage of the market, induced by obsolescence of the product, or until fundamental changes in technology launch a new product cycle.

We hypothesise that the five stages of development are determined by the following general process:

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

where

F_t = the expected number of entrants in t,

P_t = the probability of entry in t of each potential entrant,

N = the population of potential entrants,

n_{t-1} = the number of firms that have already entered the market by $t-1$.

The central issue, of course, is what determines P_t, the probability of entry. Our hypothesis is that it basically depends upon the ways in which returns can be maximised on a component of organisation capital, namely, information on new product technology. We distinguish organisation capital from human capital in that the returns to the latter can be appropriated by the individual employees who possess such capital. In contrast, organisation capital belongs to the firm either because it has legal title to it, as in the case of a patent, or because it depends upon the interdependent actions or information of more than one employee. Information on new product technology may take a wide variety of forms, including knowledge and skills relating to production processes and market characteristics for the new product.

Information on new products arises from two sources: (a) from firms already in the market and (b) from sources outside the set of current producers. Both are sources of new information or technology throughout the product cycle, but we expect that the balance between the two changes systematically over time. The former, which we label I_1, is defined as new information emanating from experience in production by existing firms. This type of information has both transferable and non-transferable components. The transferable component represents information that cannot be appropriated and is available for adoption by other firms. The non-transferable component remains the property of its producer and tends to cumulate over time. The accumulated stock of non-transferable information represents what is commonly referred to in the literature as 'learning by doing' and, in the context of a model of entry, operates as a barrier to entry contributing to its eventual decline.

In contrast, I_2, defined as technological information emanating from sources outside the set of current producers, has a positive effect on entry. Such innovation reduces the value of experience accumulated through past production and, thereby, facilitates entry. Moreover, as pointed out by Arrow (1962), there are peculiar properties of the market for information which makes the sale of information difficult. This may leave the innovator with no option but to enter the market if he wishes to realise the full value of his informational capital.[1]

A central feature of our view of entry is that systematic changes occur in the sources of innovations over the product cycle. Innovation, as already indicated, is not a single event but a continuing process encompassing all product improvements and modifications in production techniques. In the early phase of a product cycle (Stage II), we hypothesise that most innovations are of the I_2 variety. That is, they originate outside the set of current producers (from firms in technologically related markets, from independent inventors, from equip-

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[1] A similar view may be found in Mueller (1976). Williamson (1975) also notes features of new industries that operate as obstacles to the sale of information.

ment manufacturers, etc.). In contrast, later in the product cycle (Stages III, IV, and V), we expect that the balance of innovations shifts to the I_1 variety, and the cumulative stock of such innovations begins to operate as an entry barrier.

The distinction between intervals in which most innovations emanate from existing firms rather than from sources external to the set of current manufacturers of the product parallels still another change. In the early phase of the product cycle (Stage II), a much larger fraction of the innovations have *major* consequences for costs of production or for product quality. Over the product cycle, for reasons effectively developed by Burns (1934) in his study of production trends, there is a retardation in technical change as an industry matures. This retardation may be reflected primarily in the importance of the innovations rather than in their number. As contrasted with I_2, innovations of the I_1 type are much more frequently associated with minor modifications in production and marketing techniques, in methods of quality control, and in product improvements of lesser importance. Hence, the transition from I_2 to I_1 innovations corresponds to a retardation in the rate of technical advance. From the standpoint of entry, however, what is critical is not simply the reduction in the rate of technical advance but the concurrent shift in its origin.

The essence of our model of the probability of entry can be stated formally as:

$$P_t = f(I_{2t}, L_t, \pi_t), \qquad (2)$$

where

I_{2t} = number of innovations at time t emanating from sources external to the industry,

L_t = the accumulated stock of experience of incumbent producers (which depends partly on I_1) at time t,

and

π_t = profit of incumbent producers at time t.

The variables I_{2t} and L_t represent the influence of technological change on the probability of entry. We expect that $\partial f/\partial I_{2t} > 0$ and $\partial f/\partial L_t < 0$. The variable π_t represents the potential rewards of entry. We expect that, the larger the potential rewards of entry, the greater the probability that a potential entrant who possesses valuable information will enter the market.

Applying the model described in equations (1) and (2) to Stages II, III, and IV, we hypothesise the following. The entry rate accelerates at the beginning of Stage II, propelled by the two forces, I_2 and π. As technology matures and opportunities for the most dramatic product improvements are realised, the rate of important innovations declines, leading to a reduction in the entry rate. This is reinforced by: (*a*) the accumulation of experience by existing firms (itself a function of I_1) operating as an entry barrier; (*b*) the eventual decrease in π resulting from the increase in the number of producers and (*c*) a gradual reduction in $N - n_{t-1}$, the population of potential entrants that have not as yet entered the market. Finally, a point of zero net entry is reached (Stage III). This, however, is not an equilibrium but rather reflects

structural changes in the industry that, when they mature, precipitate Stage IV.

The reduction in the rate of major innovations brings to an end the higher than equilibrium rates of return to former innovators. As prices and profit margins approach normal competitive levels under pressure from imitators, there is renewed pressure to raise the rate of innovation. Now, however, the induced rise in innovation takes mainly the form of I_1 (innovations internal to the set of current producers). This not only reinforces the barriers to new entry but, in addition, compresses the profit margins of the less efficient producers who are unable to imitate the leaders from among the existing firms. Consequently, the exit rate rises sharply until the less efficient firms are forced out of the market.

Certain attributes of our evolutionary theory deserve emphasis. First, and most important, there is no unique equilibrium number of firms in a market as suggested in some theories of entry. The ultimate number of producers in Stage V, and the number at each preceding point in time, depends upon the sequence of events to that point. Second, technological change (innovations) plays a critical role in determining both entry rates and the eventual number of firms in the market. But the effect of innovations reverses between Stage II and Stages III and IV, as the character of innovations changes. Third, the number of firms in product markets technologically adjacent to those of a new product – that is, the number of potential entrants – influences the entry rate. Finally, the onset of Stage III and the ensuing net exit in Stage IV is not associated with the maturity of the market as measured by market size or the growth rate in demand. Rather, it corresponds to a decrease in the rate of innovations external to the industry, a compression of profit rates, and the accumulation of valuable experience by incumbent producers.

II. ALTERNATIVE THEORIES OF ENTRY

Our evolutionary theory may be most sharply distinguished from those that envisage a unique equilibrium solution in the number of producers. We start with the most widely used model of this type.

(1) Scale economies

The scale economies hypothesis assumes that production in the long run is ultimately characterised by decreasing returns to scale. Entry is assumed to occur when it is possible to reduce the total cost of production of the industry level of output through a change in the number of producers.[1] More formally, entry is assumed to be determined as

$$E_{it} = \alpha(N_{it}^* - N_{it-1}), \quad 0 \leqslant \alpha \leqslant 1, \tag{3}$$

$$N_{it}^* = TC(Q_{it}^e), \tag{4}$$

where E_{it} equals net entry in industry i at time t, N_{it} equals the actual number

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[1] Examples of such theories are Telser *et al.* (1975), Peltzman (1965), and Orr (1974).

of producers in industry i at t, N_{it}^* equals the anticipated cost-minimising number of producers in industry i at t, and the function $TC(.)$ relates the anticipated cost-minimising number of producers to the anticipated equilibrium level of industry output at t, Q_{it}^e.

