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I. Introduction

Today, as on any day in living memory, it is easy to admire Schumpeter's taste in problems. Our world is tossed in a torrent of change, and although economic change is not the only current in that torrent, it is clearly a very important one. The sources of economic change are themselves diverse, and some lie well outside the Schumpeterian domain of profit-motivated innovation in a market economy setting. Yet it is striking how important that domain really is as a feature of the human situation in the late twentieth century. Whether it is a question of new weapons for old antagonists or new cures for old diseases, new threats to privacy or new freedom from hunger and toil, the activities of business firms seeking profit through innovation are at a minimum important, and often are central to the story. The attempt to understand these activities and their relationship to the broader social environment of advanced capitalism is clearly a worthy intellectual endeavor. It is valuable both for what it may reveal of the future toward which the torrent of change is sweeping us, and for whatever support it may provide for attempts to steer society around the perils of change and toward its promises. Few, if any, of the topics with which economists concern themselves are more obviously deserving of attention.

The actual level of attention that economists collectively have devoted to Schumpeter's primary concerns seems to fall well short of what their importance would warrant. In particular, the textbooks and journals of economic theory continue to give vastly disproportionate attention to the investigation of static, quasi-static and meta-static models and concepts, neglecting the analysis of change much as they did in the early years of the century when Schumpeter wrote the The Theory of Economic Development. There is a sort of paradoxical irony here: In a century of massive continuing change, there are nevertheless a few constants, viz. (i) change is important, (ii) economic theorists generally neglect it. Recently, however the literature on Schumpeterian competition has expanded rapidly and the second of these natural constants has begun to seem less immutable.

This paper extends previous contributions of Nelson and Winter to the Schumpeterian competition literature. The model employed is much the same as in earlier work. It is a Markov model of a single industry in which firms produce a homogeneous product and in which cost reduction through productivity improvement is the major competitive weapon. (An optional alternative interpretation is that the major competitive weapon is product innovation, but the only economic difference among the products is in the amount of a single Lancasterian characteristic delivered per nominal product unit.) Exogenously changing technological opportunities provide the setting for the struggle to increase productivity, but taking advantage of those opportunities requires costly and uncertain innovative efforts. Firms may choose to try to imitate the successful methods of other firms instead of trying to innovate themselves, but this strategy too is costly and uncertain. Firm growth is linked to profitability, but responds negatively to market share for firms that are large relative to the market. The fact that growth is linked to profitability brings economic "natural selection" into play as an influence on industry average productivity and on industry average policies toward innovation and imitation.

The previous work was primarily concerned with elucidating some of the mechanisms of Schumpeterian competition, particularly those that are important to the growth of concentration and to the course of the evolutionary struggle between innovative and imitative strategies. For the sake of providing a clearer view of these mechanisms, the simulation experiments reported all began from stylized initial conditions for the industry modeled--for example, sixteen identical firms or a group of identical innovators and another group of identical imitators. And, for the same reason, those experiments ruled out entry. Here, however, the focus is on certain features of the "historical" shape of industry evolution, and particularly on the relative importance of entrants and established firms as sources of innovation. This emphasis obviously rules out consideration of stylized, symmetric initial conditions; no actual industry ever displays such a pattern in the course of its historical development. Even more obviously, the emphasis on the role of entrants demands that the basic model be augmented by a model of entry. The entry model described below also provides most of the answer to the problem of avoiding artificial initial conditions, for it functions as the primary constituent of a model of industry birth, i.e., of entry by the innovator-founder of the industry. Given the existence of the innovator-founder, the main entry model characterizes the processes by which the industry becomes populated with firms. Thus, the addition of the entry model to the simulation model previously used opens the way to comparison of simulated industry histories with actual industry histories, and perhaps, therefore, to explanation of some of the qualitative patterns noted in the latter. The present paper is only a beginning along this line of inquiry.

The following section lays out the conceptual basis of an approach to the analysis of technological change, drawing on previous work of Nelson and Winter. Particular emphasis is given to the many-faceted concept of a technological regime. The well-known contrast between Schumpeter's early and late writings on the sources of innovation in a capitalist system is discussed in the light of this concept. Section III describes the main features of the model of industry evolution, with particular emphasis on features not present in earlier Nelson-Winter work. Section IV describes two simulation runs. These are offered merely as extended numerical examples of the contrast between "early Schumpeter" and "late Schumpeter" patterns of industrial development. This paper is a first report on a broader effort based on the idea of taking industry life histories as the unit of analysis. For that reason, it seems appropriate to suggest the promise of the approach and underscore the realistic, pseudo-historical character of the simulations by discussing two histories in detail, rather than presenting a structured experiment involving many runs. The final section of the paper sets forth conclusions and some suggestions for the further development of the concept of technological regime.

II. Technological Regimes

Getting along without production functions

In Marshallian partial equilibrium analysis, there are short run choices and long run choices; for example, the choice of the optimal level of output in a given plant, and the choice of the optimal plant to build. For there to be long-run choice, there must be well-defined long run opportunity set. Marshallian analysis of the long run—and orthodox analysis generally—answers this need in the theory of the firm and industry by postulating a long run cost function or, more fundamentally, a production function or production set. This postulate is fundamental both to the positive theory of behavior in the long run, and to normative analysis of long run equilibrium.

Of course, the Marshallian "runs" are a rather crude expedient for avoiding the complexities of dynamic analysis. In an explicitly dynamic analysis, <u>there are no long run choices</u>. There are, generally, choices that have consequences over time (like the choice of which plant to build), but the choices themselves carry definite dates which identify the short run context in which they are made. There may be limits as T goes to infinity of the short run choices, and there may be answers to the question of what the choices would be if they were constrained to be constant over time. In the context of a particular analysis, it may be the case that these limiting or time-invariant choices coincide with the results of Marshall's heuristic analysis of long run choice. But in general, they certainly are not "conceptually" the same, for they can be defined without direct reference to the concept of a long run opportunity set.

The theoretical concept of a long run production function (or set) is a highly dispensable idea. Under its proper and standard interpretation as a characterization of any immutable state of technical knowledge, it stands squarely in the way of a natural treatment of technological change. As the preceeding paragraphs indicate, positive theory logically requires such a concept only to the extent that it proceeds on Marshallian crutches, or by way of adherence to a principle that the structure of positive and normative economic analysis should be the same. To assess the weight of the latter consideration would carry this discussion too far afield, but certainly the Marshallian crutches are employed these days only out of habit or in the interest of effective pedagogy.

There is, of course, a logical need for a characterization of the feasibility constraints on short run choices. In orthodox analysis of the individual firm, these constraints have traditionally been conceived as reflecting the fact that the levels of certain inputs are fixed in the short run, whereas technical knowledge is as comprehensive in the short run as it is in the long.[1] Implicitly, this approach seems to assume that all technical knowledge is stored in a costlessly accessible public file, and that firms therefore do not function in any significant sense as repositories of knowledge. For, if firms are repositories of technical knowledge, it is hard to imagine how the knowledge stored in a firm could be wholly independent of the inputs used in the firms--indeed, independent of whether any inputs are used at all.[2] On the other hand, the assumption that all technical knowledge is public knowledge is not only blatantly counterfactual in itself, but also rules out of existence the primary source of the incentive to innovate. The best thing that can be said of this assumption is that it does have a certain consistency with the more fundamental orthodox assumption that technological change does not exist; if all knowledge were public knowledge, perhaps technological change would _not_ exist.

The evolutionary theory proposed by Nelson and myself takes a very different tack. The fact that firms serve as repositories of knowledge is prominently featured in the theory. Knowledge is stored in the routines of the firm, and maintained by exercise in the same way that the skills of an individual are maintained by exercise. Routines--which may include ways of _thinking_ as well as ways of doing--are fixed in the short run, variable in the long, just like durable plant and equipment. Also, evolutionary theory involves a rejection of orthodoxy's sharp distinctions between capabilities and behavior, between technology and organization. Routines govern choices as well as describe methods, and reflect the facts of management practice and organizational sociology as well as those of technology. Thus, although routines play in an evolutionary model much of the role that a short run production function plays in an orthodox model, at the conceptual level routines and production functions are only distant relatives. In this sense, evolutionary theory dispenses with production functions both in the short and long run. Technological innovation and organizational innovation are placed on the same conceptual footing and indeed are expected to be intermingled in any real innovation event; the distinction between the two becomes a matter of degree. The phenomena of technological change are subsumed under the heading of "the changing prevalence of various routinized ways of doing things."

In a strategic group, industry or larger aggregate of firms, changes in the prevalence of various routines are partly a consequence of differential growth of the firms with individual firm routines held constant; this is the selection component of the total change. The remainder of the change in the aggregate is the consequence of change in routines at the individual firm level. This component we have called search. A change in routine that results from search is an innovation, at least from the point of view of the unit making the change. It need not be an innovation in any more demanding sense of the term.

Technological regimes.

In the construction of a particular evolutionary model, the characterization of search processes is obviously a key step. Implicit in this characterization are the answers to the sorts of questions about the "long run" behavior of the modeled system that orthodoxy answers so simply and unrealistically by reference to the long run production function.

Broadly speaking, the search model has to describe what happens when a firm searches. In principle, such a description might be an attempt at representation of the cognitive processes typical of some identifiable group of "searchers" in a particular economic context, and would thus incorporate much of the factual background of that context. Thus conceived, the problem of modeling search for the purposes of economic analysis would be akin to the problem of systematic characterization of the heuristics applied in a particular problem-solving or design context.[3] The latter type of activity is an active area of inquiry in computer science, though it is pursued more for the sake of its potential contribution to the actual problem-solving process than for its interest as a description of that process.

However, the focal issues of an economic analysis are ordinarily posed at a higher level of abstraction. A search model is needed, not for the purpose of predicting specific features of a new product or process, but for the sake of the insight that the economic model as a whole provides into such questions as the determinants of the level innovative effort and the amount of progress that results from that effort. Success in this undertaking requires that significant economic features of the search process be conceptualized in abstraction from the underlying technological and organizational detail. One obvious consequence of this choice of level of abstraction is that the "space" in which search is represented as taking place is commonly identified with familiar economic measures such as unit cost, productivity or input coefficient magnitudes, whereas real search activities involve the manipulation and recombination of the actual technological and organizational ideas and skills associated with a particular economic context.[4]

Recalling that the real action is at the level of ideas and skills can, however, be helpful in arriving at hypotheses regarding the structure or attributes of the search process when represented in terms of changes of cost or productivity. In particular, it is useful to consider the alternative sources of ideas or skills that the individual firm might draw upon in its searches, and the effect that adoption of an idea from any of these sources for the subsequent evolution of the system. There is first of all the possibility that the searching firm draws knowledge from other firms engaged in the same sort of activity, i.e., that search is attempted imitation. The results for the searching firm then depend first of all on what there is to imitate that is better than what the firm already has; the technological leader does not stand to gain much from imitation. For the laggard, however, imitation may present the opportunity to get caught up quickly. Under conditions of relatively complete access to the product or access being imitated, the imitator has the significant advantage of knowing in advance that the new methods he seeks to acquire are workable in practice, and of being able to adopt not merely the general concept but also the numerous details that make the concept work in practice. In the extreme case--or in the abstract world of a search model--imitation yields an exact replica of the thing imitated, and if it is exact in underlying details it is also exact at the surface level of cost or productivity.[5]

A second major category of sources of new knowledge is the firm's external environment generally, apart from other firms that are engaged in the same sort of activity. This is obviously a highly diversified category, with correspondingly diverse implications for the economics of innovation. At one extreme, the firm might draw upon the external knowledge environment only by way of the prior education and experience of its personnel, which in turn might contain little of direct relevance to the firm's operations. In that case, the entire burden of bringing general understanding of the laws of physics, patterns of human behavior, management technique and so forth to bear upon the firm's problems would fall upon the firm's own personnel, and be funded from the firm's own resources. At the other extreme, the external environment might throw up a series of fully developed and novel alternatives to the productive routines then employed by the firm, leaving the firm with only the task of making relatively minor adaptations to the unique circumstances of its own particular organization and input and output markets. The real examples of this sort of situation are cases where the government has funded the R & D that brings forth these novel alternatives, or where equipment suppliers do most of the R & D relating to the productive processes of their customers. In the range between the two extremes, what the firm typically obtains by searching its environment is a collection of fragments of knowledge of possible usefulness in the improvement of its routines--a complaint from a customer about a hazard associated with a remediable flaw in the present product design, a new lubricant for a high-speed machine, a short course that purports to increase the effectiveness of supervisory personnel. Because novel ideas of this sort are of limited scope relative to the full routine, and because an organizational routine functions as a coordinated whole, there is always a need for a process of assimilation of the novelty. Such a process requires complementary problems-solving effort by the firm itself.

