OMEGA, The Int. Jl of Mgmt Sci., Vol. 3, No. 6, 1975. Pergamon Press. Printed in Great Britain

A Dynamic Model of Process and Product Innovation

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(Received December 1974; in revised form May 1975)

This article reports results from empirical tests of relationships between the pattern of innovation within a firm and certain of the firm's characteristics: the stage of development of its production process and its chosen basis of competition. The hypothesized relationships posed for the present investigation are a synthesis of prior research by the present authors on two distinct but complementary conceptual models of innovation, concerning respectively: the relationship between competitive strategy and innovation, and the relationship between production process characteristics and innovation. The empirical investigation is carried out with data available from the Myers and Marquis study of successful technological innovation in five different industry segments.

The essential aspects of the hypothesized relationships are that the characteristics of the innovative process will systematically correspond with the stage of development exhibited by the firm's production process technology and with its strategy for competition and growth. As a more specific example these relationships predict that there will be coherent patterns in the stimuli for innovation (market, production or new technology); in the types of innovation (product or process, original or adopted, etc.) and in barriers to innovation.

The presently reported statistical evidence is decidedly favorable to the hypothesized relationships, even though the adaptations needed to implement tests with existing data introduce dependencies that limit conclusions which would otherwise be warranted. The broad implication is that strong and important relationships exist among the capability of a firm to innovate, its competitive strategy and the posture of its production resources.

MOST studies of new product and process technology to date have been descriptive and have attempted to identify consistent patterns in the sources of ideas and problem solutions used, communication processes, and characteristics of successful innovations [12]. Past work does suggest central tendencies and systematic variations in the innovative process, but offers no higher level explanation, or theory, of why these tendencies and variations are observed [9].

Our purpose is to suggest some ideas for an integrative theory which will predict differences in the innovative process and in the types of innovations attempted between firms and between different industrial segments.

IDEAS FOR AN INTEGRATIVE THEORY OF THE INNOVATIVE PROCESS

The essence of our argument is that characteristics of the innovative process and of a firm's innovation attempts will vary systematically with differences in the firm's environment and its strategy for competition and growth, and with the state of development of process technology used by a firm and by its competitors.[1] We assume that a firm can affect its environment only in minor ways. Therefore we argue there will be a strong mutual relationship between a firm's choice of a strategy and its environment[2] and given its strategy, between the types of product and process innovations that a firm undertakes and the way its productive resources will be deployed, particularly the state of development achieved in its production processes.

The conceptual basis for a model that encompasses these mutual relationships between innovation, competitive strategy and state of process development originates in the integration of two separate but complementary lines of inquiry that have been pursued independently by the present authors. One such line of inquiry has concerned the relationship between a firm's competitive environment and the objectives underlying the pattern of innovation it undertakes, whether performance maximizing, sales maximizing, or cost minimizing (addressed in [12, 13] and in research in progress). The other line of inquiry has considered the relationship between the development of a firm's production process characteristics and the type of innovative activity it undertakes, e.g. the type, source and stimuli of innovation (addressed in [1, 2] and research currently underway). Subsequent paragraphs integrate these separate approaches into a common conceptual model that relates innovation to product and process evolution; develop hypotheses; present some preliminary tests of these hypotheses using previously collected data on successful industrial innovation [7],[3] and discuss implications with respect to corporate strategy, production technology and environment.

[1] Lawrence and Lorsch (1967) in developing a similar argument with respect to variations in firms' organization structure and integrative mechanisms consider the production technology used by the firm and its competitors to be a part of the firm's environment [6].

[2] Only one or a few alternative competitive strategies will be appropriate for a given environment and set of resources. However, a firm may choose to change both its strategy and its environment.

[3] One of the authors, James Utterback, was privileged to be involved in the original study with the late Professor Donald G Marquis who kindly provided the basic data for further analysis which could not be undertaken at the time.

A MODEL OF PROCESS DEVELOPMENT

A production process is the system of process equipment, work force, task specifications, material inputs, work and information flows, etc. that are employed to produce a product or service. The basic idea underlying the proposed model of process development is that as a production process develops over time toward levels of improved output productivity, it does so with a characteristic evolutionary pattern: it becomes more capital intensive, direct labor productivity improves through greater division of labor and specialization, the flow of materials within the process takes on more of a straight line flow quality (that is flows are rationalized), the product design becomes more standardized, and the process scale becomes larger. Productivity gains result from concurrent and often incremental changes in these several variables, some of which are stimulated by changes in the market, external to the firm (i.e. volume and product standardization) and some of which arise from within the firm.