If Q_1 represents the minimum efficient size of output (at which all economies of scale are realised) and Q_2 the maximum efficient size of output (after which increases in output necessitate increases in long-run average costs), then N_{it}^* can be related to Q_{it}^e as

$$\left[\frac{Q_{it}^e}{Q_2}\right] \leqslant N_{it}^* \leqslant \left[\frac{Q_{it}^e}{Q_1}\right] + 1, \tag{5}$$

where $[.]$ is the greatest integer function.

It follows that E_{it} depends upon either current or (if there are delays in the adjustment process) lagged values of the change in the anticipated equilibrium output and on the minimum (Q_1) and maximum (Q_2) efficient levels of output. The change in the anticipated equilibrium output is most commonly proxied by the past growth in sales,[1] although some authors introduce additional variables (for example, intensity of sales promotion). Attempts have been made at direct measurement of Q_1, or of the minimal investment required for Q_1. For example, one study (Peltzman, 1965) proxied Q_1 by the merger rate. To our knowledge no attempt has yet been made to measure Q_2.

If Q_1 and Q_2 are constant over the course of development of new products, the economies-of-scale theory of entry predicts that net entry patterns should conform closely to movements in output. In terms of the five stages of net entry, the theory predicts that output growth should be low in Stage I, positive in Stage II, zero – or at least low – in Stage III, negative in Stage IV, and zero in Stage V.

(2) Technical change and shifts in optimum firm size

The simple economies-of-scale theory of entry assumes a fixed optimal (minimum and maximum) size of firm. A more complex set of predictions emerges if one assumes systematic shifts in optimum size. Mueller and Tilton (1969) argue that as a new product technology develops, producers accumulate knowledge through 'learning by doing'. The larger this base of knowledge, the larger the minimum efficient size of firm. Tilton (1971) holds that, as a product technology matures and change slows, producers shift to capital-intensive production methods. The slowing of technical change reduces the rate of obsolescence, thus making investment in capital-intensive production methods more profitable. This, in turn, raises the minimum efficient size of firm.

In terms of the five stages of development, this theory predicts that net entry should conform closely to movements in output except when there is a shift in

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[1] Current profits, or the expected return on capital, is sometimes used in place of the past growth in sales to explain entry in models that lean heavily on economies of scale, for example Mansfield (1962). However, profits as an explanatory variable for entry neither confirms nor denies an economies-of-scale hypothesis since, in itself, it offers no explanation for why the potential profits are not captured by existing firms rather than new entrants.

the minimum efficient size of firm. Mueller and Tilton (1969) hypothesise that the rate of technological change slows after Stage II, contributing to an increase in the minimum efficient size of firm. Thus the theory predicts that the rate of growth in output should be roughly zero in Stage I, positive in Stage II, but not related directly to the rate of growth in output in Stages III and IV. Assuming that the firms surviving in Stage V have all attained minimum efficient size, the theory predicts that the rate of growth in output in Stage V should be roughly zero. Moreover, it would follow that the smallest firms in the industry will account for a disproportionately high fraction of the firms exiting the industry in Stages III and IV.

(3) Adjustment costs

An alternative to the economies-of-scale model of entry is the 'dynamic adjustment cost' hypothesis of Penrose (1959). In contrast to the question of optimal scale, dynamic adjustment costs involve a concept of optimal growth rate. Below the optimal growth rate, managerial capacity is released for new tasks at a faster rate than such tasks are created. Conversely, above the optimal growth rate, managerial capacity is exceeded, with the consequence of rising costs. While the theory was not developed primarily to explain entry, it follows from the above that the entry rate should rise when demand growth is too high to permit existing firms to capture the larger market without significantly exceeding their optimal growth rates.

In terms of the five stages of development, the 'adjustment costs' hypothesis predicts that growth in output should be near the optimal rate (for existing firms) in Stages I, III, and V (when net entry is approximately zero), above the optimal rate in Stage II (when net entry is positive), and below the optimal rate in Stage IV (when net entry is negative). Moreover, it follows from the theory that the rate of growth in output will be largest in Stage II, smallest in Stage IV, and roughly equal in Stages I, III, and V.

(4) Entry and technological change

Phillips (1971) argues that an environment conducive to a rapid rate of innovation contributes to exit of producers and increasing market concentration. In a detailed study of the aircraft industry, he concludes that the rapid rate of technological change in supplying industries (partly fostered by government support for defence R & D) contributed to a larger dispersion in the profit rates of existing producers, with a consequent rise in business failures and market concentration. Nelson and Winter (1978) reach a similar conclusion in the context of a simulation model of industry market structure. Modelling technological change as a stochastic process, they find that, the higher the mean level of technological change, the greater the industry's level of market concentration.

Nelson and Winter reach the above conclusion in the context of a model which (for simplifying purposes) assumes no entry. Phillips' analysis similarly is directed to an industry where the forces of exit predominate. This hypothetical view corresponds most closely with what we identified as Stage IV and contrasts

with the phenomenon in Stage II, when entry predominates and exit is relatively small. In terms of the five stages, it implies that Stage IV should be characterised by a high level of technological change and that the rate of technological change should subside in Stage V. A subsidiary implication of the Phillips–Nelson and Winter view is that, *ceteris paribus*, the rate of net entry should be smallest (i.e. the most negative) in Stages IV and V for products subject to the greatest amount of technological change.

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Table 1

The Predictions of Alternative Hypotheses

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Hypothesis 1 (the simple scale economies hypothesis):
$$\dot{q}_2 > 0; \quad \dot{q}_4 < 0; \quad \dot{q}_1 = \dot{q}_3 = \dot{q}_5 = 0,$$
where $\dot{q}_i$ ($i = 1, 2, 3, 4, 5$) is the rate of growth in industry output in Stage (i).

Hypothesis 2 (economies of scale with changes in minimum efficient size of firm):
$$(i) \quad \dot{q}_1 = 0, \quad \dot{q}_2 > 0, \quad \dot{q}_5 = 0;$$
$$(ii) \quad t_2 > t_3 > t_4,$$
where t_i ($i = 1, 2, 3, 4, 5$) is the rate of (industry) technological change in Stage i;

  (iii) the smallest firms in the industry should account for a disproportionately high fraction of the firms exiting the industry in Stages III and IV.

Hypothesis 3 (the 'adjustment costs' hypothesis):
$$\dot{q}_2 > \dot{q}_j \ (j = 1, 3, 4, 5); \quad \dot{q}_4 < \dot{q}_j \ (j = 1, 2, 3, 5); \quad \dot{q}_1 = \dot{q}_3 = \dot{q}_5.$$

Hypothesis 4 (the Phillips–Nelson and Winter view of exit):
$$t_4 > t_3; \quad t_4 > t_5.$$

The principal predictions of the four hypotheses are summarised in Table 1. These can be contrasted with our view of the development of new product industries. Hypotheses 1 and 3 predict that the timing of the five stages corresponds to changes in the rate of growth of industry output. In contrast, in our view the timing of the five stages is dependent upon technological factors which are not necessarily keyed to changes in the rate of growth of industry output. Hypothesis 2 is closer to our view in that it stresses the importance of the rate of technological change. However, it leads to the conclusion that a reduction in the rate of technological change occurs, beginning with Stage III, and that this reduction contributes to the exit of the *smallest* producers in Stage IV. In contrast, while our theory also predicts the survival of the most efficient firms in Stage IV, it does not imply that these surviving firms are necessarily the largest firms in the industry. Finally, hypothesis 4 predicts that the exit of producers in Stage IV corresponds to a relatively high rate of technological change fuelled by technological advances outside the industry. In contrast, our theory predicts that the negative rate of net entry in Stage IV stems from a compression of profit margins resulting from increased price

competition (associated with increased numbers of producers), a reduction in the rate of technological change originating outside the industry, and increasing barriers to new firms from the accumulation of experience by existing firms and from innovations of the I_1 type.