Finally, the firm may look inward when it seeks the new ideas and skills needed to improve its routines. A large firm, and particularly a large firm that dominates its field of activity, may be able to support the development of a highly specialized branch of science or engineering to the point where it achieves, in effect, backward vertical integration into the production of knowledge relevant to its activities. In a small firm, inward-looking search might better be typified by a look in the suggestion box. Change involves insightful solutions to recurring difficulties with the existing routines, fine-tuning of process parameters, better adaptation to the idiosyncratic strengths and weaknesses of the firm's personnel or equipment, or minor design improvements in process or product.

Of course, a searching firm need not confine itself to exploiting only one of these three categories of knowledge sources. It can explore them all and choose to exploit the best of the ideas discovered, or even combine all three in the course of a single R & D project. It seems clear, however, that there are big differences among industries and technologies regarding the roles of the sources. Along with differences in the relative importance (somehow measured) of the different sources, there are differences in a variety of related aspects, including such matters as the intrinsic ease or difficulty of imitation, the number of distinguishable knowledge bases relevant to a productive routine, the degree to which successes in basic research translate easily into success in applied research (and vice versa), the size of the resource commitment typical of a "project" and so forth. To characterize the key features of a particular knowledge environment in these various respects is to define a "technological regime".

An earlier paper by Nelson and Winter examined some of the implications of the difference between a "science-based" and a "cumulative" regime of technological change.[6] The "science-based" regime as described in that work, has at least three distinguishable aspects. First, innovative R & D effort draws on knowledge sources external to the industry, and the nature of the industry's R & D is to assimilate or "reduce to practice" new ideas generated elsewhere--for example, in university science departments, or in government research laboratories. This implies that there are diminishing returns to industry R & D at any given time, because the exogenously determined external knowledge sources play the role of a "fixed factor" which is not increased by industry R & D effort. Secondly, the technological opportunity presented by the external sources is itself continuously improving. Thus, in spite of the aforementioned diminishing returns mechanism, a constant flow rate of R & D effort does not yield decreasing returns over time, because the stock of assimilable but unassimilated new technological ideas is continuously replenished. In fact a particular constant flow rate of industry R & D tends to be associated with a particular path of productivity advance, a path that tracks the exogenously advancing opportunity with a lag whose magnitude varies with the constant level of R & D expenditure. Finally, the representation of an individual innovation, an innovation R & D "draw" in the earlier paper implies that innovations are in a certain sense comprehensive. That is, an adopted innovation fully determines a firm's technological state, without reference to the state of the firm prior to he innovation. Implicitly, this suggests that the external knowledge sources on which the firm draws are yielding something like complete productive routines rather than ideas that promise improvement in only a portion of the routine.

In the "cumulative technology" regime "a firm innovates by making improvements in its own current technique--not by drawing on the new knowledge created external to the industry."[7] As applied in the earlier paper, this concept merges two ideas that might better be kept separate. The first is that the firm's innovative R & D involves looking inward for new knowledge; thus productivity levels in different firms that are making the same innovative effort evolve independently. The other is the idea that there is no diminishing returns to innovative effort, no using up of the potential for incremental improvement. Apparently, each adjustment of technique that produces an improvement in productivity also generates new puzzles, whose solution permits further advance. This implicit assumption is reflected in the explicit assumption that a constant level of innovative effort yields a constant rate of productivity increase and unit cost reduction, the rate being proportional to the innovative effort. *A priori*, one would think that these patterns characterized an extreme case, and that some degree of diminishing returns to innovative effort directed inward would be typical.

Two Schumpeterian Regimes

As is well known, the view of capitalist development that Schumpeter set forth in Capitalism, Socialism and Democracy [Schumpeter, (1950), cited henceforth as CSD] and other later works differs markedly in emphasis from the account given in his early book, The Theory of Economic Development [Schumpeter, (1934), originally published in German (1911), cited henceforth as TED]. The earlier work is deservedly famous, above all, for its insistence that episodic change is a natural, essential and characteristic feature of the capitalist economy. Numerous theoretical issues are shown to be revealed in a different and clearer light when this central fact is grasped. But it is the individual capitalist entrepreneur who plays the leading role in Schumpeter's drama of capitalism, and it is the explication of the entrepreneur's motives, personality, social function and returns that occupies most of the pages of the book. Economic development is "defined by the carrying out of new combinations", (TED, p. 66) and this is the function of the entrepreneur, the exemplar of leadership in economic life (TED, p. 88). Great pains are taken to make clear what the entrepreneur is not: He is not a mere manager, (TED, p. 77) nor is he intrinsically, a risk-bearer, or a capitalist, or an inventor (TED, p. 88).

There is another non-attribute of the entrepreneur, and it is of particular relevance to the change of emphasis between TED and CSD. He is not associated with an established firm. Rather, he is typically an outsider, a newcomer to the field in which he makes his innovative contribution.

> ... new combinations are, as a rule, embodied in new firms which generally do not arise out of the old ones but start producing beside them. This fact ... explains important features of the course of events. Especially in a competitive economy, in which new combinations mean the competitve elimination of the old, it explains on the one hand the process by which individuals and families rise and fall economically and socially and which is peculiar to this form of organization, as well as a whole series of other phenomena of the business cycle, of the mechanism of formation of private fortunes, and so on. (TED, pp. 66-67).

By contrast, the analysis of CSD calls attention to the advantages that makes the large (or monopolistic) enterprise particularly effective as an engine of economic progress. Among the many points adduced or implied in Schumpeter's ambiguous discussion, there is a reasonably clear suggestion that a large enterprise is favored in its ability to reap the returns from the innovations which spring from its own research laboratories. And it is plainly not the case that innovation is typically the work of outsiders. This fact is the key to Schumpeter's gloomy appraisal of the outlook for capitalism. By taking over the entrepreneurial function, the innovative industrial concern makes entrepreneurs obsolete and thereby undermines the sociological and ideological foundations of capitalist society itself.

> Since capitalist enterprise, by its very achievements, tends to automatize progress, we conclude that it tends to make itself superfluous--to break to pieces under the pressure of its own success. The perfectly bureaucratized giant industrial unit not only ousts the small or medium-sized firm and 'expropriates' its owners, but in the end it also ousts the entrepreneur and expropriates the bourgeoisie as a class which in the process stands to lose not only its income but also what is infinitely more important, its function. The true pacemakers of socialism were not the intellectuals or agitators who preached it but the Vanderbilts, Carnegies and Rockefellers. (CSD, 134)

This appraisal is actually prefigured in TED, at the end of the passage quoted above, and also at pp. 155-56, where it is said that "... the progressive "automatization" of development ... tends to weaken the significance of the entrepreneurial function."

It seems reasonably clear that, in Schumpeter's thinking, the contrast between the two appraisals of the process of economic development is largely a contrast of historical stages. The threatened obsolesence of the entrepreneur is itself a result of development, specifically, it is a consequence of the combination of two great meta-innovations, the giant enterprise and the industrial research laboratory. There is no suggestion in Schumpeter, and certainly the historical record provides no reason to suggest that the promise of superior efficacy in subsequent innovation was a important reason for the development of large firms. As for the industrial research laboratory, it is plainly a deliberate organizational innovation directed to the production of inventions; in itself it did not take over the entrepreneurial function. The obsolesence of the entrepreneur is apparently a fundamental but unintended result of prior entrepreneurial success--a particularly significant example of the way "economic life itself changes its own data by fits and starts". (TED, 62).

There is certainly an important element of truth in the claim that there has been a major historical shift in the sources and processes of innovation, with large firms and their R & D establishments playing a much more important role now than they did in the late nineteenth century. But entrepreneurs are not a threatened species, and neither, for that matter are individual inventors. They survive in a number of niches, sometimes in competition and sometimes in symbiosis with research-intensive industrial giants. Empirically, therefore, there is a cross-sectional phenomenon requiring explanation: under what circumstances are new firms lead by individual entrepreneurs a major source of innovation? And there is a corresponding theoretical question, a problem in comparative dynamics: what differences in exogenous factors might dispose an industry to an "entrepreneurial" mode of development, in which innovation is often associated with the appearance of new firms, while an otherwise similar industry is marked by a "routinized" mode in which innovations typically come from established large firms? In particular, is the difference between the two modes traceable in part to differences in the technological regime in which development takes place? To throw some light on these questions is the main purpose of this paper.

The following sections set these questions in the content of an evolutionary model of the birth and development of an industry. It is proposed that Schumpeter's two views of innovation can be associated with different technological regimes, which in turn are representable by different settings of the parameters of the evolutionary model. The simulations reported in Section IV indicate that this approach "works" in the sense that the simulated histories differ in numerous respects that are reminiscent of the difference between Schumpeter's two accounts. What the simulations provide is a specific quantitative illustration of an interpretation of the Schumpeterian contrast whose general structure is now to be described.

The founding of a new industry is always an entrepreneurial innovation, at least in the sense that it cannot be the action of a firm already established in that industry. And it well may happen that among the early entrants to the industry are other entrepreneurial innovators, not mere imitators of the founder. The open question is what happens as the industry matures. One possibility is that the established firms "pull away"; their technological performance is such as to leave them beyond the reach of any challenge from new entry. In this case, the shifting winds of innovative fortune in the industry will be registered in concentration-increasing stochastic growth; eventually there will be a few large, old firms who generate most of the progress. In the polar opposite case, the early entrants find it difficult to move beyond their original achievements; new possibilities emerge and are seized by new entrants, driving the older firms into decline and perhaps out of existence. The later entrants in their turn then cling to the sources of their original success, and the cycle repeats. The contrast between these two cases could be expressed as a contrast between high and low technological barriers to entry--but this is a description rather than an explanation. The problem is to explain the relative roles of entrants and established firms.

So far as established firms are concerned, their innovative performance will presumably be strong if industry economics are favorable to innovation. This requires that some combination of secrecy, patent protection and intrinsic difficulty of imitation permits the innovator to appropriate substantial returns from innovation. It also requires that technological opportunity be improving over time, either from sources external to the industry or because a cumulative advance of knowledge can be generated within the narrow sphere of the industry's own activity. Finally, the appearance of larger firms through growth may be a cause, as well as an effect, of sustained and profitable innovative achievement.

What determines the strength of the challenge that established firms face from innovative entry? Although the actual level of innovative (and imitative) entry is jointly determined with all other aspects of the industry outcome, it is proposed here that the supply of innovative entry is limited and usually determined by considerations external to the industry. Innovative entry is an action that is not considered in the abstract--"Let's think up a new recipe for fried chicken and make millions"--but as the realization of a specific possibility that is already in hand--"This is an awfully good recipe for fried chicken; is there some way to make a lot of money off of it?" For a particular industry, the supply of (or "potential") innovative entry in a particular time period is determined by the joint occurrence of innovative ideas relevant to the industry with the entrepreneurial traits and dispositions that will lead to serious consideration of an entry attempt. The latter factor is difficult to relate to the circumstances of a particular industry, but the former is likely to be roughly proportional to the number of people exposed to the knowledge base from which innovative ideas might derive. While it would be difficult to make a comprehensive measurement of such exposure, it is easy to name particular circumstances that favor large exposure and hence a high level of potential innovative entry. One possibility is that the industry's activity involves no specialized knowledge base at all; understanding of its elements is accessible to large numbers of people, given the general education and experience typical of the society. For industries that do have a specialized knowledge base, the question is what activities in the society, apart from the industry itself, generate exposure to that base. The answer may be a similar production or research activity carried on under governmental or non-profit auspices, or in an upstream industry that supplies equipment embodying the specialized technology, or a downstream industry that relies on the first industry for components.

What the potential innovative entrant has in hand, according to this account, is one promising idea. But it may be that one such idea, even a very good one, constitutes only a part of a recipe for innovative success. If the other ingredients are commonplace, it may be relatively easy to carry out the "new combination" and create a productive routine that will challenge the established firms. If there are numerous esoteric elements in the activities of established firms, and particularly if the coordination of different elements is itself esoteric, then the potential innovative entry is unlikely to be followed by actual entry.

The distinction between the two Schumpeterian regimes involves a reversal of the <u>relative</u> roles of innovation by entrants and established firms. An entrepreneurial regime is one that is favorable to innovative entry <u>and</u> unfavorable to innovative activity by established firms; a routinized regime is one in which conditions are the other way around. This is the pattern of the parameter settings in the simulations that follow. But there is clearly no reason to expect that real situations would necessarily fall neatly and clearly into one box or the other.