As a process continues to develop toward states of higher productivity through incremental changes in these factors, a cumulative effect is achieved that significantly alters the overall nature of the process. Definite stages of development that are similar in different industries and economic sectors can be identified in the characteristics of the productivity factors of various processes. The pattern of changes from one stage to another in the process are pervasive in character going beyond the physical attributes to the productivity factors themselves. As a process develops there may also be changes in the internal organizational structure, the development of a supplier industry for special materials, and technology based capital goods. We will describe three different stages of process development which are referred to here as uncoordinated, segmental and systemic.

Uncoordinated. Early in the life of process and product, market expansion and redefinition result in frequent competitive improvements. The rates of product and process changes are high and there is great product diversity among competitors. Typically the process itself is composed largely of unstandardized and manual operations, or operations that rely upon general purpose equipment. During this state, the process is fluid, with loose and unsettled relationships between process elements. Such a system is "organic" and responds easily to environmental change, but necessarily has "slack" and is "inefficient".[4]

Segmental. As an industry and its product group mature, price competition becomes more intense. Production systems, designed increasingly for efficiency, become mechanistic and rigid. Tasks become more specialized and are subjected to more formal operating controls. In terms of process, the production system

[4] The term "organic" and the contrasting term "mechanistic" are used to describe the nature of organizational relationships within a company or department, as developed earlier by Burns and Stalker (1961).

tends to become elaborated and tightly integrated through automation and process control. Some subprocesses may be highly automated with process specific technology while others may still be essentially manual or rely upon general purpose equipment. As a result, production processes in this state will have a segmented quality. Such extensive development cannot occur however until a product group is mature enough to have sufficient sales volume and at least a few stable product designs.

Systemic. As a process becomes more highly developed and integrated and as investment in it becomes large, selective improvement of process elements becomes increasingly more difficult. The process becomes so well integrated that changes become very costly, because even a minor change may require changes in other elements of the process and in the product design. Process redesign typically comes more slowly at this stage, but it may be spurred either by the development of new technology or by a sudden or cumulative shift in the requirements of the market. If changes are resisted as process technology and the market continue to evolve, then the stage is set for either economic decay or a revolutionary as opposed to evolutionary change.

The unit of analysis used here is not necessarily the firm, but rather the overall production process which is employed to create a product (or service). The term *process segment* will be used to describe the elements which would typically be managed by the senior operating executive in an organization. In the simplest case of a firm with a small set of related products, this will be the operations of the firm itself. However, in the case of a conglomerate, or a firm with a high degree of vertical integration, it will be more appropriate to consider each division as a segment. In the case of highly fragmented industries a process segment might reasonably be defined to include the activities of several firms.

The essential idea here is that a process, or productive segment, tends to evolve and change over time in a consistent and identifiable manner as described above.[5]

THE MODEL OF PRODUCT DEVELOPMENT

A product innovation is a new technology or combination of technologies introduced commercially to meet a user or a market need. As was the case with process development a basic idea underlying the proposed model of product innovation is that products will be developed over time in a predictable manner with initial emphasis on product performance, then emphasis on product variety and later emphasis on product standardization and costs.

This idea has the advantage that it allows one to distinguish both among the innovative patterns of firms in an industry at a given time and among those of a given firm at different times based on dominant competitive strategy. Thus, a

[5] For a more complete discussion of this model see Abernathy and Townsend (1975) [1].

firm at one time may attempt to be the first to introduce technically advanced products (performance-maximizing), or to watch others innovate but be prepared to quickly adapt and introduce new product variations and features (sales-maximizing), or to enter the market later in the product life cycle with simpler and less expensive versions (cost-minimizing) [3, 10]. Similarly, the strategies of a firm or segment may evolve from one dominant strategy to another with time. Research on the product life cycle has started from the perspective of treating product characteristics as the unit of analysis, and several studies have shown a relationship with changing process characteristics.[6] Studies of major products (petrochemicals, automotive, electronics) in international trade have demonstrated a consistent pattern [15].

Performance-maximizing. In the early phases of the product life cycle the rate of product change is expected to be rapid and margins to be large. A firm with a performance-maximizing strategy might be expected to emphasize unique products and product performance, often in the anticipation that a new capability will expand customer requirements.

A majority of innovations produced by performance-maximizing firms would be expected to be market-stimulated with a high degree of uncertainty about their ultimate market potential. Technology to meet market needs may come from many sources. Innovation may often arise from unexpected sources or directions of inquiry. Performance-maximizing firms would be expected to rely more heavily on external sources of information, and on more diverse sources of information than would others.