III. THE EVIDENCE

(1) Choice of sample and data

To test the various hypotheses, we assembled data on the historical development of 46 new products.[1] The 46 were chosen on the basis of three criteria: (1) to allow sufficient diversity by including consumer, industrial, and military products; (2) to include only products that were 'basic' innovations; (3) to include products with adequate data on net entry. The 46 products are listed in Table 2 along with the year they were first commercially introduced.[2] The initial dates of commercial introduction span a 73-year period, beginning with phonograph records in 1887 and ending with lasers in 1960.

For the products in the sample, annual data were developed, from the inception of commercial production through to 1973, on the number of producers, the number of patents issued, the number of innovations, and price and output. Data on the number of producers were taken from *Thomas' Register of American Manufactures*, supplemented with data obtained from individual companies. With the exception of the early years in several instances, data on number of producers are complete for all 46 products. Information on the annual rate of patenting was obtained from United States Patent Office records. Patent data were compiled for all but four of the 46 products.

Counts of innovations were derived from a variety of published and unpublished sources, including trade publications, company histories, and information specially compiled for us by companies that first introduced the new product, or that produced it through most of its history. It was possible to construct a meaningful count of innovations for only 23 products in our sample of 46. Finally, data on price and output were drawn from a variety of government and private sources including trade publications. Price data were successfully compiled for 23 products and output data for 25. In contrast to the other series, price and output data, even where available, sometimes have gaps for part of the relevant history.

(2) Decomposing diffusion into stages

We decompose the product histories into (a maximum of) five stages. The stages are defined in terms of net entry (i.e. changes in the number of producers). The five-stage prototype is pictured in Fig. 1.

[1] Two products, procaine and sulphonamides, were deleted from an original sample of 48 because they had not reached Stage II by 1973. The effect of patents may have permanently precluded a Stage II for both products.

[2] The initial year of commercial production is in most cases the year the product was first listed in *Thomas' Register of American Manufactures* (the source for the data on number of producers). For products which were commercially introduced before 1906, the first year *Thomas' Register* was published, the initial year of production was supplied by producers in the industry. In some cases of products introduced after 1906, producers in the industry informed us that the initial year of commercial production preceded the first year the product was listed in *Thomas' Register*. In such cases, we adopted the date supplied by the maker of the product.

Stage I encompasses the interval in which the number of producers in the market remains relatively small (usually between one and three). Stage II is the interval from the 'take-off' point of net entry to the time that net entry decelerates drastically. Stage III is the ensuing period of low or zero net entry, and Stage IV is the subsequent period of negative net entry. Stage 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.
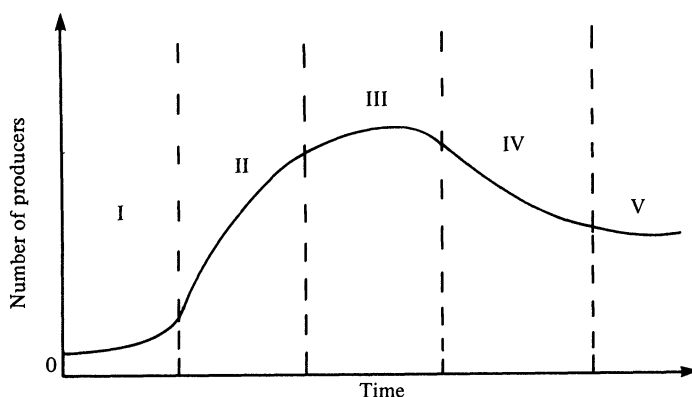
Fig. 1. The five stages of new product industries.

We do not assume, *a priori*, that all new products proceed through all five stages. Instead, we allow the data to determine how many of the five stages are present in each case.

The decomposition into stages was achieved as follows. First, for each product, data were examined on annual net entry rates. Intervals that clearly were components of each of the five stages were identified by visual inspection of the plotted series.

The remaining years – that is, those for which the entry rates could have been associated with either of the two adjacent stages – were then classified into four 'in-between' stages. The principal remaining task consisted of reducing the resulting nine classes into five by devising a method for assigning the observations in the four 'in-between' stages to the original five stages. The initial classification procedure resulted in the assignment of 1,247 observations for the 46 products into one of the five stages, leaving 695 observations initially assigned to the 'in-between' stages to be reassigned.

The assignment procedure consisted basically of the following steps. First we 'standardised' the net entry rates across products to eliminate the effect of cross-sectional differences in levels of net entry. This was accomplished by dividing each observation for a given product by the mean value of net entry for Stage II for the preclassified years for that product.[1] Secondly, the standardised

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[1] We also experimented with other deflating schemes. The results were extremely insensitive to the choice of the deflator.

values for each stage were pooled across all products. These standardised values continue to reflect inter-stage variations in entry rates, but they no longer reflect the wide variations in average net entry rates across products. Third, we used a generalisation of a standard discriminant analysis procedure to classify the 695 points that had not been initially assigned to one of the five stages. The procedure essentially classified points according to the stage they most resembled, where each stage was characterised by the mean rate of entry of the points that had initially been classified in that stage. A detailed description of the procedure is contained in the Appendix.

Results of the decomposition are presented in Tables 2 and 3. For each product, Table 2 lists the number of years classified in each stage and Table 3 lists the mean rate of net entry of the years classified in each stage.

Notwithstanding considerable variation in the duration of stages among products, certain dominant attributes of the process of entry stand out in Tables 2 and 3 with remarkable consistency. First, as Table 2 demonstrates, there are few instances of initial commercial introduction of a product that are immediately followed by rapid entry. For all but three of the forty-six innovations, there was at least one year in Stage I (preceding take-off in entry). Closer examination of Table 2 indicates that the average length of Stage I has declined over time. While the overall average length of Stage I is 14·4 years, the average length of Stage I for products introduced before 1930 was 23·1 years; it was 9·6 years for those introduced in 1930–9 and only 4·9 years for products introduced in 1940 or later. While the result could arise partly from sample selection bias, it strongly suggests that the interval required for successful imitation has systematically declined over time.

Table 2 further indicates that, of the 36 products which had attained Stages IV or V by 1973, all proceeded through a distinct contraction phase in the number of producers. As indicated in Table 3, the average annual rate of net entry in this period for the 36 products was −4·84 firms. The average duration of the stage was 5·4 years – roughly half the average duration of 9·7 years for Stage II.