III. The Model

The model set forth here is a further elaboration of that employed in previous Nelson and Winter work on Schumpeterian competition. Only the novel features of the present model will be motivated and described in detail here, but the basic structure of the model will be reviewed.

<u>Basic Structure</u>

The model describes an industry composed of a number of single product firms. The industry faces a downward sloping demand curve in the output market and constant prices in its input markets. There is a single input, capital, that is fixed in the "short run" of a single period. Each firm also is committed, in the short run, to a single technique. It employs this technique at the highest level consistent with available capital. All techniques have the same variable input cost per unit capital; given this assumption techniques can be characterized by their productivity levels (output per unit capital). Capital physically depreciates at rate δ per period, and interest rate ρ represents the normal return on capital in the industry.

In addition to their productive techniques, the organizational routines of the firms in the model include decision rules governing spending on R & D. These rules are characterized by expenditure rates, per unit capital per period, on two types of R & D, innovative and imitative. These are the only non-production costs incurred by the firms.

Thus the short run system is simply:

1) $$Q_{it} = A_{it} \cdot K_{it}$$

2a) $$Q_t = \sum Q_{it}$$

2b) $$P_t = D(Q_t)$$

3) $$\pi_{it} = P_t . A_{it} - c - r_{imt} - r_{int}$$

where K is capital, A is the productivity of capital, Q is output, P is the price of output, D(.) is the demand-price function, production cost per unit capital is $c = \rho + \delta + v$, v is variable production cost per unit capital, π is economic profit per unit capital, and r_{imt} and r_{int} are the rates of imitative and innovative R & D expenditure per unit capital.

The dynamic equations of the model specify the probabilistic dependence of the shot run state of period t+1 on the short run state of period t. These transitions include the entry of new firms, the disappearance of firms that have shrunk below minimum size or are systematically earning negative returns, and changes in the variables K_{it}, A_{it}, r_{imt}, r_{int}. A fifth variable describing the state of the individual firm plays a role in the specification of these transitions. This is X_{it}; in effect it is a distributed lag function of π_{it}. Subject to a qualification noted below, this is generated by the following partial adjustment equation

4) $$X_{it} = \theta X_{i(t-1)} + (1 - \theta)\,\pi_{it} \qquad 0 < \theta < 1$$

The variable X is called performance. The full specification of the industry state at time t requires specification of the five state variables for each individual firm existing at time t, plus the level of latent productivity at time t, L_t. Given this information, the probability distribution of the next industry state--including characteristics of new entrants--is determined, in the manner now to be described.

Productivity Change. The value of $A_{i(t+1)}$ is determined by a two stage random process. In the first stage, the question is whether the firm's innovative and imitative R & D activities will yield innovation or imitation "draws" in the current period. The answer is determined by independent random variables d_{imt} and d_{int} that take on values zero (no) and one (yes) with

5a) $$Pr[d_{imt} = 1] = a_m \cdot r_{imt} \cdot K_{it} \text{, and}$$

5b) $$Pr[d_{int} = 1] = a_n \cdot r_{int} \cdot K_{it} \text{ .}$$

These relations should be thought of as a discrete bionomial approximation to a continuous time Poisson process governing imitation and innovation draws; the approximation is a good one if the probabilities in 5a-b) are small. In the second stage, the issue is the outcome of the draw(s). If a firm gets an imitation draw, it samples from a distribution derived from the actual capital-weighted distribution of productivity levels currently prevailing in the industry. If a firm gets an innovation draw, its second stage process includes a sampling from a distribution of technological opportunities $F(A\, ;\, t,\, A_{it})$ that depends on time and its own current productivity. The details of the imitation and innovation assumptions involved in the simulation runs of the present paper are given in the following section. The actual productivity level of the firm in period (t+1) is the best available from its current technique and the results of its draws, if any. When it obtains both types of draws, then,

6) $$A_{i(t+1)} = \text{Max}\,[A_{it}\, ,\, A^*_{it}\, ,\, \tilde{A}_{it}] \text{ ,}$$

where A^*_{it} and $\tilde{A}_{it}$ are respectively the results of the imitation and innovation draws.

<u>Investment</u> (viable firms). In the investment equation

$$7)\qquad K_{i(t+1)} = I\left(\frac{P_t \cdot A_{i(t+1)}}{c}, \frac{Q_{it}}{Q_t}, \pi_{it}, \delta\right) \cdot K_{it} + (1 - \delta)\, K_{it}$$

the gross investment function I(.) is desired investment bounded below by the nonnegativity condition and above by financable investment. Desired investment may be thought of as based on a comparison of the firms actual markup over production cost with a target markup that depends positively on the firm's market share, with positive net investment implied when actual markup exceeds the target. The result is that desired gross investment responds positively to the ratio of current price to unit production cost; the latter is calculated by reference to the productivity level that will prevail in the following period. Desired investment responds negatively to market share, Q_{it}/Q_t. The financial constraint is determined by net income plus depreciation expense augmented, if positive, by external financing in some ratio to net income. Note that the dependence of the financial constraint on current profitability implies that a highly liquid firm that has been profitable in the past may have a binding financing constraint if its current profitability is low. This is somewhat unrealistic implication reflects a commitment to a more basic assumption made in the interests of simplicity: balance sheet magnitudes do not affect firm behavior. Abandonment of that assumption would introduce into the model a substantial set of interrelated complexities, involving modeling of financial accounting, dividend policy, debt structure, and capital market functioning. This undertaking will have to be left to the future.[9]

Exit. A firm may exit the industry, never to reappear, for either of two reasons. One is that by investing less than the amount of physical depreciation, it shrinks below a minimum capital stock level, K^{min}. A special condition on the desired investment function assures that this never happens "voluntarily"; a firm will invest to cover depreciation if it can, when failure to do so would result in exit.

This exit condition is interpreted as a very simple approximation to a situation in which there are sharply increasing returns to scale up to a critical output level, above which returns are constant. Note that since minimum scale is here specified in terms of the capital input, the effective "minimum optimal scale" in term of output increases with productivity.

The other condition for exit is that the firm's rate of return on capital is persistently below a critical negative level, X^{min}, in the sense that the performance variable X_{it} is below this level. In the context of the model as a whole, the logical value for X^{min} is minus the level of costs other than variable production costs per unit capital; since these costs vary across firms with different R & D policies and since X^{min} is specified in advance, this can be achieved only approximately. The rationale for this value of X^{min} is that the exit condition then corresponds to a persistent failure to cover variable production costs. Since there is no cyclical or random variation in demand in the model, in "practice"--that is, under conditions typical of the simulations that have been done with the model—such a failure indicates that the firm has fallen far below the average industry productivity track because it does not spend enough on R & D. There is always the possibility that a lucky R & D draw would reverse the decline of such a firm, but against that prospect (in "practice" remote) must be weighed the fact of continuing out-of-pocket losses.

Capital is treated as irreversibly committed at the firm level, so the capital of exiting firms simply disappears. Other things equal, exit reduces industry output of the following period and raises price.

In summary then,

$$
8)\quad \begin{cases} K_{i\tau} = 0 \text{ for all } \tau > t \text{ if} \\[1em] \left[I\left(\dfrac{P_t \cdot A_{i(t+1)}}{c}, \dfrac{Q_{it}}{Q_t}, \pi_{it}, \delta\right) + (1-\delta)\right] \cdot K_{it} < K^{min}, \\[1em] \text{or if} \\[1em] X_{it} < X^{min} \end{cases}
$$

Adaptive Change in R & D Policies

In the previously published Nelson and Winter simulations, the R & D policy parameters r_{imt} and r_{int} have been fixed at the firm level, and thus the industry average policies have changed in the course of simulated time only as a result of selection. Here, a simple satisficing and random search mechanism operates to modify the policies of individual firms. The definition of "satisfactory"--the aspiration level of the satisficing model—is performance that is at least as good as the current industry capital-weighted average return, $\bar{\pi}_t$. A firm that has an unsatisfactory performance makes incremental adjustments of its policy in the direction of industry average policy, modified by random disturbances.

$$
9a \left\{ \begin{array}{ll} r_{im(t+1)} = r_{imt} & \text{for } X_{it} \geqq \bar{\pi}_t \\ r_{im(t+1)} = (1-\beta)\, r_{im} + \beta \cdot \bar{r}_{mt} + u_{imt} & \text{for } X_{it} < \bar{\pi}_t \end{array} \right.
$$

$$
9b \left\{ \begin{array}{ll} r_{in(t+1)} = r_{int} & \text{for } X_{it} \geqq \bar{\pi}_t \\ r_{in(t+1)} = (1-\beta)\, r_{int} + \beta\, \bar{r}_{nt} + u_{int} & \text{for } X_{it} < \bar{\pi}_t \end{array} \right.
$$

Here, $\bar{r}_{mt}$ and $\bar{r}_{nt}$ are the (capital-weighted) industry average policies of the period, parameter β satisfies $0 < \beta < 1$, and random variables u_{imt} and u_{int} are normal, i.i.d. across firms and time, with zero means and standard deviations σ_m and σ_n respectively.

Note that these adaptation rules incorporate a rationality that is decidedly bounded. Firms do not inquire into the relevance of firm size to their policies, nor even ask whether their current productivity levels are high or low in the industry, or how long it has been since they had an

R & D success. One could easily set forth adaptation rules that displayed a higher level of procedural rationality. In favor of a simple formulation like 9a-b), it may be said (i) that it is simple (ii) that the fact that a real firm might rationally ask itself more sophisticated questions about its policies does not assure that such questions could be rationally answered, given the information and insight actually available, (iii) that the mechanism will work effectively when firm policies are badly out of line with what makes sense in the environment, but some are more out of line than other.

Of course, the picture that emerges in a particular simulation will reflect the values of the parameters β, σ_m, and σ_n. The issues involved in choosing these settings reflect some genuine conundrums relevant to a world in which actors must grope for successful policies with the aid of very limited information and understanding about the total system in which they are embedded. For example, large values of σ_m and σ_n imply that if there are well-defined optimal policies, firms will be broadly dispersed around the optima even after the adaptation process has done its work. On the other hand, high dispersion means faster movement toward the optimum if it is far away--which is possible even after adaptation has occurred, since the environment may change and the optimal policies with it.

Finally, since the policies at issue here have stochastic results, it is reasonable to impute to the model actors some awareness of this fact, and a corresponding recognition that sensible judgement of policies requires some sort of averaging over time. This is accomplished first of all by the use of the "smoothed" performance measure X_{it} rather than π_{it} in the satisficing condition. It is also reflected in the fact (and to the extent) that $\beta < 1$: firms tend to retain the "identities" of their policy commitments over time, even while changing policies. And it is reflected in two qualifications to the foregoing account. (i) Even when the satisficing trigger is activated, the change process then ensures only with a probability $h_r < 1$. With probability $1 - h_r$ the firm thinks "Maybe the problem will go away," and chooses not to deal with it "just now". (ii) When policy change does occur, the performance measure X_{it} is incremented by an amount Δ. This is an indirect (but appealing) way of reflecting the familiar and rational desire to give new policies some time to establish a record on which their merits can be judged.

Entry and Industry Birth

It seems reasonable to approach the problem of modeling entry on the assumption that entry into a line of business is an action taken in an attempt to seize a perceived profit opportunity. However, this general statement attains a high degree of plausibility by virtue, in part, of a corresponding vagueness. The number of questions requiring answers to specify a particular model within the general framework of a profit-seeking approach is large, and important differences in the implications of the model turn on the answers supplied.

It is widely recognized that the problem of defining a "perceived profit opportunity" is central to the task of modeling entry, and hence to the theory of industrial structure. This issue has long been prominent in discussion of the limit pricing theories of the Bain-Sylos type, and has become even more so in the recent developments of the theory of strategic entry deterrence (see, e.g., Salop 1979, Eaton - Lipsey 1981, Kreps and Wilson 1982, Milgrom and Roberts 1982). The key point is that entry, even more than most economic behavior, is an action taken in response to an image of the future. The portion of that image that relates to the market environment may be rooted in the actual state of the market being entered, as of the time the entry calculation is made. For a variety of reasons, however, the image of the post-entry state of the market cannot automatically be identified with its actual pre-entry state: the market situation may change autonomously over the time interval in which entry occurs, it may change as a direct result of the new capacity and sales added by the entrant, or it may change because incumbent firms modify their behavior in response to the appearance of the entrant.

Of course, to assess a possible profit opportunity, a potential entrant must also work with an image of itself as a participant in the market. It must, for example, have an idea of what its costs of production will be, and how they will change over time. It may need to ask what distinctive competitive advantages it brings to the market, and whether there are likely to prove permanent or are likely to be eroded over time by the imitative activities of its rivals, or by other processes. All of the these appraisals are, of course, subject to error. A model of entry must contain, in however simplified a form, some characterization of the self-perception of the entrant.

