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Research on Productivity Growth and Productivity Differences: Dead Ends and New Departures

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THERE SURELY isn't any excuse for another review of main line economic research on the sources of productivity growth, and this isn't one. There is a real need for a paper that convincingly explains the recent productivity growth slow-down so that one can see the basic causes, whether they be persistent or transitory, and the policy options. This, however, is not a paper about the slow-down either, although it is motivated by the inconclusiveness of studies on that topic. The premise behind this paper is that the theoretical model underlying most research by economists on productivity growth over time, and across countries, is superficial and to some degree even misleading regarding the following matters: the determinants of productivity at the level of the firm and of inter-firm differences; the processes that generate, screen, and spread new technologies; the influence of macroeconomic conditions and economic institutions on productivity growth. Sections II through IV will deal with these topics, considering heterodox as well as orthodox literature bearing on them. In Section V, I review recent efforts to develop evolutionary models of productivity growth. But first, Section I briefly takes up the current state of the art regarding productivity studies. I suggest that there is evident unrest about the prevailing theoretical formulation. While some empirical research sticks quite close to it, a substantial body of research proceeds along lines that deviate in important ways from the tenets of that theory.

I. *The Schizophrenia of Contemporary Research on Productivity Growth and Related Phenomena*

To begin, a bit of intellectual history is in order. While the conceptual apparatus used today is relatively new, the interest of economists in productivity growth is venerable. Chapter I of the *Wealth of Nations* is mostly about technological advance and productivity growth, as it is called today. John Stuart Mill, like Karl Marx, was a growth theorist. Alfred Marshall was much interested in long-run economic change. In classical growth theory, as in neoclassical growth theory, firms were viewed as profit-seeking and industries as competitive. But the connotation was more flexible than that of contemporary orthodox price theory. In the verbal discussion, if not in the formal analysis, growth was viewed as an evolutionary process. A nation's institutions were regarded as stimulating or blocking, fruitfully channeling or diverting that process.

It is worth noting that, during the early post-war era, the microeconomic conceptions underlying empirical analyses of productivity growth seem closer to the older theoretical tradition than to the newer one. In his 1952 review article, Moses Abramovitz stressed the links of then current empirical research to classical thinking, and remarked upon the absence of many recent theoretical developments. Yet, despite the absence of the modern framework for thinking about productivity growth, the papers by Jacob Schmookler (1952), Theodore Schultz (1953), Solomon Fabricant (1954), John Kendrick (1956), and Abramovitz (1956) are remarkable in foreshadowing the central conclusion of studies done somewhat later within the neoclassical framework—that the growth of output experienced in the United States has been significantly greater than reasonably can be ascribed to input growth. Technological advance, changing composition of the work force, investments in human capital, reallocation of resources from lower to higher productivity activities, economies of scale, all were recognized as parts of the explanation. But no attempt was made to divide up the credit. The possibility of significant interaction was recognized. In these studies factor prices were used to weight the various inputs in order to get a measure of total input growth; however, there was no elaborate justification of this as a means of tracking movements along a production function, nor did the authors postulate that the economic growth path being followed was one of moving competitive equilibrium. Schmookler refers to Joseph Schumpeter, and Abramovitz to Simon Kuznets, both of whom had stressed that growth was a disequilibrium process.

It is also interesting that the early post-war theoretical discussion about economic growth did not proceed using the language and concepts of microeconomic theory, but involved the extensions of Keynesian theory by Roy Harrod and Evsey Domar. These models employed neither the assumption of profit maximization, nor the presumption of competitive equilibrium, nor even full employment. Indeed, the models were designed to explore the conditions under which aggregate demand and full employment output could grow at the same rate. Given the assumptions, the required conditions were extremely stringent.

1.1 *The Neoclassical Art Form and Its Elaboration.* Robert Solow's 1956 theoretical article was largely addressed to the pessimism about full employment growth built into the Harrod-Domar model. Solow pointed out that the razor's edge property of that model was due largely to the assumption of fixed coefficients. With flexible factor coefficients the capital-labor ratio could adjust so that, for any savings (investment) rate, demand for and supply of labor could grow at the same rate. He went on to develop what has come to be called the (stripped down) neoclassical model of economic growth. (Trevor Swan published a similar, if less influential, analysis in 1956.) In that model he admitted the possibility of technological advance which shifted the production function. In his 1957 empirical article, Solow showed how to attribute growth to various sources and how to measure technological advance, consistent with his theoretical formulation. Let me review here the basic ideas to call attention to certain features that by now are so familiar they seldom are reflected upon.

Firms are the key productive actors, transforming inputs into outputs according to a production function. The production function, which defines the maximum output achievable with any given quantity of inputs, is determined by the state of technological knowledge. Technological knowledge is assumed to be public or at least this is implicit in models based on an industry or an economy-wide production function. Firms choose a point on their production function to maximize profits, given product demand and factor supply conditions. Generally these markets are assumed to be perfectly competitive so that a firm treats prices as parameters. Assuming factor prices adjust, and no Keynesian difficulties exist, the model is consistent with full employment and usually this condition is assumed. Over time, output grows as inputs increase and firms move along their production functions, and as technology advances. Assuming differentiability of the production function, profit maximization, and factor price taking on the part of the firms, the elasticity of output with respect to any input equals its share of total factor returns, at least for small increments to inputs. Proportional output growth due to input growth along the production function equals the sum of share-weighted proportional input growths. The residual (if any) is a measure of production function shift, or technological advance.