The industry will probably be composed of relatively few firms, and these will be either small new firms or older firms entering a completely new market based on their existing technological strengths. Production capacity will be flexible permitting easy variation in production input, and will tend to be located near affluent markets and where a variety of production inputs are available.

In the beginning stages of both the product and process segment's development, corresponding to the uncoordinated state, product markets are ill defined, products are nonstandard and the production process is inchoate. Product innovation tends to be driven or stimulated by new market needs and opportunities. The critical insight for innovation is often obtained by identifying the relevant product requirements rather than in new scientific results or advanced technology. The locus for innovation is in the individual or organization that is intimately familiar with needs. Here if advanced technology is critical, it is predominantly so in applications to product rather than process innovation. Technological innovations which may have market application, lie fallow until markets can be identified or created.

Sales-maximizing. As experience is gained by both producers and users of a product, market uncertainty will be correspondingly reduced. We might expect a greater degree of competition based on product differentiation with

[6] See for example Stobaugh (1972) [11] and Vernon (1966) [14].

some product designs beginning to dominate. Sales-maximizing firms would tend to define needs based on their visibility to the customer. Innovations leading to better product performance might be expected to be less likely, unless performance improvement is easy for the customer to evaluate and compare.

The reduction in market need uncertainty, with greater diffusion of product use enables increased application of advanced technology as a source of further product innovation. The result will more often be product variation, or new components. More fundamental changes might occur with the intent of replacing an existing product rather than creating an entirely new product application. Economic impact can be almost immediate. At the same time forces that reduce the rate of product change and innovation are beginning to build up. As obvious improvements are introduced it becomes increasingly difficult to better past performance, users develop loyalties and preferences and the practicalities of marketing, distribution, maintenance, advertising, etc. demand greater standardization. Advanced technology plays an increasingly important role here in stimulating product innovation and process innovation.

This stage of product innovation roughly corresponds to the segmental stage of process evolution. Process changes will largely be stimulated by the demand for increased output and these may tend to be discontinuous (or major) process innovations that involve new methods of organization and product design as well as production.

Cost-minimizing. As the product life cycle evolves product variety tends to be reduced and the product becomes standardized. Then as a progression the basis of competition begins to shift to product price, margins are reduced, the industry often becomes an oligopoly, and efficiency and economies of scale are emphasized in production. As price competition increases production processes become more capital intensive and may be relocated to achieve lower costs of factor inputs. Relocation may shift capacity overseas.[7]

In the cost-minimizing stage significant change frequently involves both product and process modifications and must be dealt with as a system. Because investment in process equipment in place is high and product and process change are interdependent, innovations in both product and process may be expected to be principally incremental. The prospects for high rates of market and organizational growth from radical innovation, either product feature improvement or cost reduction, is not appreciable. Under these conditions, however, both product and process features are well articulated and easily analyzed. The conditions necessary for the application of scientific results and systems techniques are present. Unfortunately the pay-off required to justify the cost of change is large while potential benefits are often marginal. Innovations

[7] This model has been used very successfully in explaining international trade. In terms of the present purposes it is particularly interesting because of the relationship hypothesized between product characteristics and process characteristics.

will typically be developed by equipment suppliers for whom the incentives are relatively greater and adopted by the larger user firms [5].

INNOVATION AND STAGE OF DEVELOPMENT

The pattern of relationships between a segment's stage of development and innovation can be conceptualized as shown in Fig. 1. Changes in frequency of innovation are shown on the vertical axis and related to the stage of process and product development on the horizontal axis. Presenting the ideas discussed above in this manner implies an orderly and even progression of product and process development, standardization and increase in sales volume. Process segments which exhibit the highest rates of improvement in productivity do indeed seem to progress rapidly through the stages indicated. But this is not necessarily the case for all process segments [1].