Finally, a model of entry needs to specify where potential entrants and their perceived opportunities come from. Textbook economic theory evades the difficult and interesting part of this problem by working either with models in which the number of firms in considered fixed, or with "free entry" conditions in which entry opportunities are undifferentiated among potential entrants, who themselves exist in indefinitely large numbers. The former assumption is unrealistic and clearly bars the door to <u>explaining</u> entry and industrial structure, while the latter is equally unrealistic as a general proposition and also very troublesome when incorporated in a model that attempts to characterize the dynamics of industry adjustment.[10] As a natural consequence of its greater concern with the realities of the economic policy arena, the industrial organization literature has given more attention to the possibility that potential entrants might be limited in number and differentiated in their positions relative to the market. But there are few modeling efforts along this line.

The specific model described below, and incorporated in the computer simulation model, embodies very simple assumptions about each of these aspects of the entry problem. As in the remainder of the simulation model, the guiding principles in the formulation of this portion include a high valuation placed on simplicity and comprehensibility, a reasonable degree of contact with orthodox theory at least in its "appreciative" version, a desire to capture important qualitative features of the observed phenomena, and a preference for representing individual actors as making straightforward calculations on the basis of data likely to be available to them, as opposed to inputing to them a deep understanding of the system as a whole.

<u>Model specifics: the entry decision.</u> The foundation of the model entry is a particular characterization of the nature of received entry opportunities and the process by which they arise. It is assumed that there is some level of "background" R & D activity that is relevant to the industry's technology but is not funded by the industry itself. Some of this is "innovative" R & D that generates possible production techniques by drawing on the general fund of knowledge relevant to the industry's practice, while some is "imitative" effort that explores the possibility of

replicating the production routines of extant firms. In the model, the amount of activity of these two types is represented by equivalent R & D expenditure levels, although no identified actor is making the expenditure.

The two expenditure levels are the model's abstract representation of a variety of real world processes. For example, the innovative component may be thought as reflecting the fact that R & D in technologically related industries sometimes yields, serendipitously, results useful in a particular industry, or the fact that such results are sometimes generated by R & D programs financed by governments or non-profit institutions, or by inventors who pursue their activities on the basis of personal commitment and enthusiasm rather than on the basis of close calculation of prospective returns on investment. The imitative component, on the other hand, may be thought of a representing the level of diffuse search for profit opportunities carried on in the economy as a whole, relative to the number of possible targets for such activity. Search of this type requires the dedication of real resources to the task of locating and evaluating opportunities, and thus does not go on at an arbitrarily high level. Such search is motivated by the prospect that profit opportunities of quality sufficient to justify the costs of the search will be located <u>somewhere</u>, but because it is not targeted on the particular industry under analysis its level is appropriately assumed to be unaffected by what transpires in that industry.

External innovative and imitative R & D expenditure is assumed to turn up possible production techniques--represented in the model by productivity levels--in just the same fashion that the R & D expenditure of firms in the industry does so. The number of such "draws" generated in a single model period is Poisson variable with parameter proportional to the level of equivalent external R & D expenditure specified.

10a) $$M_t = a_m \cdot E_m$$

10b) $$N_t = a_n \cdot E_n$$

Here M_t and N_t are the means of the independent Poisson variates "number of imitative potential entrants in period t" and "number of innovative potential entrants in period t".[11]

Whether a potential entrant becomes an actual entrant depends on the evaluation of the profit opportunity represented by the draw. The evaluation consists of multiplying the productivity level that is the result of the draw by the current price of output and subtracting from the result the cost of production per unit capital, thus arriving at a net rate of excess return per market period. The possibility of error in this calculation--particularly, of error in the judgement of the productivity level prior to actual use of the technique--is represented by adding to this difference a random error term. The resulting "perceived " rate of return r is compared with "entry barrier" rate, r_e, and if the former exceeds the latter, entry occurs.

The "entry barrier" rate may be thought of as a channel through which one or more of the following causes influence the rate of entry. First, it may be regarded as reflecting the potential entrant's recognition that its own entry at a non-negligible scale relative to existing industry output will depress the output price below the current level.

On this interpretation, the magnitude of r_e would depend upon the intended scale of entry, the perceived demand elasticity in the output market, and the reaction (if any) of incumbent firms to the appearance of the new entrant and its output. In a similar but more general vein, the rate r_e may be thought as a measure of the appropriate level of caution induced by the thought that future market conditions may be less favorable than those of the moment; such a turn for the worse might be expected not only because of the entrant's own impact but also because other firms may enter subsequently, or because technological change may be expected to render the now-profitable technique of the entrant obsolescent. Third, but related to the point just mentioned, the r_e may be regarded as corresponding to the level of R & D expenditure per unit capital that is required to keep the new firm's technique advancing at a rate that will make positive production profits possible. Finally, the entry barrier rate may be conceived as the excess return per unit of production capital required (at intended entry scale) to amortize an investment in initial learning or other start-up costs of the enterprise.

In brief, the potential entrant becomes an actual entrant if

11) $$P_t \cdot A_e - c > r_e + u_{et} ,$$

where A_e is the productivity level from the potential entrant's R & D draw and will be its productivity level in period t+1 if it enters. r_e is the entry barrier rate whose flexible interpretation was just described, and u_{iet} is the random error term (normal, mean zero, standard deviation σ_e)

Model specifics: entrant characteristics. Given that entry is to occur, there remains the problem of specifying the initial characteristics of the new firm. Only the productivity level is already explicitly determined when the entry decision is made--a fact which emphasizes the point that the theory underlying the model treats entry as an attempt to exploit a profitable production technique that is already in hand, rather than, for example, an attempt to exploit an R & D strategy.

The initial capital stock of an entrant is determined by a draw from a normal distribution (mean K^*, standard deviation σ_K), truncated below at K^{min}. The model's logic imposes no further structure on the determination of the entry scale. Implicitly, however, both the assumed form of the entry criterion and the separation of the entry question from the determination of entry scale reflect a supposition that entry scale is small relative to the size of the market. Where entry at large scale is a possibility, realism both of assumptions and results would call for the prospective entrant to survey alternative scales, consider the likely impact on output price, and choose among the alternatives with an eye to prospective profitability. When entry scale is small relative to the market, the impact on price is also small and the realized rate of return is therefore insensitive to the entry scale; the survey of alternatives is inessential. But of course, it still matters a great deal to industry structure (and to absolute profitability) whether "small" means a tenth of the market or a hundredth of the market.

The policies toward imitative and innovative R & D of an entering firm are determined by essentially the same mechanism that operates for an existing firm when it makes a policy change. One difference is that the parameter β appearing in equations 9a-b) is taken equal to one, there being no existing policies from which to change incrementally. Also, if the policy resulting from this process would leave the firm making losses at the current price, the policy is scaled down proportionally to the breakeven level.

Finally, the performance variable X_{it} of the entering firm is initialized at the value of the post-policy change increment, Δ.

Industry Birth. With a few adjustments and additions, the model that describes entry when the industry is already in existence can serve to describe industry birth--entry by the innovator-founder(s) of the industry. As in the entry model proper, the key assumption is that there exists "background R & D" that is supported for reasons that have little or nothing specifically to do with the prospect of profitable operation in the industry-to-be. Some such assumption seems indicated if one concedes that the discovery and evaluation of entry opportunities is not costless in itself. It strains credulity to suppose that the R & D activity that leads to the birth of an industry typically derives from an economic calculation that depends closely on the (unknown) characteristics of the industry-to-be--although it might well derive from a calculation favoring a generalized alertness to the existence of innovative opportunity.

The imitative component of background R & D of course irrelevant when there is as yet nothing to imitate. The effort represented by the innovative component, it is assumed, antedates the industry itself. The birth of the industry occurs when this background effort generates a technique with an associated productivity level that looks profitable. To determine the profitability of its technique, the potential entrant needs to have some information about the prices of input and outputs. For simplicity, the strong assumption made is that input prices and the demand-price of the first unit can be reasonably assessed on the basis of the price of some existing product that is a close functional substitute for the new one. In this case, it is also plausible that the demand-price remains roughly constant over a substantial output range in which the new product is being substituted for the old.[12]

Considered as a general framework of explanation for the time at which a new industry appears, the foregoing points to three relevant considerations. The first is demand, or more precisely, the demand-price of the first unit. The second is technology, in the sense of the knowledge sources that may be drawn upon to create the industry's processes and products. The third is the level of background R & D. These three factors operate in combination, but of course there are three different stories that might be told in which one of the three is the central dynamic factor.[13] In the simulations reported below, the story is that technology improves while demand and the level of background R & D are constant.

IV. Simulations

The simulations reported here may be regarded as rather elaborate numerical illustrations of the distinction between the two Schumpeterian regimes discussed in Section II. They demonstrate that the model described in Section III is capable of generating such illustrations when the distinction between the regimes is identified with different values of a small number of model parameters. The model also generates a wealth of realistic detail, some of which is relevant to the distinction between the regimes, relating, for example, to number of firms, firm lifetimes, concentration, patterns of innovation and diffusion, patterns of price and productivity change. Some of these patterns correspond to identified qualitative features typical of industrial development, others may be regarded as hypotheses that could be tested on real data.

The Setting

First is is necessary to describe the numerical context in which the contrast of the two regimes is set. The objective in establishing this context was not to represent any particular empirical situation, but to achieve general empirical plausibility together with theoretical simplicity and familiarity--as illustrated by the use of a unit-elastic demand curve. These would seem to be the characteristics of a good numerical example. Also, of course, some of the particular quantitative magnitudes set forth here amount to nothing more than arbitrary choices of units and thus represent no restriction of the generality of the results.

Demand and Cost. The demand curve facing the industry is constant, unit-elastic with total revenue of 64, It is truncated and becomes perfectly elastic at a price of 1.20, which is conceived as corresponding to the price of a close substitute. The demand-price function is, therefore,

$$P_t = \left.\begin{matrix} 1.20 \\ \\ \dfrac{64}{Q_t} \end{matrix}\right\} \text{for} \left\{\begin{matrix} Q_t \leqq 53.33 \\ \\ Q_t > 53.33 \end{matrix}\right.$$

The time period is a quarter year--that is, this is the interpretation suggested for all quantities involving time rates. Cost parameters are as follows,

normal rate of return: (per quarter)	ρ	= .015
physical depreciation: (per quarter)	δ	= .03
variable production cost: (per unit capital)	v	= .115
total production cost: (per unit capital)	c	= .16

If the productivity of capital were the same for all firms and constant at the level A = .16, the ordinary long run equilibrium implied by these values would be as shown in Figure 1. The equilibrium level of capital is 400; the capital/output ratio in value terms is 1.56/year.

Investment. As explained above, desired investment in the model depends on a comparison of the actual markup over production cost with a target markup that depends on market share. Previous work has featured the use of the Cournot formula for the markup factor appropriate to a regime of relatively restrained competition. The Cournot formula is

12) $$\mu = \frac{\eta}{\eta - s}$$

where η is the elasticity of demand perceived by the firm, and s is market share. A related but more general result is the markup formula for a dominant firm that expects a competitive fringe to respond along a supply curve of elasticity σ; this is

13) $$\mu = \frac{\eta + (1-s)\sigma}{\eta + (1-s)\sigma - s}$$

In the spirit of Schumpeter's discussion, and in light of previous work with the model, it seemed appropriate to experiment with a somewhat more aggressive investment policy than the Cournot formula generates. The choice made was the formula (13) with η = 1 and σ= 2, subject to a qualification that reflects awareness of the price lid at 1.2. The actual numerical formula for the markup factor is then,

14) $$\mu(s) = \mathrm{Min}\left[\frac{3 - 2\cdot s}{3 - 3\cdot s},\ .999\,\frac{(1.2 + P_t)\cdot A_{i(t+1)}}{2\cdot c}\right]$$

where c = .16. Figure 2 shows the price corresponding to target markup for a firm with unit cost c/A = 1.0, and shows the Cournot formula for comparison. Desired gross investment per unit of existing capital i given by

$$I_D = \delta + 1 - \mu(s) \cdot \frac{c}{P_t \cdot A_{i(t+1)}}$$

15a)

$$= 1.03 - \frac{\mu(s)\ .16}{P_t \cdot A_{i(t+1)}}$$

Financeable investment is net income plus depreciation plus, if net income is positive, twice net income in borrowed funds.