A further indication of how pronounced Stage IV is can be seen from Table 4. For the products attaining Stage V by 1973, Table 4 contains a summary of the peak number of producers prior to Stage IV and the total net decrease in the number of producers in Stage IV, both in absolute terms and as a percentage of the peak number of producers. The percentages indicate that, on average, the total reduction in the number of producers in Stage IV equalled 40 % of the peak number of producers prior to Stage IV. For some industries, Table 4 indicates that the total reduction during Stage IV in the number of producers exceeded 70 % of the peak number.

The net exit in Stage IV can be contrasted with Stage V. Table 2 shows that, for the 20 products that attained Stage V by 1973, there is no clear trend of either increasing or decreasing numbers of producers. For ten of the twenty products, there was a negative mean annual rate of net entry in Stage V, and for the other ten, a positive one.

Table 2

Number of Years in Each Stage and Year of
Initial Introduction for 46 Products

Product name	Stage					Year of initial commercial introduction of product
	I	II	III	IV	V	
Baseboard radiant heating	5	9	12	1	—	1946
Compressor, Freon	6	5	25	2	—	1935
Computers	17	8	11	2	—	1935
Crystals, Piezo	5	14	0	2	16	1936
DDT	2	2	8	12	6	1943
Electrocardiographs	39	3	8	5	4	1914
Electric blankets	10	4	37	11	—	1911
Electric shavers	6	2	0	7	28	1930
Engines, Jet-propelled	NA	17	0	2	7	1943
Engines, Rocket	13	8	8	—	—	1944
Fluorescent lamps	0	2	0	1	32	1938
Freezers, Home and farm	NA	9	9	10	—	1929
Gauges, Beta-ray	6	3	9	—	—	1955
Gyroscopes	41	9	5	7	—	1911
Lasers	NA	11	—	—	—	1960
Machinery, Adding and calculating	NA	3	13	2	44	1889
Missiles, Guided	12	8	3	8	—	1942
Motors, Outboard	5	4	4	2	50	1908
Nylon	13	14	7	—	—	1939
Paints, Rubber and rubber base	12	21	1	6	—	1933
Penicillin	0	7	0	3	20	1943
Pens, Ballpoint	10	18	—	—	—	1945
Photocopy machines	2	23	0	8	—	1940
Polariscopes	40	7	11	3	6	1906
Pumps, Heat	5	8	4	3	—	1953
Radar, Marine, airborne, other	NA	10	7	11	—	1940
Radio transmitters	19	4	28	—	—	1922
Reactors, Nuclear	12	9	2	8	—	1942
Readers, Microfilm	31	13	—	—	—	1929
Records, Phonograph	33	3	0	11	39	1887
Saccharin	10	2	0	8	47	1906
Shampoo	33	18	24	—	—	1898
Streptomycin	1	7	15	5	—	1945
Styrene	19	11	1	7	—	1935
Tanks, Cryogenic	0	8	0	1	5	1959
Tapes, Recording	4	20	2	—	—	1947
Telemeters	19	10	14	2	—	1928
Television, apparatus, parts	19	6	8	7	4	1929
Tents, Oxygen	16	16	9	6	—	1926
Tyres, Automobile	NA	16	0	10	41	1896
Transistors	NA	9	4	4	4	1948
Trees, Artificial Xmas	50	2	4	2	3	1912
Tubes, Cathode ray	19	18	4	4	6	1922
Turbine, Gas	8	17	12	—	—	1936
Wipers, Windscreen	2	9	2	8	38	1914
Zippers	25	25	13	5	—	1904
Mean number of years	14.4	9.7	7.5	5.4	—	

NA denotes a gap in the net entry series which precludes the dating of the end of Stage I. The entry for Stage II for products with an NA in Stage I represents the minimum number of years elapsed in Stage II.

— Denotes that the stage had not appeared in the product's history by 1973.

Table 3

Mean Annual Net Entry Rates in the Five Stages for 46 Products

Product name	Stage				
	I	II	III	IV	V
Baseboard, radiant heating	0·6	2·1	0·3	−3·0	—
Compressor, Freon	0·8	2·2	0·2	−2·5	—
Computers	2·8	14·3	6·6	−13·0	—
Crystals, Piezo	0·0	3·1	—	−7·0	−0·1
DDT	1·0	15·0	0·6	−1·6	−1·7*
Electrocardiographs	0·2	1·3	0·3	−0·8	0·0
Electric blankets	0·0	1·5	0·3	−0·1	—
Electric shavers	0·2	15·0	—	−2·9	−0·1
Engines, Jet-propelled	NA	1·5	—	−3·0	−0·3
Engines, Rocket	NA	1·6	−0·1	—	—
Fluorescent lamps	—	16·0	—	−14·0	0·2
Freezers, Home and farm	NA	5·8	−0·9	−3·0	—
Gauges, Beta-ray	0·2	2·0	0·2	—	—
Gyroscopes	0·2	3·6	1·0	−1·7	—
Lasers	NA	5·6	—	—	—
Machinery, Adding and calculating	NA	5·0	0·6	−7·0	0·5
Missiles, Guided	3·0	30·9	−2·0	−12·9	—
Motors, Outboard	0·0	5·0	−1·0	−2·0	0·2
Nylon	0·1	1·7	0·4	—	—
Paints, Rubber and rubber base	1·8	4·6	−1·0	−3·2	—
Penicillin	—	3·9	—	−4·7	−0·5
Pens, Ballpoint	0·1	1·4	—	—	—
Photocopy machines	0·5	1·8	—	−2·3	—
Polariscopes	0·0	1·3	−0·1	−1·3	0·3
Pumps, Heat	0·6	2·5	0·0	−2·0	—
Radar, Marine, airborne, other	NA	12·3	2·1	−5·6	—
Radio transmitters	−0·2	8·5	0·2	—	—
Reactors, Nuclear	0·0	4·9	0·5	−2·5	—
Readers, Microfilm	0·2	1·7	—	—	—
Records, Phonograph	0·4	11·7	—	−3·2	0·4
Saccharin	0·3	16·5	—	−3·5	−0·2
Shampoo	0·8	4·9	−1·0	—	—
Streptomycin	0·0	1·7	−0·4	−1·2	—
Styrene	0·3	1·9	0·0	−0·7	0·0
Tanks, Cryogenic	—	10·4	—	−29·0	−0·2
Tapes, Recording	0·0	2·7	−0·5	—	—
Telemeters	0·2	1·9	0·1	−3·0	—
Television, apparatus, parts	6·3	81·0	−1·8	−16·4	−9·5
Tents, Oxygen	0·3	1·2	−0·2	−2·2	—
Tyres, Automobile	NA	16·6	—	−21·1	−0·6
Transistors	NA	7·1	−0·3	−4·5	1·3
Trees, Artificial Xmas	0·2	3·5	0·0	−2·0	0·3
Tubes, Cathode ray	0·1	2·0	−0·3	−3·0	0·7
Turbine, Gas	0·0	1·7	0·3	—	—
Wipers, Windscreen	0·1	5·4	0·0	−3·0	0·0
Zippers	0·0	1·9	−0·2	−1·4	—
Average	0·50	5·67	0·13	−4·84	−0·47
Average of Deflated Means†	0·08	0·98	0·04	−0·68	−0·01

NA denotes a gap in the net entry series which precludes the calculation of the relevant net entry measure.