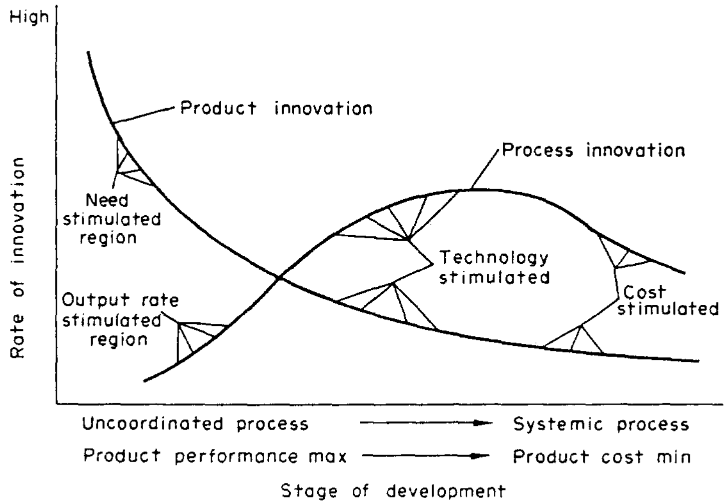

FIG. 1. *Innovation and stage of development.*

There is reason to believe that in many cases the progression may stop for long periods, or even reverse. A firm which does pursue the evolution of its process segment to the extreme however may find that it has achieved the benefits of high productivity only at the cost of decreased flexibility and innovative capacity. It must face competition from: innovative products that are produced by other more flexible segments that are more capable of substituting products, foreign imports, competing products from other industries with high cross-elasticity of demand, or process changes by customers to eliminate the product directly [2].

In other cases it may not be possible to achieve progression because of certain barriers or from a strategic point of view the firm may find it advantageous to inhibit progression by maintaining a high rate of product or model change. Any of these considerations may alter the path of progression for a particular segment without necessarily changing the relationship among the characteristics of strategy, innovation and process development, exhibited at a given stage for a given process segment. It may also be that computer aided manufacturing will ultimately reduce some of the interdependence between product and process change and deflect the pattern represented in Fig. 1, but until this happens it does not obviate the general proposition presented by Fig. 1 and descriptive model—that for a usefully large class of process segments, important internal consistency will be present among strategy, innovation and process characteristics.

Several important issues in managing technological innovation are addressed by the model: the natural locus of innovation (or the most potentially fruitful source); the most appropriate type of innovation; and the array of barriers to innovation [1].

1. The locus of innovation shifts with the stage of development. During the unconnected stage in the development of a process, innovative insight comes from those individuals or organizations that are intimately familiar with the recipient process, rather than those intimately familiar with new technologies. The critical input is not state-of-the-art technology but new insights about the need. Later, in the systemic stage, needs are well defined, "system like", and easily articulated. These needs lend themselves to complex technological solutions and the innovator will frequently be one that brings new technological insights to the problem. This may be a formal engineering or R & D group, an equipment company, or some other external source. In undertaking action to stimulate innovation, it is important to appreciate these distinctions so that the most likely sources of innovation can be identified, nurtured, and supported.

2. The type of innovation that is likely to succeed, whether technologically complex or simple, and whether applied to product or process, also depends upon the stage of development. During the unconnected state most technological applications are to the products that the productive segment will produce. Few are to process improvement and those that do occur tend to be simple in application and to address single needs. Complex technological systems of process equipment do not "take" well when the recipient process is ill defined, uncertain and unstructured. Systems technology has not been very successfully applied to solve ill defined process needs. The converse is true in the systemic stage. Isolated radical innovations, of even major significance, seldom gain ready acceptance when the recipient productive

segment is in the systemic stage. The seemingly isolated innovation must in reality be incorporated as change throughout the systemic productive segment. A realistic assessment of the type of innovations that will be successful, and how they should be introduced, depends upon an understanding of the productive process that will receive them.

3. The total array of barriers to an innovation, like the appropriate type of innovation, changes composition with the stage of development. In the unconnected stage, resistance centers around perceptions of irrelevance. Will the innovation work and meet a need? In the systemic stage resistance stems from the disruptive nature of innovation. Will it displace vested interest and disrupt current practice? The model begins to help to clarify the changing nature of these barriers.

A TEST OF THE FEASIBILITY OF THE MODEL WITH DATA FROM MYERS AND MARQUIS' STUDY

Myers and Marquis' [1969] study of 567 commercially successful innovations (from five industries and 120 firms) provides data on such questions as whether each innovation was a product, component or process, on its cost and impact on the production process and other details which should be helpful in performing at least an initial feasibility test of many aspects of the model outlined above.

To carry out an initial feasibility test of the model using this data the following steps were taken. First, the firms included in the Myers and Marquis study were classified by stage of development (Stage I, II or III) corresponding to three categorical intervals along the ordinate of Fig. 1. Since the identity of firms included in the original study remains confidential this classification was performed by the first author of the present paper based on data reflecting patterns in source of information for the reported innovations. As noted in (1) above the model predicts that the sources of information of most frequent importance will depend upon the stages of development. Second, a set of hypotheses were developed that would be tested using the data. These were formulated by the second author who had not previously had access to the data or results from its analysis. Finally characteristics of innovative behavior were analyzed by firms' stage of development to test the hypotheses.