15b) $$I_F = \begin{cases} .03 + \pi_{it} & \text{for } \pi_{it} \leq 0 \\ .03 + 3 \cdot \pi_{it} & \pi_{it} > 0 \end{cases}$$

Finally,

15c) $$I = \text{Max}[0, \text{Min}(I_D , I_F)]$$

<u>Performance and Exit.</u> The performance index is the .75, .25 weighted average of past performance and the current rate of return:

16) $$X_t = .75\ X_{t-1} + .25\ \pi_{it}$$

Exit occurs when capital falls below $K^{min} = 10$, or performance falls below $X^{min} = -.051$ per quarter.

<u>Adaptive Policy Change.</u> For a firm with below average rate of return, policy change occurs with probability .5, implying that the probability of going four quarters with below average return and changing policy is only .0625. The parameter in equations is .167; that is, the distribution of new policies is centered one-sixth of the way from current policy to the

industry average. The standard deviations σ_m and σ_n are .0004 and .002 respectively. The innovator-founder is assigned a policy of r_{imt} = .002 and r_{int} = .005. Translating roughly into percentage of sales on the basis of sales/capital = production cost/capital = .16, the founder spends about 1.25% of sales on imitative R & D, and about 3.13% on innovative R & D; the two standard deviations correspond to .25% and 1.25% of sales.

Technical Change and Entry: Common Features. The exogenously determined advance in knowledge relevant to the industry is represented by an increase of latent productivity at the rate of 4% per year. Latent productivity defines the central tendency of the distribution of results of innovative R & D draws, n a manner described in detail below.

The imitation conditions of the runs correspond to a situation in which there is no patent protection but industrial secrecy is reasonably effective at preventing prompt imitation. A new productivity level achieved by innovative R & D is initially a secret entirely impervious to imitative efforts, but becomes vulnerable to such efforts with probability .125 per quarter--implying an expected life of the period of "invisibility" of two years. An imitation draw reveals to the imitator the technique and productivity level of a visible technique, where the probability that any particular visible technique is seen is proportional to the amount of capital on which that technique is employed. In particular, then an innovative entrant who is small relative to the market is protected not only by a random period of total invisibility, but also by the fact that its small share makes it unlikely to be the target of successful imitative effort. The latter advantage dwindles if the firm succeeds in increasing its share.

The coefficient a_m relating the probability of an imitation draw to imitate R & D expenditure is equal to 2.5. This implies that a firm with a tenth of industry capital and the founder's imitation policy gets an imitation draw in a particular quarter with probability of approximately 20%. The level of external imitative R & D is set to .2, so the expected number of imitative potential entrants generated per period is .5 . For a positive entry decision, revenue per unit capital per quarter must exceed production cost by .007, this makes allowance for the founder's level of R & D expenditure. The standard deviation of the error in the entry calculation is .014 . Entrants are assigned initial capital values drawn from a normal distribution with mean 25 and standard deviation 7.5, truncated below at the K^{min} value of 10.

The two regimes considered below are identical with respect to the expected level of innovative potential entry. The expected number of such entrants generated per period is .05; equivalently, the expected rate is one every five years. With this rather low level of the expected entry rate, and with additional contributions of randomness from the sampling of the productivity distribution and the error term in the entry test, the date of appearance of the innovator-founder of the industry is rather weakly determined. To enhance the interest in the comparison of the two regimes the date of industry founding and the characteristics of the founder were make identical in the two regimes. The values chosen were central to the relevant distributions. Specifically, in the first period of the industry's existence latent productivity is .135, the founder's productivity is .15, and founder's capital is 25. After deduction of R & D expense, founder makes an excess return of .013 (1.3% per quarter), and grows in two years by 40.7%.

Technical Change and Entry: Two Regimes

The two regimes differ, first of all, in terms of the basis of the explanation for the common rate of innovative potential entry. In the entrepreneurial case, there is a large base of effort external R & D effort, but it generates usable results with low probability. Specifically, $E_n = 2$, and $a_n = .025$. This level of external effort is approximately the same as the level of innovative R & D that the industry itself would perform if every firm followed the founder's policy. In the routinized regime, the two factors are an order of magnitude different in opposite directions: $E_n = .2$, $a_n = .25$. In this case, if every firm followed the founder's policy, the innovation draws associated with potential entrants would be an order of magnitude rarer than those arising from internally financed R & D. In a sense, therefore, the different parameter settings directly imply a large difference in the relative impotance of externally and internally generated innovation. But there is more to the story than that: potential entry is not actual entry, and firms do not slavishly imitate the founder's policy. Entry, R & D intensity and other industry characteristics evolve endogenously.

The other dimension of difference between the two regimes is the degree of comprehensiveness of a single innovation. In the entrepreneurial regime, a typical innovation is comprehensive in the sense that the productivity level arising from an innovation draw is itself the productivity level of the new technique. In the routinized case, the new technique compromises features of the innovation with features of the old technique, and the resulting compromise productivity level is the geometric mean of the level associated with the innovation and the level associated with the old technique.

Specifically, in the entrepreneurial regime the distribution $F(A; A_{it}, t)$ of the productivity level resulting from an innovation draw is log normal, with log mean equal to the value L_t of latent productivity at t and log standard deviation equal to .1177 (corresponding to three years of latent productivity increase). In the routinized regime, the difference is that the log mean of the distribution is .5 $(\log L_t + \log A_{it})$, and standard deviation .0589 = .5 (.1177). The reduction of the standard deviation reflects an assumption that the variability of the innovation result is governed by the comprehensiveness of the innovation.

A significant distinction between the two regimes is that the model of innovative entry requires some further elaboration in the "routinized" regime, but not in the "entrepreneurial" regime. In the latter, the comprehensiveness of innovation means that the productivity level of an innovative entrant is defined by its innovation draw. In the routinized regime, on the other hand, a question arises as to what, for the entrant, plays the role of the old technique of an established firm. The answer provided is that this role is played by a constant base level of publicly available knowledge. The productivity level associated with this knowledge base cannot logically be higher than the level required for profitable operation at the maximum price--for if it were, the industry should have been in existence for however long that knowledge has been available. The assumption here is that the base level productivity is just equal to the level required to breakeven at the maximum price, namely .16/1.2 = .1333. An optional interpretation is that the relevant base level public knowledge is the knowledge needed in production of the pre-existing substitute for the industry's product, whose price sets the maximum price.

The tendency of this assumption about entry is to confine actual innovative entry to the early stages of the industry development; the more rapid is latent productivity growth, the stronger is this tendency. After latent productivity has diverged substantially from base level productivity, the potential innovative entrant faces the handicap that the single good idea represented by his one non-comprehensive innovation tends not to be enough to permit him to match the efficiency of the established competition; his productivity is dragged down by the admixture of mere publicly available knowledge. This mechanism will receive further attention in the concluding comments of Section V.

Results

The results of the simulation runs are much easier to characterize than the numerous qualitative and quantitative assumptions that underlie them. In one respect after another, the synthetic industry history generated in the routinized regime plainly evokes the modern capitalist system described in Capitalism, Socialism and Democracy, while the history in the entrepreneurial regime suggests the world of The Theory of Economic Development.

To begin with, in the entrepreneurial regime, adopted innovations associated with new entry (excluding the founder) outnumber those by established firm by two to one, whereas in the routinized regime there almost 23 innovations by established firms for every one associated with entry. The discrepancy between these ratios considerably exceeds the factor of ten that was noted as being, in one sense, the direct implication of the difference in the draw-yield of innovative R & D. Part of the reason is that the incremental innovation process of the routinized regime shuts off innovative entry: the third and last such entry in the routinized case occurred after the industry had existed for nine years. The rest of the explanation is the difference in innovative R & D intensity. From an initial value of about 2.8% of sales, industry innovative R & D evolves upward to 4.4% of sales in the routinized case, but evolves downward to 1.5% of sales in the entrepreneurial case.

The much larger number of innovations in the routinized regime more than offsets their more incremental nature, and results by the end of the run in substantially higher productivity and lower price than in the entrepreneurial case. But, because of the incremental nature of the change in the routinized case and the diminishing returns associated with exogenously determined latent productivity, a major effect of the high innovation rate is to produce a smoother advance. One way to measure this is to count the number of distinct productivity levels that represented industry "best practice" at some time in the forty year history of the industry. The count is 11 in the entrepreneurial regime, 24 in the routinized regime. Figures 3a and 3b show the evolution of best practice and industry average productivity.

There are other indications in the results that the name of the routinized regime is well warranted. Of the three leading firms at the end of the run in the routinized regime, two were created in the first five years of the industry's existence; the average age of these three firms is over 32 years. These are the "giant industrial units" that tend to "automatize process": [CSD, p.134]. In the final period the leader has a market share of 39% and a research-to-sales ratio of 4.4%; the second firm is somewhat more research intensive and, interestingly, the third firm does no research at all. The high concentration of the model industry is reflected in rates of return. The industry as a whole generates positive excess returns consistently in the last five years of the run, and the leader's excess return in the final period is over 2.5% per quarter.

The corresponding results in the entrepreneurial regime reflect, in a variety of ways, the fact that innovation is primarily associated with new entry. Only one of the old time firms in the industry survives through the fortieth year; it dates from the fifth year of the industry's existence. The second oldest survivor was created in the industry seventeenth year, and the average age of the three largest firms at the end is only about fifteen years.

The leading firm is the remnant of a giant that ten years previously had a share of over 50%. This firm was an innovative entrant at the end of year twenty, and with that technique and two successor innovations it represented "best practice" for eighteen years, with one brief interruption. But by the end of the run, its share has shrunk to 16%. The wave of the future is the number three firm, which entered within the last two years with a technique that is about 28% more productive than the leader's, and that remains a secret. This firm is the only one in the industry that is not using the leader's technique. In fact, just prior to the new challenger's entry the industry was virtually in long run equilibrium with a single technique, the only ongoing change being the slow yielding of market share by the leader to the fringe of imitators, particularly those who spend little on R & D.

Overall, the industry structure in the entrepreneurial regime is much less concentrated and less profitable at the end of the run than in the routinized regime. But, as the foregoing discussion suggests and Figures

4a-4b illustrate, the significant point about concentration in the entrepreneurial case is not that it does not occur, but that it is likely to be temporary--swept away in a gale of "creative destruction."

Table 1 and the other figures display a number of comparisons of the two runs, some of which have been discussed above. Figure 6a-6b presents one final illustration of the verisimilitude of the model's results: A plot of size (sales) against rank of log-log paper shows that the size distributions conform roughly to the Pareto law, particularly in the routinized case.

V. Concluding Comments

The real phenomena of technical progress and industrial development display great diversity. A portion of that diversity is a reflection of underlying differences in technological regime, that is, of the character and functioning of the underlying system of knowledge sources that feeds the wellsprings of progress. The contrast developed here between stylized entrepreneurial and routinized regimes has served to illustrate this point, and also to suggest the promise of evolutionary theory as an interpretive framework for the study of industry histories.

A great deal more can be done, within the framework of the model in Section III, to trace the implications of regime differences for the course of industrial development. For example, it would be interesting to explore cases in which the externally generated technological opportunities, represented by latent productivity, were stationary but remote from the initial position of the industry, and exploitable only through incremental innovations. One would expect actual productivity advance to decelerate over time, perhaps after an initial phase in which the increased appplication of R & D resources more than counterbalanced the diminution of the stock of unexploited opportunites. The case is worth examining partly because the pattern of decelerating progress is often taken to be a stylized fact about industrial development; also, it is an interesting context for further exploration of the relationships among policy, progress and industrial concentration.

This is only one of many opportunities for further use of the model of Section III; it is important to note, however, that there are some important considerations and issues that are not represented in that model and cannot be explored with its aid. One is the implications of the fact that industries and firms are multi-product and the technological regime may differ importantly among produts. Another is the significance and sources of the pattern in which entrepreneurial innovative entry is followed sooner or later by merger with an industry leader, with attendant technology transfer.

Mention of these omitted considerations prompts a final look at the nature of the barrier that increasingly inhibits innovative entry in the routinized regime. The problem facing the aspiring entrepreneur is that his key idea must be complemented with other elements to constitute a functioning routine, and the persistent innovative efforts of established firms have given them enough of an edge in these complementary elements to outweigh the advantage of his key idea. This difficulty would be lessened if the entrepreneur could enter the market for an isolatable <u>component</u> of the product or product line offered by established firms, a component in which his key idea played a much larger relative role. The feasibility of this course of action depends on the isolatability of the component, both intrinsically and as a result of the deliberate policies of the established firm. And although entry into the component market may provide a profitable way to exploit the idea, it does not directly constitute a solution to the problem of how to enter the original market--the established firms remain protected by their comprehensive command of relevant technology.