— Denotes that the stage had not appeared in the product's history by 1973.

* Affected in Stage V by the prohibition on sales of DDT in 1971.

† Deflated for each product by the average of the first and last observation in each stage.

(3) *Tests of hypotheses*

We next review the consistency of alternative hypotheses with observed behaviour in successive stages of the measured variables. The method of analysis permits us to evaluate one hypothesis at a time, but not a more complex, multivariate model. It may, therefore, be regarded as an important first step towards the eventual development of a more complex model. However, some of the hypotheses outlined in Section II have been put forward as sufficient explanations of entry in themselves. An assessment of one hypothesis at a time is, therefore, appropriate.

Table 4

Severity of Net Exit in Stage IV for those Products
Attaining Stage V (by 1973)

Product name	Peak number of producers prior to Stage IV	Total decrease in number of producers in Stage IV	Total decrease in number of producers in Stage IV/peak number of producers prior to Stage IV
Crystals, Piezo	44	14	0·32
DDT	38	19	0·50
Electrocardiographs	14	4	0·29
Electric shavers	32	20	0·63
Engines, Jet-propelled	29	6	0·21
Fluorescent lamps	34	14	0·41
Machinery, Adding and calculating	55	14	0·25
Motors, Outboard	21	4	0·19
Penicillin	30	14	0·47
Polariscopes	16	4	0·25
Records, Phonograph	49	35	0·71
Saccharin	39	28	0·72
Tanks, Cryogenic	84	29	0·35
Television, apparatus, parts	613	115	0·19
Tyres, Automobile	275	211	0·77
Transistors	70	18	0·26
Trees, Artificial Xmas	17	4	0·24
Tubes, Cathode ray	39	12	0·31
Wipers, Windscreen	51	31	0·61
Average	—	—	0·40

(a) *Scale economies and adjustment costs*

The critical evidence for the scale economies and adjustment costs hypotheses involves the relationship between entry and changes in output. Data on changes in output for 25 of the 46 new product industries are summarised in Table 5. The table shows the mean rates of growth in output in each of the relevant stages for each of the 25 products. In addition, at the bottom of Table 5 are a series of summary statistics describing the general pattern of rate of growth in output in the five stages. The row labelled 'Average' (of mean percentage changes in output) shows for each stage the average of the mean rates of growth in output for all the products for which data are available. The row labelled

'Binary comparisons' indicates the results of binary comparisons between the mean rates of growth in output for contiguous stages for all products for which data were available, as shown in the table. (For example, the entry under column I, 7/8, indicates that for the eight products with data for both Stages I and II, seven had a higher mean rate of growth in output in Stage I than in Stage II.) The row labelled 'Probability of extreme event' indicates the

Table 5

Percentage Change in Output for 25 Products*

Product name	Stage				
	I	II	III	IV	V
Baseboard radiant heating	NA	9·6	1·1	—	—
Computers	NA	65·2	19·3	—	—
Crystals, Piezo	NA	NA	—	NA	6·2
DDT	126·9	5·9	15·6	−2·8	−32·1
Electrocardiographs	NA	NA	36·4	5·9	−1·5
Electric blankets	NA	NA	19·6	−0·9	—
Electric shavers	120·2	3·1	—	−12·8	8·6
Engines, Jet-propelled	NA	10·6	—	22·1	−29·6
Fluorescent lamps	—	178·5	—	113·1	8·4
Freezers, Home and farm	NA	43·4	1·1	4·1	—
Gyroscopes	NA	NA	4·6	−11·3	—
Lasers	NA	51·0	—	—	—
Motors, Outboard	NA	NA	NA	NA	6·6
Nylon	32·5	14·1	7·0	—	—
Penicillin	—	65·0	—	22·0	8·1
Pens, Ballpoint	3·8	11·5	—	—	—
Records, Phonograph	24·2	−2·6	—	−13·7	8·4
Streptomycin	NA	56·4	11·0	NA	—
Styrene	29·1	12·1	19·0	6·3	—
Tapes, Recording	NA	14·4	22·8	—	—
Television	61·0	33·9	−1·5	−3·3	2·0
Tyres, Automobile	NA	25·2	—	−0·2	4·2
Transistors	NA	71·3	23·2	15·8	3·7
Tubes, Cathode ray	NA	19·8	−1·5	−16·8	−5·4
Zippers	54·9	15·1	7·3	−2·7	—
Average	56·6	35·1	12·3	8·1	1·0
Binary comparisons	7/8	9/12	9/10	6/11	
Probability of extreme event	0·035	0·073	0·011	0·50	

NA denotes that the data are not available.

— Denotes that the stage had not appeared in the product's history by 1973.

* The percentage change in output in each stage is defined as the value of r which solves: $Q_t = Q_1 e^{r(t-1)}$, where Q_1 and Q_t are output indexes for the first and last years of data in the respective stage.

probability of the recorded binary comparison or a more extreme binary comparison in the same direction if, in fact, the true rates of growth in output for each product were equal in successive stages. This was computed from the binomial distribution. For example, the entry 0·035 in column I of Table 5 is the probability of 7 or 8 successes in 8 trials if the probability of success for each trial is 0·5.

The summary statistics in Table 5 suggest that the rate of growth of output

declines steadily over the course of the development of new product industries.[1] In general, this pattern is not consistent with either of the two versions of the scale economies hypothesis (hypotheses one and two in Table 1) nor the adjustment costs hypothesis (hypothesis three in Table 1). Beginning first with Stage I, all three of the hypotheses predict a relatively low rate of growth of output in Stage I, with the scale economies hypotheses predicting a zero rate. This is clearly inconsistent with the patterns reported in Table 5 in which the rate of growth in output is positive and highest in Stage I. However, the high rate of growth in output in Stage I, coupled with roughly a zero rate of net entry, is, in itself, an inconclusive test of the role of scale economies. The result could arise partly from low starting levels for growth, and partly because entry in some markets may be blocked by patents during the early stages of the industry's development.

More compelling are the relative rates of growth in output in Stages II, III, IV and V. The simple scale economies hypothesis and the adjustment costs hypothesis (hypotheses one and three, respectively, in Table 1) both predict that the rate of growth of output should be lowest in Stage IV, highest in Stage II, and equal in Stages III and V. This is clearly contradicted by the data in Table 5. Moreover, the simple economies of scale hypothesis predicts that the rate of growth in output should be zero in Stages III and V and negative in Stage IV. However, the data in Table 5 indicate that the rate of growth of output in Stage III is positive for 13 of 15 products. The data for Stage IV indicate that the rate of growth of output continues to be positive in that stage for 7 of the 16 products, with a high positive average of the mean annual rates of growth in output for the various products.