This procedure assumes a certain equivalence between a process segment and a firm that should be recognized. The model as developed above relates to the characteristics of a process segment or single product line, while analysis has been carried out by firm. In general it would not be anticipated that the innovative characteristics of a multidivisional firm would correspond to the characteristics of one of the process segments included in its portfolio of segments, unless all or most were in approximately the same stage of development, or of course unless the firm were essentially a single product firm. To abridge limitations in the data which result because the original study focused on the characteristics of firms rather than those of subsidiary product lines or divisions and because of confidentiality agreements which prohibit further efforts to enrich available data, the present method of analysis relies upon reported characteristics of the firm as surrogates for the characteristics of the process segment. While this assumption is not ideal it does not severely distort the conceptual basis of the hypotheses because of the special characteristics of the data set and precautions taken in the classification methodology. First, the majority of the firms included are small, and therefore likely to have the characteristics of a single product firm. Second, it is our understanding that with large firms the original data collection effort typically focused on one division so that the reported data is much more likely to reflect the desired characteristics of the responsible division or business group rather than the corporate shell. Finally, firms which failed to exhibit a coherent pattern of innovation, as would be anticipated for multidivisional firms which provided data about segments in different stages of development, have been excluded from the subset of firms presently analysed. An analysis of the set of firms excluded on this basis shows that on average they reported more innovations per firm than other groups, which tends to support the idea that they would be large multidivisional firms. Taken collectively these conditions provide sufficient equivalency so that the so called characteristics of the firms can be used as surrogates for process segment characteristics.

To implement a classification methodology, the stimulus to which a majority of a firm's innovations responded seemed the most reasonable way to classify firms into stages. The resulting partitions will represent differences in the nature of uncertainties and the competitive environment the firm may face. Thus the predominant stimuli, as shown in Fig. 1, are the point of departure for our predictions. Two variables in the Myers and Marquis study, "primary initiating factor for the innovation" and "nature of the information used", provide operational measures for the predominant stimuli. For example, if a majority of the firm's innovations were initiated by production related factors such as "quality failure or deterioration" or "attention drawn to high cost" *and* if the nature of information used in these cases was "information relating to the availability of capital equipment or materials" or "data concerning equipment or materials utilization" then that firm was classified in the systemic-production cost-minimizing stage. Similar definitions and classification criteria are applied to these two variables (primary initiating factor and the nature of information used) to assign each firm to a stage, as described in the Appendix. In brief these are:

Stage I Uncoordinated process
Product performance-maximizing strategy

Classified on the basis that most innovations are market need stimulated.

Stage II Segmental process
Sales-maximizing strategy
Classified on the basis that most innovations are stimulated by technological opportunities.

Stage III Systemic process
Cost-minimizing strategy
Classified on the basis that most innovations are stimulated by production related factors.

In fact most of the firms (77 of 120) do show a dominant pattern as expected. These firms also contributed a majority (330 of 567) of the innovations in the sample. While data on firms would have allowed us to use the entire sample, the present method does provide a usefully large subset (of 77 firms and 330 innovations).

The measured characteristics of innovations in the Myers and Marquis data support quantitative tests of six specified hypotheses that arise from the general model. These were either selected from the set of several hypotheses that had been developed as described above or from the present conceptual model and previously referenced work. Tests of the hypotheses are reported and discussed below and are considered a source of strong, if preliminary, evidence supporting the validity of the model.

Hypothesis 1. The proportion of product innovations undertaken by firms will be largest in Stage I and will be less for firms in Stages II and III. Conversely, the proportion of process innovations will be expected to be small in Stage I, but process innovations are expected to be predominant in Stage III (as shown graphically in Fig. 1).

TABLE 1. NATURE OF THE INNOVATION AND STAGE OF DEVELOPMENT

Nature of the innovation	Firms' stage of product and process development			
	Stage I	Stage II	Stage III	Row total
Product	114	46	13	173
	65·5	49·5	20·6	52·4
Component	39	8	6	53
	22·4	8·6	9·5	16·1
Process	21	39	44	104
	12·1	41·9	69·8	31·5

$\chi^2 = 80{\cdot}70634$, $P < 0{\cdot}0001$.

A breakdown of frequencies of product, component, and process innovations in Myers and Marquis' sample with firms classified into Stages I–III is shown in Table 1. The results support the hypothesis ($P < 0{\cdot}0001$), with 65·5% of the innovations introduced by firms in Stage I being new products and only 12·1% processes followed by a complete reversal, 20·6% products and 69·8% processes in Stage III. We did expect a larger degree of component innovation in Stage II than is in fact the case.