Alternatively the entrant could conceivably choose to enter and produce at a loss, recognizing that with enough R & D effort and reasonable luck it is possible to catch up with the established firm. The question, of course, is whether this type of entry is likely to pay off--in modeling terms, the question is what profitability test replaces the simple current profitability test that has been abandoned. This question leads back to the issues addressed in the strategic entry deterrence literature; the entrant's image of the post-entry market game becomes crucial. More fundamentally, it leads to a very different conception of entry than the one incorporated in the present paper, which uses the modeling devices of external innovation R & D and resulting innovation draws as a way to focus attention on the <u>supply</u> of <u>differentiated</u> potential entrants. These are aspiring entrepreneurs who have reason to think that they may have in hand the key, or rather the "new combination", to innovative success in the industry.

Table 1

SELECTED COMPARISONS OF THE TWO RUNS

A. Final Period Values

	Price	Av. Prod.	Av. In. Policy (1)	Av. Im. Policy (2)	Rate of Ex. Ret. (3)	Firms
Entrepreneurial	.36	.45	.0025	.0020	-.0016	14
Routinized	.29	.61	.0078	.0016	.0092	8

	Shr. Lgst.	Shr. 4 Lgst.	H. Num. Equiv. (4)	Av. Age 3 Lgst.
Entrepreneurial	.16	.52	10.3	15.3
Routinized	.39	.84	4.4	32.3

B. Totals Over Run

	Firms	Innov. Entrants (5)	Inno-vations (6)	Best Pr. Tech. (7)	Sel. Effect (8)
Entrepreneurial	42	8	12	11	-.00098
Routinized	30	3	71	24	.00047

Notes:

(1) Innovative R & D expense per quarter, as a fraction of capital, capital-weighted.

(2) Imitative R & D expense per quarter, as a fraction of capital, capital-weighted.

(3) Industry total excess profits, per quarter, as a fraction of industry capital.

(4) Reciprocal of Herfindahl-Hirschman concentration index.

(5) Excluding founder.

(6) Excluding founder's technique.

(7) Number of distinct values of best practice productivity level level (including founder's)

(8) Sum over run of individual period selection effects on innovative R & D policy, defined as the change in industry average policy brought about by changing capital weights alone, that is, as it would have been in the absence of changes in firm policy and entry.

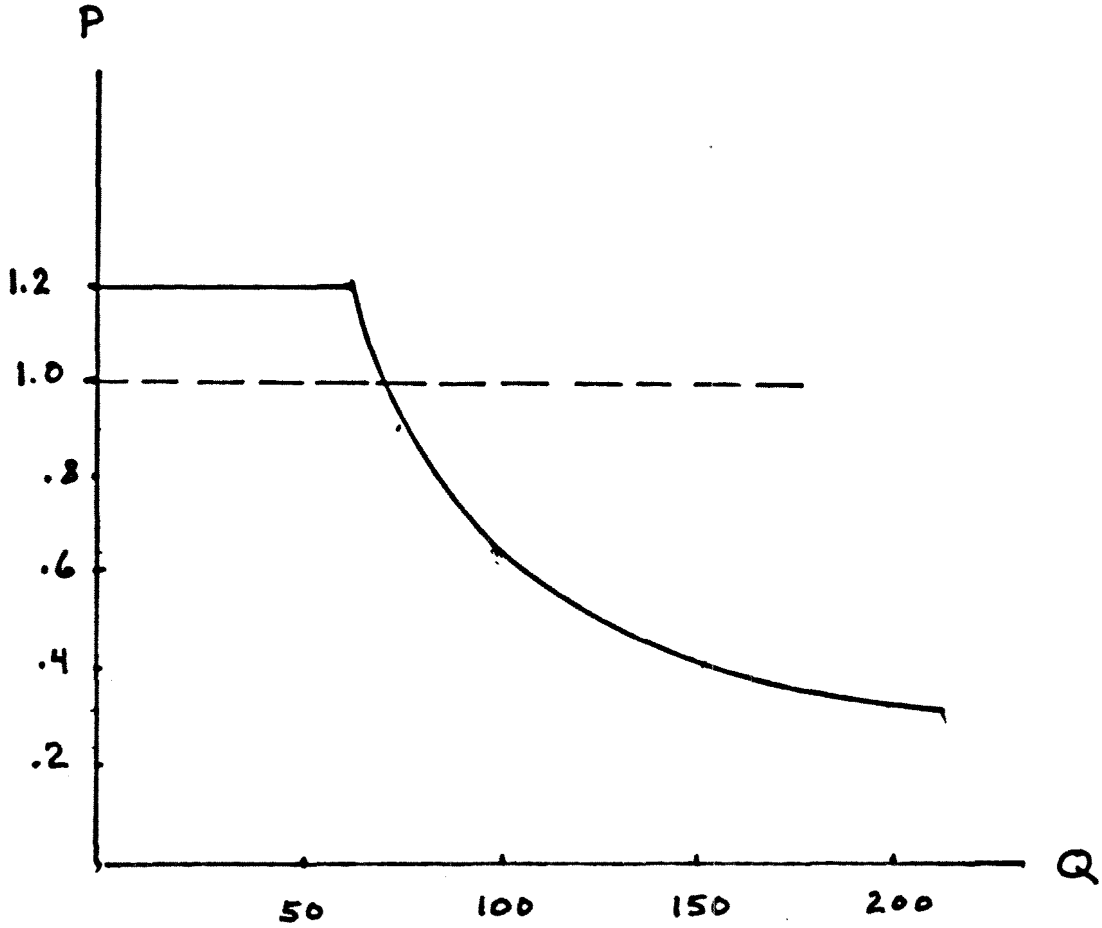

Figure 1. Demand curve and long run equilibrium.

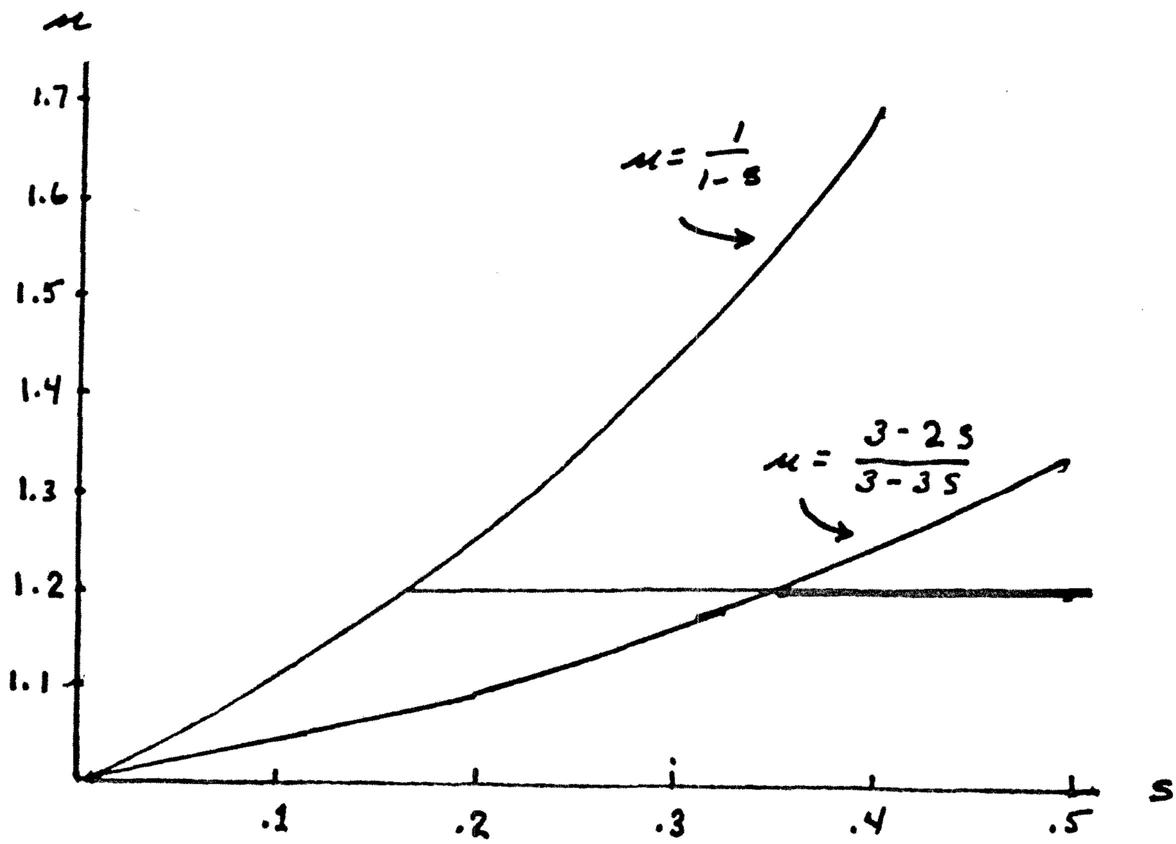

Figure 2. Formulas for target markup factor.

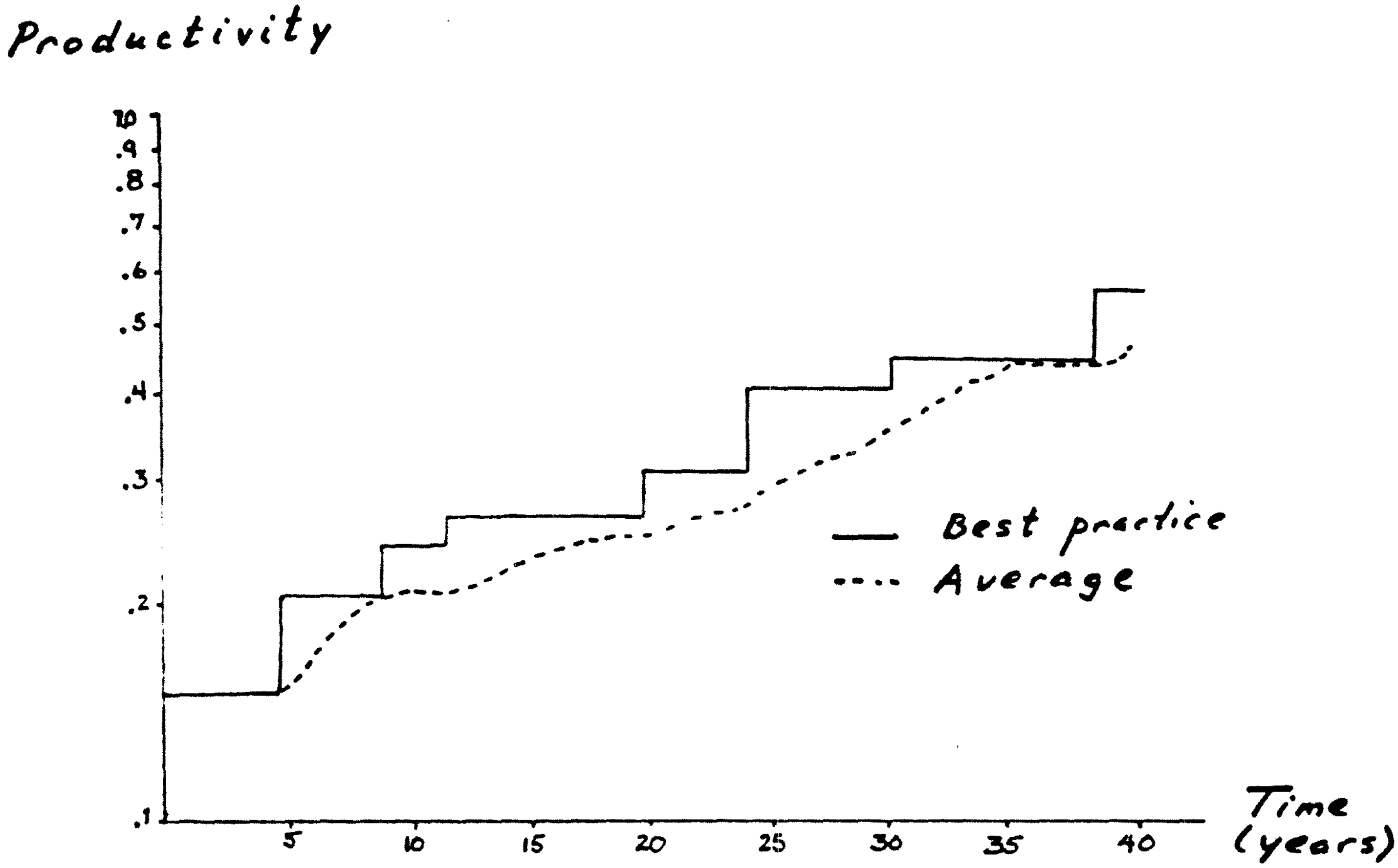

Figure 3a. Productivity in the entrepreneurial regime.