Overall, the more complex scale economies hypothesis which allows for changes in the minimum efficient size of firm fares better in Table 5 than the simpler version. This, however, stems partly from the fact that its implications are less clear. Its sharpest prediction concerns the nature of exiting firms in Stages III and IV. The hypothesis is somewhat difficult to test because of inadequacies in the data on firm sizes. However, it appears that Stages III and IV are characterised by a continued presence of a broad spectrum of firm sizes in most of the 46 markets.[2] Thus there does not appear to be evidence of a pronounced tendency towards disappearance of small firms during Stage IV. Indeed, one finds some of the larger as well as the smaller firms exiting in Stage IV. While this is not inconsistent with an inference that less efficient producers were being forced out of the market in Stage IV, it does not support

[1] For a number of reasons, it is likely that the decrease in the rate of growth of output over time is actually more pronounced than the summary statistics in Table 5 indicate. First, the output data are quite crude and contain considerable measurement error. This will tend to make the binary comparisons less extreme than they would be in the absence of measurement error. Secondly, there are a number of products for which there are very few observations on output in some stages, either because the data were not reported (there are gaps in a number of the output series) or because the relevant stage is brief. A disproportionate number of the binary comparisons which do not suggest a declining rate of growth of output over time involve mean rates of growth of output which were calculated from a (relatively) small number of observations.

[2] This conclusion was reached using the limited information available about the identity and sizes of the producers listed in *Thomas' Register of American Manufactures*.

the conclusion that the observed phenomenon of high exit rates is an aspect of scale economies.

(b) Hypotheses concerning the effects of innovation

Technological change can be measured in numerous ways. We examine three measures of technological change used in this study. The first is the number of 'important' innovations for the new product, further subdivided into 'major' and 'minor' (important) innovations. This information was compiled for a subset of the industries in our sample from a variety of sources, including information provided by the companies that historically produced the new product. The data on innovations consist mainly of product improvements, although some changes in production processes used for the new products are also included. The innovations are classified as major and minor based on judgement and expert advice. For example, the production of a lightweight aluminium motor and the electric starting motor were classified as major innovations for the new product, outboard motors, while the development of an abrasion-resisting water pump and an internal reed valve induction system were classified as minor innovations. Similarly, the initial introduction of a reliable internal mirror laser was classified as a major innovation for the new product, lasers, while the development of moisture-resistant seals for a helium–neon laser was classified as a minor innovation.

The second measure of technological change is the real percentage decrease in the average price of the new product. For new products, price declines are a common attribute of technological change. They arise from improvements in production processes as new techniques develop with accumulated knowledge, and from declines in the prices of key components of a product as production processes of component manufacturers also change. Price declines may also arise from scale economies, particularly in the early phases of a market's development. Indeed, changes in scale are an aspect of changes in production processes.

The analytical problem, however, is made more complex by the fact that product prices also change as the result of changes in competition induced by entry. Without discounting the possibility of some effect of entry on prices, we interpret price declines primarily as a reflection of improvements in production processes. The magnitude of such declines renders it implausible that they reflect mainly a compression of profit margins.

The last measure of technological change is the number of patents issued in each of the new product categories. Included are patents relating to both product and process innovations. The number of patents issued measures primarily the *input* (or effort) devoted to innovative activity rather than the output of useful innovations. Input should be positively associated with both market size and the number of producers. In contrast, output depends not only on innovative effort but on technological opportunities, and the latter, as the evidence presented below indicates, appear to decline in economic importance as a product market matures.

The evidence from the three measures of technological change is presented in Tables 6, 7 and 8. The data are reported in the same format as the output

data in Table 5. The principal implications of the three measures of technological change are summarised below.

Table 6

Mean Annual Number of Innovations, Classified by Importance and by Stage, for 23 Products

Product	Stage I Major	Minor	Stage II Major	Minor	Stage III Major	Minor	Stage IV Major	Minor	Stage V Major	Minor
Crystals, Piezo	0·20	0	0	0	—	—	0	0	0·07	0
Electrocardiographs	0	0·03	0	0	0·13	0·38	0	0·20	0	0·25
Electric blankets	0	0	0	0	0·11	0·27	0·27	0	—	—
Electric shavers	0	0	0	0	—	—	0·14	0·14	0·18	0·11
Engines, Jet-propelled	NA	NA	0·35	0·18	—	—	0	0·50	0·29	0
Fluorescent lamps	—	—	0·67	0	—	—	0	0	0·41	0·34
Freezers, Home and farm	NA	NA	0·22	0·22	0·22	0·33	0	0·10	—	—
Gyroscopes	0·27	0·24	0·44	0·22	0·80	0·40	0	0·14	—	—
Lasers	NA	NA	1·0	0·82	—	—	—	—	—	—
Missiles, Guided	0·25	1·25	0·88	1·50	0	0·33	0	0·38	—	—
Motors, Outboard	0	0	0	0	0·25	0	0·50	0	0·18	0·32
Nylon	0	0·69	0·29	0·15	0·14	1·14	—	—	—	—
Penicillin	—	—	0·43	0·14	—	—	0	0	0·10	0·25
Pens, Ballpoint	0·50	0·40	0·28	0·17	—	—	—	—	—	—
Records, Phonograph	0·12	0	0	0	—	—	0·09	0	0·08	0·03
Streptomycin	1·0	0	0	0	0	0	0	0	—	—
Styrene	0·21	0·63	0	0·72	0	0	0	0·29	—	—
Tapes, Recording	0·50	0	0·25	0·30	0	0	—	—	—	—
Television, apparatus, parts	0·16	NA	0·50	NA	0·25	NA	0·57	NA	0·25	NA
Tyres, Automobile	NA	NA	0·19	0·25	—	—	0·20	0	0·15	0.17
Transistors	NA	NA	0·78	0·44	1·5	2·25	1·75	1·75	0·75	0·50
Tubes, Cathode ray	0·37	0·21	0·22	0·28	0·25	0·50	0·75	0	0·67	0
Zippers	0·32	0·08	0·20	0·12	0·31	0·46	0·20	0·20	—	—
Average of means	0·24	0·24	0·29	0·25	0·28	0·47	0·24	0·22	0·26	0·18
Binary comparisons (ties excluded)	8/12	4/9	4/11	3/11	4/9	7/9	6/11	3/9		
Probability of extreme event	0·194	0·500	0·275	0·113	0·500	0·090	0·500	0·254		

NA denotes that the data are not available.
— Denotes that the stage had not appeared in the product's history by 1973.

First, based on annual percentage changes in price (Table 7), we find: (1) the greatest percentage decreases in price occur during the early stages of development; (2) the decreases in price fall thereafter, dropping markedly in Stage V.[1] Secondly, based on counts of innovations (Table 6), we find: (1) the

[1] While the binary comparisons indicate that the rate of decrease in price falls after Stage II, the average of the means suggests that the percentage decrease in price rises from Stage III to Stage IV. This is a manifestation of the changing mix of products for which observations on price were available for Stages III and IV. Focusing only on those products for which observations on price were available for *both* Stages III and IV, the average of the mean rate of decrease in price for these products is 5·7% in Stage III and 5·5% in Stage IV. Thus, after correcting for the mix of products, there appears to be a slight decline in the rate of decrease in price from Stage III to Stage IV. The binary comparisons for Stages III and IV point to a similar conclusion. In general, the binary comparisons are likely to understate the differences between the rate of decrease in price in successive stages for the same reasons that they understate the decline in the rate of growth of output over time (cf. note 1 on p. 645).

number of major innovations appears to peak slightly in Stage II and remains roughly level in the subsequent stages; (2) the number of minor innovations appears to peak in Stage III and remain roughly level in Stages IV and V. Finally, based on annual number of patents (Table 8), the binary comparisons point to a steadily increasing rate of patenting up to Stages I-III, a levelling