The data in Table 1 cannot be plotted directly to derive the curves in Fig. 1, because the data can only be expressed accurately as percentages, while Fig. 1 shows both expected frequencies and rates of change (the slope of the curves) of product and process innovation. The proportions of product and process innovations shown in Table 1 are consistent with those which could be derived from frequency data plotted as in Fig. 1. We recognize that the qualifying basis for a Stage III classification (stimulated by production related factors), bears a natural relationship to the hypothesized high frequency of process innovations for this category. To argue that this dependency detracts from the validity of the test would miss the point of the model. The strength of the model derives from the fact that it is an integrative framework encompassing a broad range of independently logical relationships. The intuitive plausibility of such results are therefore taken as support rather than detracting considerations.

Hypothesis 2. The emphasis and priority given by the firm to innovation as a competitive strategy will be greatest in Stage I and will be less for firms in Stages II and III.

TABLE 2. PRIOR ACTIVITY OF FIRM AND STAGE OF DEVELOPMENT

Prior activity of the firm*	Firms' stage of product and process development			
	Stage I	Stage II	Stage III	Row total
High priority	74	29	14	117
	42·5	31·2	22·2	35·5
Low priority	58	26	30	114
	33·3	28·0	47·6	34·5
Related problem	19	14	11	44
	10·9	15·1	17·5	13·3
Not working on the problem	23	24	8	55
	13·2	25·9	12·7	16·6

$\chi^2 = 21{\cdot}06704$, $P < 0{\cdot}01$.

* The question asked was whether the firm or the innovator was actively working on the problem.

This hypothesis follows directly from our argument about frequency of innovation and the changing nature of firms' strategies for competition and growth as a segment matures. It can be tested directly using Myers and Marquis' data as in Table 2 by looking at the percentage of successful innovations introduced which were given high priority during their development by firms in each stage. This figure is highest (42·5 %) in Stage I, and steadily declines in Stages II (31·2 %) and III (22·2 %). The data support the hypothesis ($P < 0{\cdot}01$).

Hypothesis 3. A larger proportion of innovations introduced by firms in Stage I will incorporate new technology as opposed to existing technology transferred from other applications.

TABLE 3. DEGREE OF INVENTION AND STAGE OF DEVELOPMENT

Degree of invention required	Firms' stage of product and process development			
	Stage I	Stage II	Stage III	Row total
Little	25	18	21	64
	14·4	19·4	33·3	19·4
Considerable	71	46	30	147
	40·8	49·5	47·6	44·5
Invention needed	78	29	12	119
	44·8	31·2	19·0	36·1

$\chi^2 = 19{\cdot}14243$, $P < 0{\cdot}001$.

Innovations introduced by firms in Stage I are expected to be relatively more original, not necessarily more complex or sophisticated technologically. They may frequently involve synthesis of existing (though not widely known) technical information into a new concept or invention. Myers and Marquis asked for each case whether "a high degree of inventiveness was called for, so that it may be said that 'invention' was required" [7, p. 78]. Table 3 shows that 44·8 % of the innovations sampled for firms in Stage I were considered to have required invention, while this was true for fewer (31·2 %) in Stage II and in Stage III (19·0 %). Fully one third of the innovations by firms in Stage III required little or no change in existing technology to accomplish. These data strongly ($P < 0{\cdot}001$) support the hypothesis.

Hypothesis 4. Most innovations introduced by firms in Stage I will be original, while in Stage III most will be adopted (from material suppliers, equipment suppliers, by license, imitation, etc.)

Three-quarters (74·2 %) of the innovations introduced by firms in Stage I were original products and components while half (50·8 %) of all innovations introduced in Stage III were wholly adopted from other firms. While there were few process innovations in Stage I (21 cases, 12·1 % as shown in Table 1), as large a proportion of process as product innovations were original (18 of the 21). These data strongly support the hypothesis ($P < 0{\cdot}0001$) as shown in Table 4.

Hypothesis 5. Innovations introduced in Stage I will require little perceived change in process technology. Innovations introduced in Stage II will require the greatest degree of perceived change in process technology, while those in Stage III will result in only incremental and/or adopted process changes.

TABLE 4. ORIGINAL OR ADOPTED INNOVATION AND STAGE OF DEVELOPMENT

Original or adopted innovations	Firms' stage of product and process development			
	Stage I	Stage II	Stage III	Row total
Original products and components	129 74·2	44 47·3	12 19·1	185 56·1
Original processes	18 10·3	34 36·6	19 30·2	71 21·5
Adopted products, components, and processes	27 15·5	15 16·1	32 50·8	74 22·4

$\chi^2 = 72{\cdot}826$, $P < 0{\cdot}0001$.