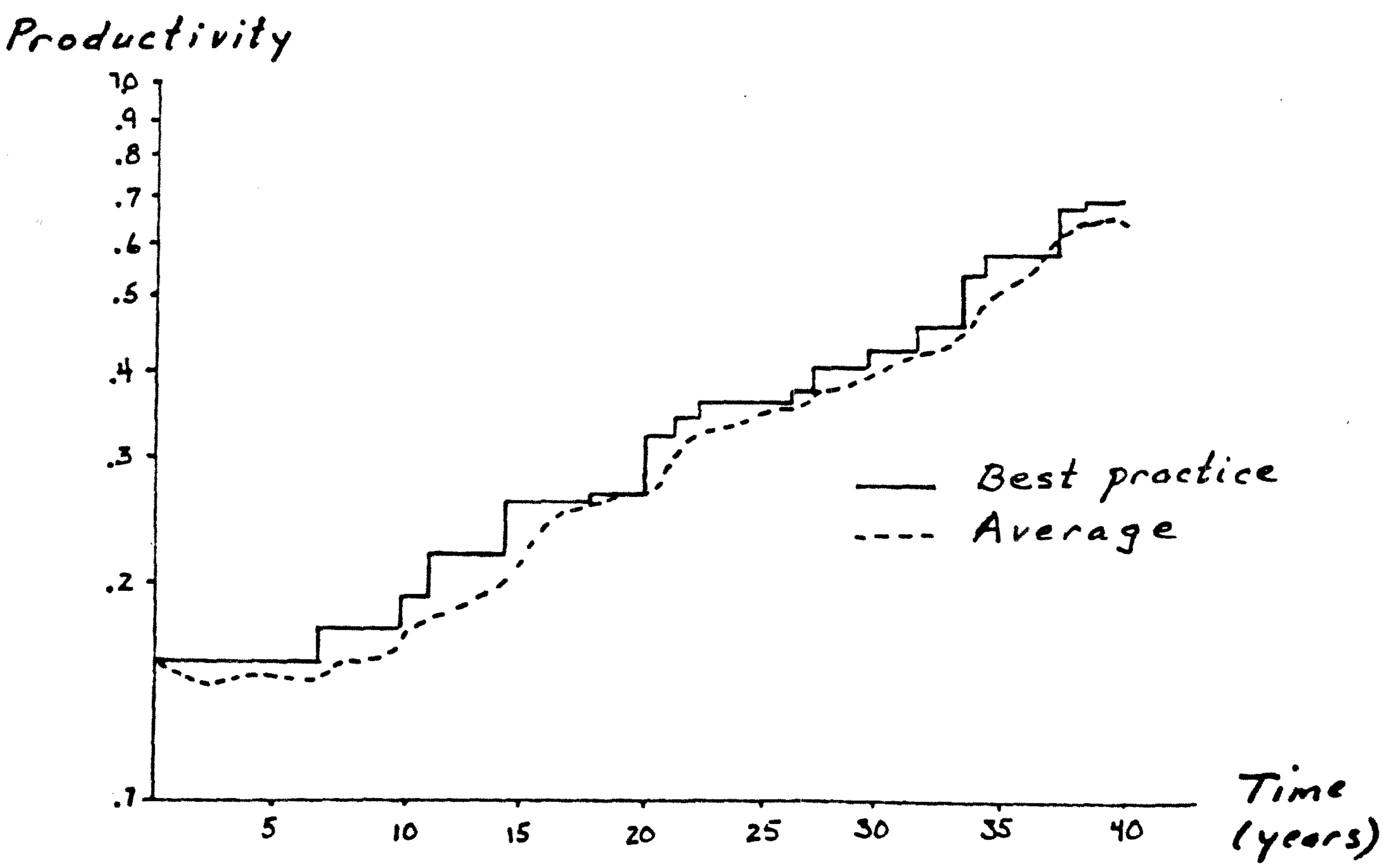

Figure 3b. Productivity in the routinized regime.

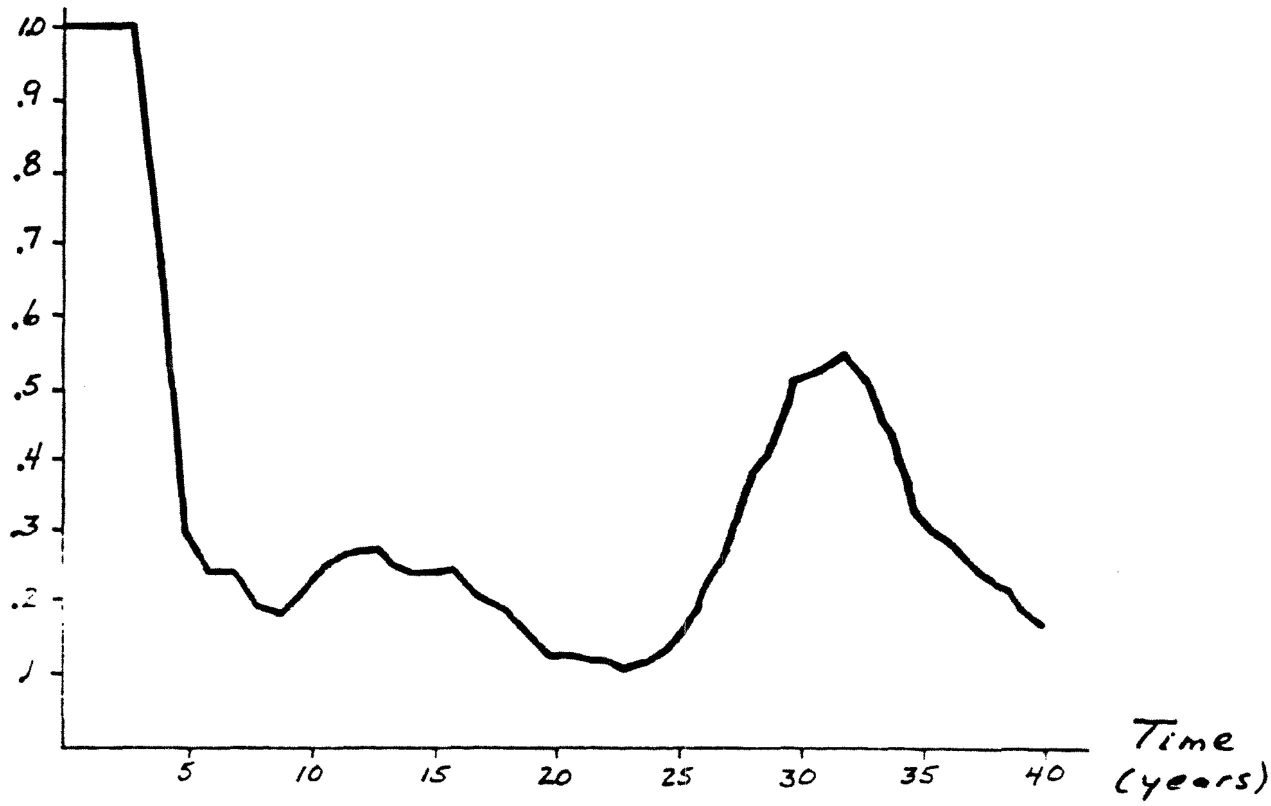

Figure 4a. Market share of largest firm, entrepreneurial regime.

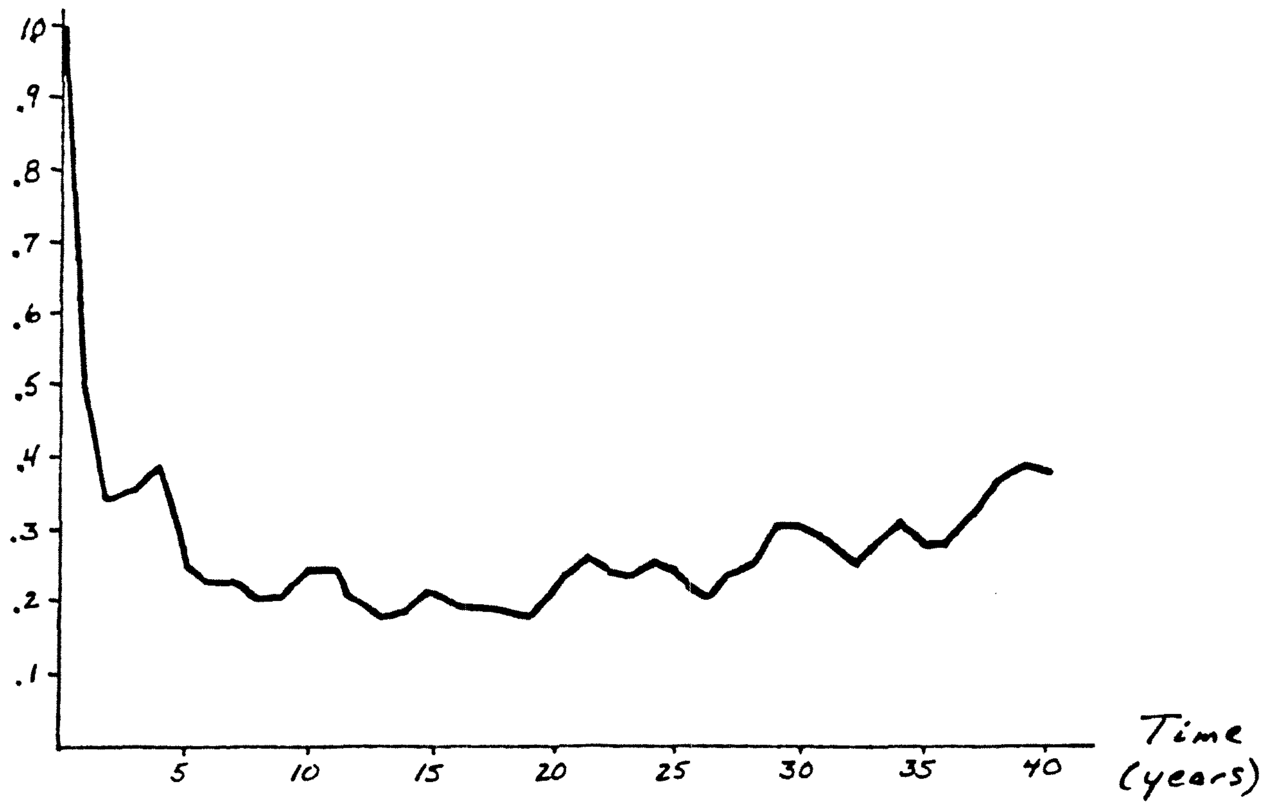

Figure 4b. Market share of largest firm, routinized regime.

Figure 5a. Number of firms, entrepreneurial regime.

Figure 5b. Number of firms, routinized regime.