Table 7

*Percentage Change in Real Price for 23 Products**

Product name	Stage				
	I	II	III	IV	V
Computers	NA	−16·5	0·2	—	—
Crystals, Piezo	NA	NA	—	NA	−10·0
DDT	−53·7	−23·0	−11·0	−4·2	−7·3
Electrocardiographs	NA	NA	13·6	−0·9	2·1
Electric blankets	NA	NA	−7·5	−3·1	—
Electric shavers	−7·0	−0·8	—	−2·1	−3·2
Fluorescent lamps	—	−21·3	—	−27·4	−2·8
Freezers, Home and farm	NA	1·9	−6·4	−5·2	—
Gyroscopes	NA	NA	−18·4	−5·8	—
Lasers	NA	−1·9	—	—	—
Motors, Outboard	NA	NA	NA	NA	2·0
Nylon	−8·5	−2·4	−4·4	—	—
Penicillin	—	−56·9	—	−41·7	−14·5
Pens, Ballpoint	−24·6	−7·2	—	—	—
Records, Phonograph	−3·1	−2·1	—	−3·7	−2·4
Streptomycin	NA	−52·7	−21·6	—	—
Styrene	−4·5	−8·3	2·5	−10·2	—
Tapes, Recording	NA	−5·2	−17·5	—	—
Television, apparatus, parts	−4·5	−10·3	−2·6	−7·9	−6·8
Tyres, Automobile	NA	−3·0	—	−5·4	0·0
Transistors	NA	−14·6	−22·8	−18·6	−13·3
Tubes, Cathode ray	NA	−4·3	−2·0	−4·0	−6·3
Zippers	−2·7	−5·9	−2·3	4·7	—
Average of mean percentage changes	−13·6	−13·0	−7·2	−9·0	−5·2
Binary comparison	5/8	7/11	6/10	7/10	
Probability of extreme event	0·363	0·275	0·378	0·173	

NA denotes that the data are not available.

— Denotes that the stage had not appeared in the product's history by 1973.

* The percentage change in price in each stage is defined as the value of r which solves: $P_t/CPI_t = (P_1/CPI_1)e^{r(t-1)}$, where P_1 and P_t are the price indexes for the first and last years of data in the respective stage and CPI_1 and CPI_t are the values of the Consumer Price Index in first and last years of data in the respective stage.

in Stage IV, and a surge in the rate in Stage V. While the simple average of the means indicates that the rate of patenting turns down from Stage II to Stage IV and then falls sharply in Stage V, this is misleading. The latter measure is quite sensitive to the changing mix of products for which patent observations are recorded. This is apparent from the row at the bottom of Table 8 marked 'Average of deflated means'. This measures the within-stage averages of the mean rates of patenting for all products after the patent observations for each product are 'standardised'. Standardisation is accomplished by dividing the

Table 8

Mean Annual Rate of Patenting for 42 Products*

Product name	Stage				
	I	II	III	IV	V
Baseboard radiant heating	3·2	4·0	2·9	—	—
Computers	1·3	10·9	15·8	NA	—
Crystals, Piezo	0·7	1·5	—	0·5	2·5
DDT	20·0	41·5	25·0	46·5†	†
Electrocardiographs	1·4	1·0	6·0	31·8	NA
Electric blankets	0·1	0·0	2·0	2·8	—
Electric shavers	1·3	0·0	—	0·0	0·8
Engines, Jet-propelled	NA	2·3	—	0·5	0·5
Engines, Rocket	0·3	0·8	1·7	—	—
Fluorescent lamps	—	0·5	—	0·0	12·5
Gauges, Beta ray	70·3	81·3	91·3	—	—
Gyroscopes	13·5	56·9	78·0	31·5	—
Lasers	NA	131·1	—	—	—
Machinery, Adding and calculating	NA	4·9	9·2	7·0	17·4
Missiles, Guided	0·0	0·9	1·7	0·3	—
Motors, Outboard	3·2	10·0	4·3	11·0	10·9
Nylon	10·5	41·4	105·5	—	—
Paints, Rubber and rubber base	11·6	51·2	64·0	123·0	—
Penicillin	—	24·7	—	12·7	18·7
Pens, Ballpoint	3·4	4·6	—	—	—
Photocopy machines	0·0	12·0	—	128·7	—
Polariscopes	0·1	0·0	0·5	1·3	1·0
Pumps, Heat	8·6	9·1	4·0	NA	—
Radar, Marine, airborne, other	NA	8·1	23·4	21·0	—
Radio transmitters	0·2	0·0	0·1	—	—
Reactors, Nuclear	0·5	104·8	233·0	106·7	—
Readers, Microfilm	0·8	4·1	—	—	—
Records, Phonograph	3·8	5·7	—	4·9	2·4
Saccharin	0·0	0·0	—	0·4	1·2
Streptomycin	17·0	16·4	19·5	NA	—
Styrene	8·4	10·6	18·0	13·0	—
Tanks, Cryogenic	—	6·0	—	3·0	—
Tapes, Recording	3·0	4·2	NA	—	—
Telemeters	2·7	1·7	1·5	NA	—
Television, apparatus, parts	7·9	11·8	14·6	25·0	NA
Tents, Oxygen	3·8	2·2	1·3	0·0	—
Tyres, Automobile	NA	0·8	—	0·9	5·1
Transistors	NA	8·5	6·5	2·7	NA
Trees, Artificial Xmas	0·5	3·0	1·3	NA	NA
Tubes, Cathode ray	17·0	8·2	10·5	15·3	16·6
Wipers, Windscreen	0·0	1·0	3·5	0·7	1·9
Zippers	1·5	2·2	1·0	NA	—
Average	6·6	16·4	26·6	21·9	7·0
Average of deflated means‡	0·90	1·21	1·29	1·25	3·57
Binary comparisons (ties excluded)	9/32	9/28	9/17	3/12	
Probability of extreme event	0·023	0·092	0·500	0·073	

NA denotes that the data are not available.

— Denotes that the stage did not appear in the product's history as of 1973.

* To allow for the lag between patent applications and awards, the patent data were lagged by one year for years prior to 1916, two years for the period 1916–39, and four years for the period 1939–72 (cf. Schmookler (1965)).

† The mean was calculated only for years prior to 1971, the year DDT was banned. After 1970, the number of patents was zero. Including 1971 and 1972, the Stage IV mean is 31·3 and the Stage V mean is 0·0.

‡ This was computed by deflating the mean for each stage for each product by the average number of patents for the five years following Stage II, or for all the years following Stage II for products with less than five years of patent data following Stage II.

number of patents by the average number (for that product) in the five years following Stage II.[1] The resulting measure is far less sensitive to the changing composition of products, since it converts patent observations for different products to a comparable scale. It confirms the impression gained from the binary comparisons that the rate of patenting increases steadily from Stage I to Stage III and then surges in Stage V.

The differing patterns in the three measures lend support to our view that patents are not a good measure of the rate of technological change. While the average rate of patenting increases from Stage I to Stage III and then rises sharply in Stage V, the percentage decreases in price decline over time, dropping markedly in Stage V when the rate of patenting surges. Furthermore, the counts of innovations are at variance with the trends in patenting, with no indication of increases over time comparable to those shown for patents (particularly in Stage V).