The basis for the hypothesis originates from the proposition that production processes are more fluid or adaptable in early stages of development. Change is normal and even though considerable change may be involved *vis à vis* later stage segments, it is not expected that it will be perceived or reported as significant. Myers and Marquis were implicitly following a concept similar to that in Fig. 1 when they asked in each case about the impact of the innovation on the production process. They comment that "relatively small product changes may be of great significance to the firm if they result in large changes in the manufacturing process" (as in Stage III). And, "even a fairly large product innovation may have relatively little significance to the production process" (as in Stage I) [7, p.78]. Looking at their data again classified by firms' stage in product development in Table 5 one can see that fully half (50·0%) of the innovations introduced by firms in Stage I required no change whatever in the production process. On the other hand nearly half (43·0%) of the innovations in Stage II required a wholly new process for their production or use, and half (49·2%) of the Stage III innovations were adopted (new for the firm only). These data support the hypothesis ($P < 0{\cdot}0001$).

TABLE 5. IMPACT ON PRODUCTION PROCESS AND STAGE OF DEVELOPMENT

Impact of the innovation on the production process	Firms' stage of product and process development			
	Stage I	Stage II	Stage III	Row total
New process	39 22·4	40 43·0	17 27·0	96 29·1
New for the firm only	48 27·6	20 21·5	31 49·2	99 30·0
No change	87 50·0	33 35·5	15 23·8	135 40·9

$\chi^2 = 27{\cdot}96568$, $P < 0{\cdot}0001$.

Hypothesis 6. Costs of innovations introduced by firms in Stage I will be relatively greater than those for Stage II and will be lowest for firms in Stage III.

Hypothesis 7. Most firms in Stage I will be relatively small while most firms in Stages II and III will be relatively large.

The last two hypotheses will be discussed together, because they are the net result of counter balancing forces and because at first glance they appear contradictory. Hypothesis 6 follows logically from the fact that we expected innovations in Stage I to be given high priority, to be original and to require inventiveness, while those in Stage III were expected to be given lower priority and to be largely adopted from other firms (suppliers or competitors). While the cost of introducing innovations of an equivalent degree of novelty is expected to be much higher for Stage III firms, they are not expected to introduce innovations of such a radical nature. Rather it is hypothesized that priorities here will be placed on less expensive incremental change that will not be disruptive, and on balance the cost per innovation will be lower. At the same time we argued that firms in Stage I would tend to be small, that more firms would enter in Stage II, that some would grow rapidly and others merge or drop out so that Stage III would be characterized by a few large firms competing on the basis of scale economies and low costs. Can a small firm succeed with high cost innovations?

Project SAPPHO [8] which compared paired cases of commercially successful and unsuccessful innovations found that this was indeed the case. The greater the amount of resources devoted to a project the more likely it was to be a success. But resources devoted bore no relationship to firm size. Small firms concentrating their resources on a few large projects tended to succeed, while larger firms which devoted fewer resources to more projects tended to fail when trying to introduce the same innovation. Thus the hypotheses are not necessarily contradictory.

Table 6 shows that Stage I innovations are expensive, with 21·3% costing

TABLE 6. COST OF INNOVATION IN THOUSANDS AND STAGE OF DEVELOPMENT

Cost of the firms' innovations (thousands)	Firms' stage of product and process development			
	Stage I	Stage II	Stage III	Row total
Less than $25	44	22	36	102
	25·3	23·7	57·1	30·9
$25–$100	51	41	8	100
	29·3	44·1	12·7	30·3
$100–$1000	42	21	13	76
	24·1	22·6	20·6	23·0
More than $1000	37	9	6	52
	21·3	9·7	9·5	15·8

$\chi^2 = 37{\cdot}06130$, $P < 0{\cdot}0001$.

more than one million dollars as opposed to 9·7 and 9·5% in Stages II and III respectively. More than half (57·1%) of the Stage III innovations were incremental (cost less than $25,000) as opposed to one-quarter (25·3%) in Stage I. These data support ($P < 0·0001$) hypothesis 6.

Data on firm size were not available for the entire sample. However, those firms for which size (sales volume) data are lacking are most likely to be smaller than average and privately owned. Table 7 displays data on size and dominant type of innovations introduced for those cases where data are available.

TABLE 7. FIRM SIZE AND STAGE OF DEVELOPMENT

Sales in $000,000	Firms' stage of product and process development	
	Stage I	Stages II and III
Less than 100	24	2
More than 100	16	15

$\chi^2 = 11·1887$, $P < 0·01$.