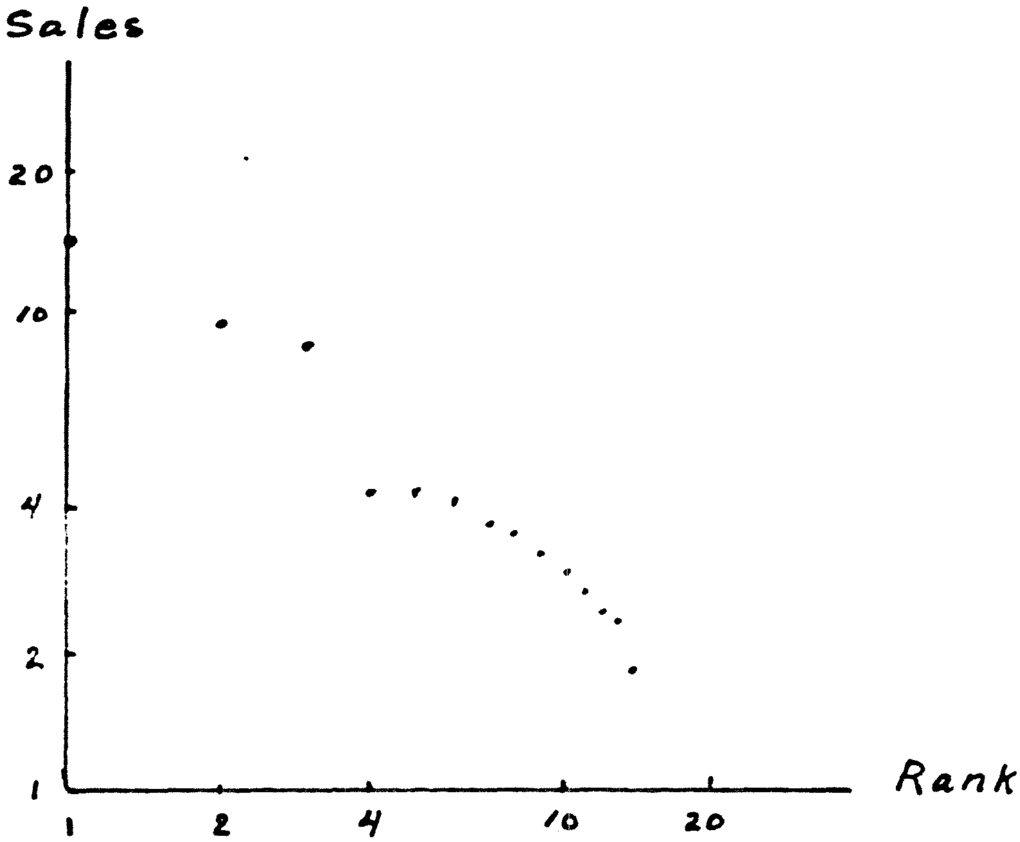

Figure 6a. Firm size and rank, log-log scale.
(entrepreneurial regime)

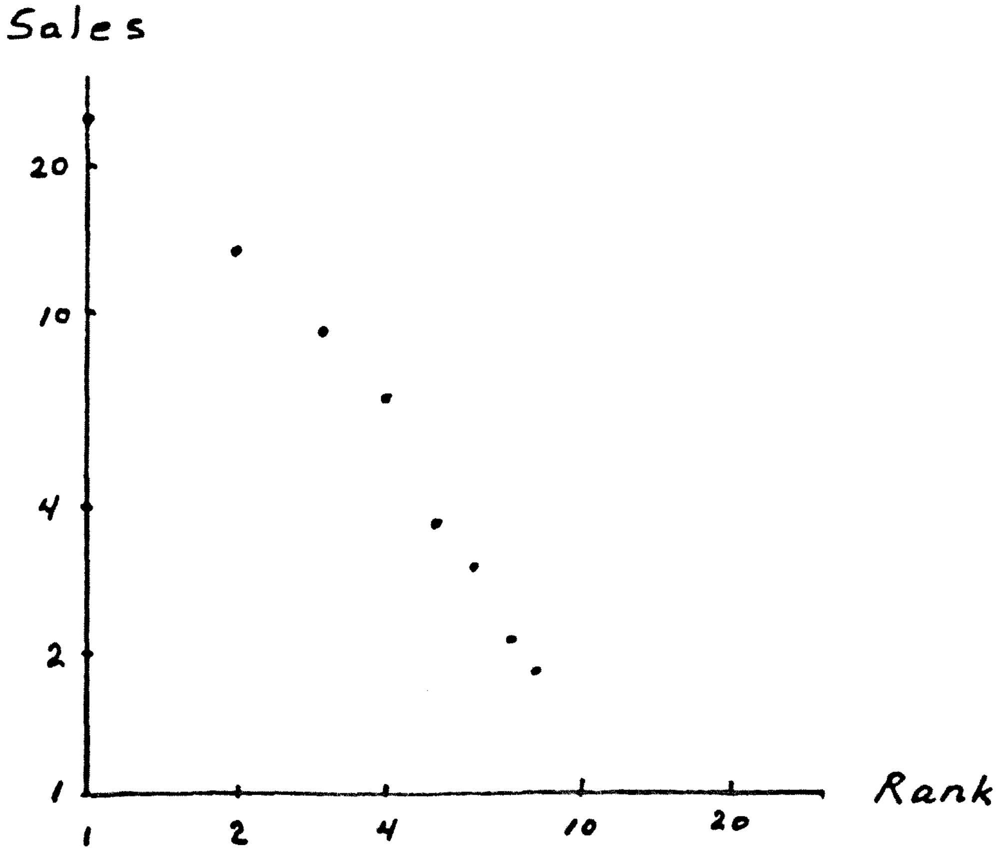

Figure 6b. Firm size and rank, log-log scale.
(routinized regime)

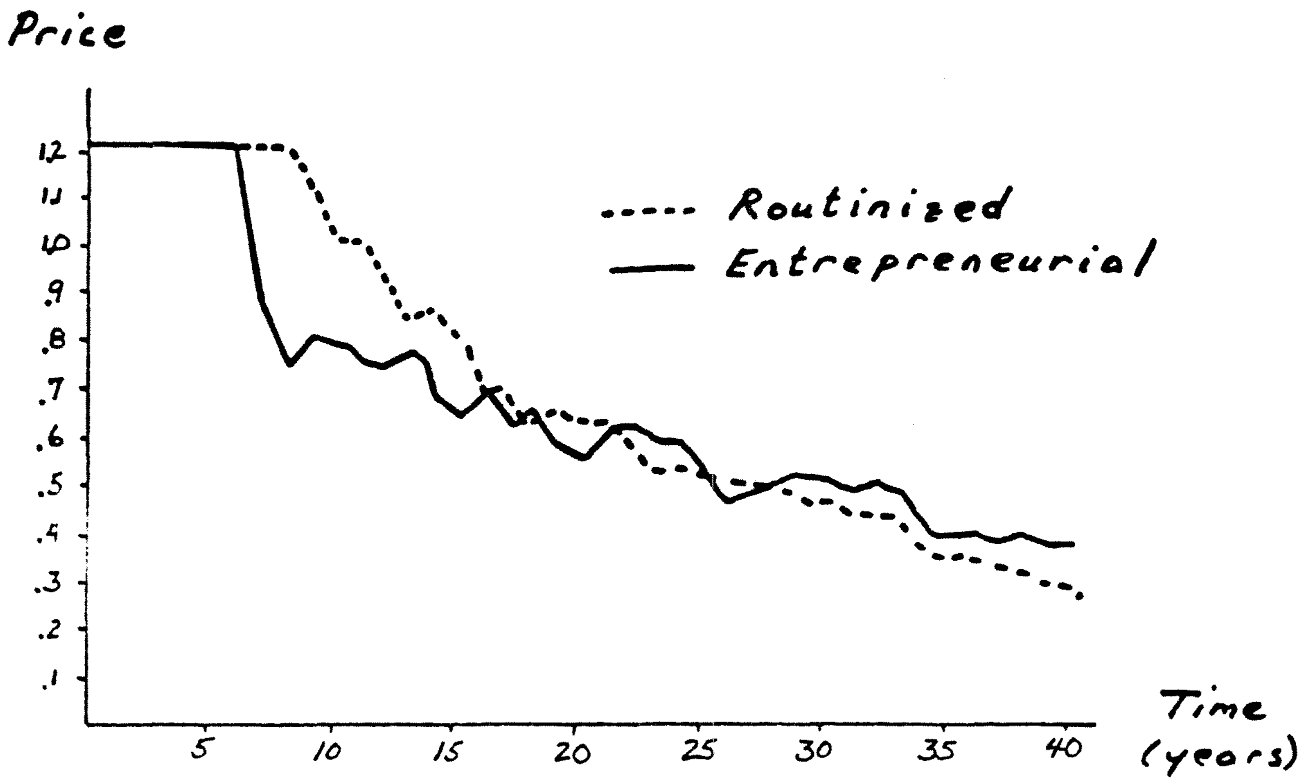

Figure 7. Price.

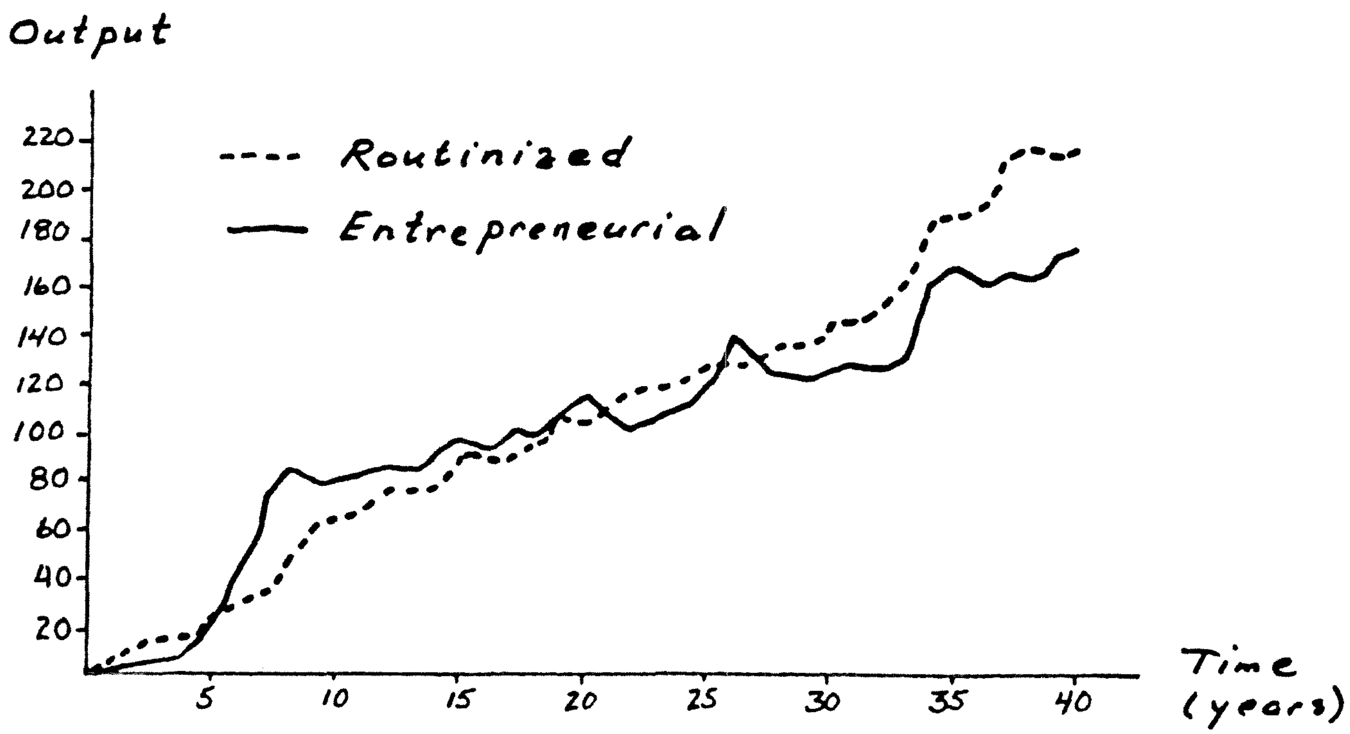

Figure 8. Output.

Figure 9. Research Expense

Footnotes

1. See, for example, the treatment in Varian, (1978, sec. 1.2)

2. This is a very abbreviated statement of the Nelson-Winter critique of orthodox production theory. A reasonably complete statement would be the union of the discussions in Nelson (1980), Nelson and Winter (1982, Chapter 3) and Winter (1982).

3. A description of one example of this sort of work is Powers (1975).

4. Reference is made to "skills" as well as "ideas" so as to avoid any implication that technological and organizational knowledge is necessarily symbolically representable and articulable. See Nelson and Winter (1982, Chapter 4) for discussion of the nature and role of tacit knowledge. Subsequent references to "ideas" should be understood to encompass skills as well.

5. When imitation is attempted under conditions that permit only limited access to the thing imitated, it becomes very similar to innovation and of course is unlikely to yield an exact copy. The full continuum between pure imitation and pure innovation is not explored here.

6. See Nelson and Winter (1982, Chapter 14).

7. Ibid., p. 283.

9. Herbert Schuette's dissertation (1980) represents the first attempt at evolutionary modeling in this area.

10. The reason it is troublesome is that it tends to maximize the destabilizing consequences of the imperfect coordination of behavior when the industry is not in equilibrium, and thus makes it (artificially) hard to explain how stable adjustment could occur. See G.B. Richardson (1960), also Porter and Spence (1982), and my comment that follows their paper. Of course, the free entry assumption is very convenient for static analysis of long run equilibrium.

11. This constitutes a minor technical difference from the representation of R & D by firms in the industry, since the latter can have at most one innovation draw and one imitation draw per period. However, this difference becomes negligible when the model time period is chosen to be short; as noted previously, the simulation model as a whole is best thought of as a discrete time approximation to an underlying continuous time model.

12. This assumption also provides a plausible explanation for the existence of a downward kink in the plot of price against time for a new industry or product market. See Figure 7 and compare to some of

the illustrations provided by the Boston Consulting Group (1972).

13. A degenerate case of the explanatory scheme arises if all three factors are constant over time. The probability that the industry will appear is then constant over time. If the probability is positive then presumably the implication is that the industry has already existed for a long time--assuming that the probability is large relative to (time periods elapsed since the whole system began)$^{-1}$.

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