The increase in the rate of patenting over time is probably attributable to an increase in innovative effort. The failure of the price and innovations series to rise comparably indicates that innovative effort may be rising over time even though the productivity of this effort is declining. There are two circumstances which may render such an outcome consistent with maximising behaviour by firms. First, while the success rate of innovative effort may decline, the continued growth in market size may raise the returns to successful innovations, thus maintaining incentives for investment in technological change. Secondly, to an important degree innovative activity is an unplanned consequence of production and, as such, entails only small incremental costs. Accordingly, as output continues to grow, innovative activity rises, in part, independently of changes in the productivity of such activity.

The behaviour of the three series appears to support the hypotheses presented in Section I. It was argued that in the early stages of the development of new industries technological change has a positive effect on entry and delays exit of less efficient producers. It follows that Stage II should be characterised by a relatively high rate of technical change and that the onset of Stage III would be associated with a decrease in technical change. The data on price changes are consistent with this hypothesis. While our data on innovations do not point to a decline in the rate of technical change, there are indications that the 'major innovations' occurring during the early stages of development of new product industries are of greater importance than those occurring later. This explains the flatness in the innovations series notwithstanding the downward trend in the rate of decrease in prices.

It was further hypothesised that exit of the less efficient producers in Stage IV was associated with intensified technological competition originating from sources internal to the industry. The increase in the rate of patenting over time, particularly in Stage V, is generally consistent with this interpretation.

Our conclusions on the process of technical change and its implications for

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[1] The choice of a deflator for the patent series was determined by the availability of data. Experimentation with alternative deflators suggested that the results are not particularly sensitive to this choice.

the development of new industries can be contrasted with those of Phillips (1971) and of Nelson and Winter (1978). In their view, technical change is an important determinant of market structure; high rates of change are thought to contribute to a greater dispersion of profit rates among producers, leading to a higher rate of exit (of less successful innovators). In terms of the five stages of development, this theory suggests that the rate of technical change should be particularly high in Stage IV and then fall in Stage V.

The patterns reported in Tables 6, 7 and 8 are not consistent with this view. Decreases in price decline over time, while the counts of innovations do not indicate a higher rate of technical change in Stage IV than in either Stages III or V. While patent data suggest a different pattern, they also offer no support to a hypothesis that the rate of technological change is especially high in Stage IV. It is possible that the industries with the highest exit rate in Stage IV are those that experienced the highest rate of technical change in that stage. While our data do not indicate a correlation across industries in the rate of technical change (as measured by price decreases, innovations, or patents) and exit rates in Stage IV, or technical change and the rates of net entry in Stage V, our data may be too crude to reveal this pattern.

IV. CONCLUSIONS

Though our historical method of analysis necessarily leaves many questions only partially resolved, a number of strong results emerge from the record. These, briefly, are as follows.

(1) The markets for most new products appear to pass through at least five distinguishable stages in the course of their evolution.

(2) New industries generally pass through a stage in which the number of producers declines significantly.

(3) The evidence does not support the hypothesis that variations in entry of producers into new markets can be explained largely by economies of scale.

(4) The dynamic adjustment costs hypothesis as an explanation of entry rates is consistent with some of the evidence but is not a sufficient explanation for many of the observed phenomena.

(5) There appears to be an association between rises and declines in the rate of innovation and the rate of entry into new markets. We interpret the causal relation as being positive, and flowing primarily from innovations to entry rates during the period of positive net entry.

(6) The character, importance, and sources of innovations appear to change over the product cycle.

(7) The results support the conclusion that the structure of markets (in terms of number and composition of producers) is shaped, to an important degree, by discrete events such as technical change and the flow of information among existing and potential producers.

We view many of these inferences as only first steps toward developing a theory of the evolution of industries. Much more data and further theoretical

refinements will be needed to determine the degree to which different forces are at work in the development of new industries.

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<div align="center">APPENDIX</div>

The procedure used to classify the observations that were initially placed in the four in-between stages can be described as follows. Let $x_1, x_2, ..., x_T$ represent T consecutive years of observations on net entry (after they are 'standardised' as described earlier) for a product that we initially classified in category 1–2. The problem is to choose an optimal dividing year j such that observations $x_1, x_2, ..., x_j$ are classified in Stage I and observations $x_{j+1}, x_{j+2}, ..., x_T$ are classified in Stage II.

Let $\hat{\mu}_1$ and $\hat{\mu}_2$ represent the mean rate of net entry of the standardised observations that were initially classified in Stages I and II respectively. Intuitively, we want to choose a classification procedure such that the observations $x_1, x_2, ..., x_j$ classified in Stage I 'resemble' the observations initially classified in Stage I more than they resemble those initially classified in Stage II, and conversely the observations $x_{j+1}, x_{j+2}, ..., x_T$ classified in Stage II resemble the observations initially classified in Stage II more than they resemble those initially classified in Stage I.

This was accomplished using the following three-step procedure:

(1) For each $j = 1, 2, ..., T$, we computed

$$d_1(j) \equiv \sum_{i=1}^{j} x_i / j$$

$$d_2(j) \equiv \sum_{i=j+1}^{T} x_i / (T-j)$$

(2) The choice of a dividing year was limited to those values of j for which

$$|d_1(j) - \hat{\mu}_1| \le |(\hat{\mu}_1 - \hat{\mu}_2)/2| \tag{6}$$

$$|d_2(j) - \hat{\mu}_2| \le |(\hat{\mu}_1 - \hat{\mu}_2)/2|. \tag{7}$$

If there were no values of j satisfying both (6) and (7) then all the observations were classified in Stage I if $|d_1(T) - \hat{\mu}_1| < |d_1(T) - \hat{\mu}_2|$ and in Stage II otherwise.

(3) If there were multiple values of j satisfying (6) and (7), then we selected the value of j from this set that maximised $|d_1(j) - d_2(j)|$.

Step 2 ensures that for each product the mean rate of net entry for the years classified in Stage I is closer to $\hat{\mu}_1$ than to $\hat{\mu}_2$ and that the mean rate of net entry for the years classified in Stage II is closer to $\hat{\mu}_2$ than $\hat{\mu}_1$. Let $\hat{v}_1$ and $\hat{v}_2$ represent the mean rates of net entry of all the points classified in Stages I and II (including the years classified initially) after the $x_1, x_2, ..., x_T$ have been

classified. Step 3 ensures that, once classified, $x_1, x_2, ..., x_T$ cannot be reclassified without lowering $|\vartheta_1 - \vartheta_2|$.

This procedure generalises one often used to classify a single observation. It is easy to demonstrate that if a single observation x must be classified in one of two populations, where each population is characterised by the same symmetric distribution and the same variance, then the probability of misclassification is minimised if x is classified in the population whose mean is closest to x (cf. Dhyrmes (1970, pp. 63–5)). Similarly, step 2 requires that the mean of the observations classified in each of the two stages is closer to the sample mean of the observations initially classified in those stages than in the alternative stage. Step 3 ensures that, from among the classifications that would satisfy step 2, the classification that is chosen maximises the difference between the means of the points classified in the two alternative stages. It attempts to maximise the 'difference' between the points classified in contiguous stages.

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