Twenty-four of the firms classified as being in Stage I were relatively small having sales of less than one hundred million dollars, while 16 had sales of more than this amount. Moreover, 18 of the 24 small firms had sales of less than ten million dollars. Conversely only two firms in Stages II and III combined were small while 15 were large. These data support ($P < 0·01$) hypothesis 7.

DISCUSSION

We believe that the conceptual model outlined above represents several important and original conbutritions.

It is a serious attempt to formulate a multivariate hypothesis about the process of innovation in firms and to explain variations noted in past descriptive studies. The model suggests a consistent pattern of variables which will change systematically with changes in firms' product and process development. Further, it suggests ways to integrate concepts of the innovative process from different disciplines and perspectives including: economics (firm size and market structure, product costs and price elasticity, trade flows) management and engineering (type of innovation, cost impact on production process, degree of technical change required) and organization theory and behavior (organization structure, formality, planning process, communication).

The model facilitates predictive statements about differences between firms in different competitive environments and with varying resources and constraints. It suggests some ideas of the dynamics of the innovative process as the firm and its environment change. It provides some ideas of possible and plausible cause and effect relationships—explanations about why systematic variations in the innovation process may occur as a firm grows and changes.

An initial feasibility test using Myers and Marquis data provides compelling support for each one of the hypotheses derived from the model. The idea of looking at differences between firms rather than looking for differences in the characteristics of individual successful innovations provides significant insights not gained in the original analysis of the same data.

The model has operational relevance. That is it suggests the sources and types of innovations a given firm might expect to undertake successfully, critical resources required and potential problems or constraints. Special attention is called to the interrelated nature of decisions within the firm. The capabilities of a firm to innovate, to achieve efficient operations, etc. cannot be divorced from one another, but are a matter of overall strategy.

Many problems remain before these claims can be fully investigated or supported. Each of the hypotheses implied by our argument should be formally stated and examined in the light of existing literature and cases. Further feasibility testing using existing sets of data can be easily accomplished. Hypotheses about innovation process dynamics will typically have to be tested by using retrospective data for process segments for time periods on the order of decades. An investment in sustained longitudinal study of cases where product and process evolution is occurring rapidly would be useful.

Careful descriptive studies of product and process innovation have contributed much to our understanding. But we believe further efforts along established directions for empirical research, attempting to draw and refine general propositions, will have little marginal benefit. A synthesis and integration along lines similar to those suggested above is required in our opinion if we are to achieve a more comprehensive and useful understanding of technological change as it involves the firm.

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APPENDIX

Details of the classification of firms into stages I–III

Stage I: uncoordinated process, product performance-maximizing strategy
Classified on the basis that the primary initiating factor was market related *and* that the information used was about design or performance characteristics or state of the art for the largest group of the firm's innovations. Includes 52 firms of which 10 reported a single innovation meeting the criteria, and 174 innovations; a mean of 3·35 innovations per firm.

Stage II: segmental process, sales-maximizing strategy
Classified on the basis that the primary initiating factor was the perception of a technical opportunity to create or improve a product or the production process *and* that the information used was (as above) about design or performance characteristics or state of the art for the largest group of the firm's innovations. Includes 14 firms of which 2 reported a single innovation meeting the criteria, and 93 innovations; a mean of 6·65 innovations per firm.

Stage III: systemic process, cost-minimizing strategy
Classified on the basis that the primary initiating factor was production related or administrative *and* that the information used was about capital equipment or materials or the use of equipment or materials for the largest group of the firm's innovations. Includes 11 firms of which 2 reported a single innovation meeting the criteria, and 63 innovations; a mean of 5·72 innovations per firm.

Unclassified
Firms having no significant group of innovations meeting one of the sets of critieria stated above. Includes 43 firms of which 10 reported a single commercially successful innovation, and 33 firms reported 227 innovations with a mean of 6·87 per firm (a mean of 5·50 per firm overall).

Thirteen ties (usually cases having 2 or 4 innovations divided evenly between two sets of criteria) were broken by comparing the firm's distribution of cases with the marginal distribution for the industry. The firm was then classified on the basis of the greatest difference between its pattern and the marginal distribution. That is if most housing supplier firms were cost-minimizing, and if the firm in question had an equal number of sales-maximizing and cost-minimizing innovations it would be classified as sales-maximizing. Five doubtful cases, where two categories had roughly the same number of innovations with the unclassified category usually being slightly larger were classified using the same procedure for ties.