There clearly are some strong presumptions here. The view of firms and markets is very stylized—not much room for incompetent management, labor-management strife, or oligopolistic rivalry. Technological advance, while acknowledged as a central feature of growth, is treated in a very simple way, and the Schumpeterian proposition that technological advance (via entrepreneurial innovation) and competitive equilibrium cannot co-exist is ignored. Full employment is simply presumed; the model contains no specific mechanism to assure this condition. The sources of growth are viewed as operating independently and additively. While in part this reflects the mathematical analysis of small changes, in growth accounting this view is carried over to analysis of the sources of growth over relatively long periods of time. The institutional environment is very simple—there is no particular place in the structure for labor unions, banking systems, schools, or regulatory regimes.

The purpose of any theoretical formulation is to provide a particular focus and interpretation. Reality inevitably is much richer than any theory. Empirical scholars in economics recognize that theory is abstraction, and try to take into account important factors omitted by prevailing theory. Further, a simple theory, initially formulated, is amenable to later widening, deepening, and to modifications that deal with anomalies. The fruitfulness of a broad theoretical structure has to be judged in terms of the energy it lends to research, and the power of the knowledge won through that research. By these criteria the neoclassical art form clearly must be judged as having been very fruitful. It has given life, direction, and a considerable degree of coherency to research done by a large number of economists over a considerable period of time. That research has greatly enhanced our knowledge of the factors behind productivity growth.

But while sensible scholars treat formal theoretical frameworks pragmatically, still these frameworks constrain as well as focus, blind as well as illuminate, the empirical research endeavor. Prevailing formal theory influences profoundly what empirical data are ignored, and how attended empirical data are interpreted. Where empirical scholars consider phenomena beyond those that have a theoretical place, analysis tends to be ad hoc.

It is my belief that research, guided by the neoclassical paradigm, has reached a stage of sharply diminishing returns, with many important questions still not resolved adequately. Further, a sizable portion of research on productivity growth, while perhaps initially undertaken to widen and deepen the simple neoclassical model, has identified phenomena and relationships not treated adequately, or even denied, by that theory. It is not my purpose to review in any detail all of the research under discussion; there have been a plethora of such reviews. But to establish my point, it is useful to review some of that literature, organized under two headings. The first consists of research that appears, at first glance, to follow the neoclassical line rather closely. The second has clearly deviated in certain important ways.

1.1.1 *Growth Theory and Growth Accounting.* Since the mid-1950s, considerable research has proceeded closely guided by the neoclassical formulation. Some of this work has been theoretical. Various forms of the production function have been invented. Models have been developed which assume that technological advance must be embodied in new capital. Technological advance has been made endogenous to the theory through linking it to an increasing R&D capital stock. In some models technological advance is assumed to be steered toward saving on labor or on capital by factor prices. Many of these models were reviewed in Solow (1970), and by Hans Binswanger and Vernon Ruttan (1978).

Much of the work has been empirical and guided by the growth accounting framework implicit in the neoclassical model. Edward Denison (1962, 1967, 1974), Kendrick (1961 and 1973), Zvi Griliches (1960), and Dale W. Jorgenson and Griliches (1967) made especially important early contributions to this literature. A good portion of this work has been concerned with squeezing down the size of the residual. While Solow's interpretation gave particular economic meaning to it, *viz.*, technological advance, in most economists' eyes the residual had much weaker analytic standing than that part of growth that could be explained by movements along a production function. There certainly was reason for economists to try to assure themselves that any change in productivity that could be accounted for by movements along the production function in fact were so treated. Labor input was disaggregated and attention paid to the education, sex, and age composition of workers. Capital input was disaggregated into machinery and structures, and its "vintage" considered. Some scholars attempted to account for natural resource input. In recent years energy has been counted as a separate input. For good surveys of the earlier work, see M. I. Nadiri (1970), and F. H. Hahn and R. C. O. Matthews (1967). Denison (1979) and Kendrick and E. Grossman (1980) provide more recent, if less sweeping, reviews, along with analyses of more contemporary trends.

Several empirical scholars have incorporated depreciated R&D in a "meta" production function, and attempt to measure the contribution of R&D spending to growth of productivity. See Edwin Mansfield (1968, Chapter 3); Griliches (1980), and Nadiri (1980). These approaches preserve the potential importance of technological advance as part of the neoclassical growth story, but remove or soften the association of technological advance with the residual.

An important recent methodological development in production function fitting and growth accounting has been the exploitation of duality relations implicit in the theory of the profit-maximizing cost-minimizing firm. The solution to a firm's profit-maximization problem simultaneously determines output and input, costs and profits, as a function of product and factor prices. Duality theory points to ways to calculate production function shape and shift indirectly through estimation, for example, of the shape and shift of factor demand curves, or of the cost function. These methods permit greater use to be made of price data in estimating production relations. Jorgenson and his colleagues (see particularly L. Christensen and Jorgenson, 1971, and Frank M. Gollop and Jorgenson, 1980) have been prominent in developing these methods.

The research briefly described above varies considerably in the extent of adherence to the basic neoclassical model of economic growth. The work of Jorgenson and his colleagues, and of Griliches, stays quite close to the theoretical line. The growth accounting work of Kendrick, and particularly of Denison, demonstrates vividly, however, a point made earlier. Sensible empirical researchers often will add variables that the formal theoretical models do not contain and, more generally, interpret the background theory very flexibly. Thus Denison explicitly considers inefficiencies in resource allocation, and institutional obstacles to the adoption or spread of best practice technology. In his recent studies of the productivity growth slowdown, Denison has included variables like the extent of regulation, and the cost of crime. It is important to note, however, that where relatively formal theoretical arguments are used in growth accounting studies, these are drawn from the neoclassical model. The non-neoclassical variables are, simply, just added on, in an ad hoc way. But variables take on meaning only in the context of a theoretical framework, formal or informal. If these kinds of variables, or processes, are important, we need to revise our conceptualization of the growth process. I review below certain bodies of research which, even more than the growth accounting studies, suggest a need for reconceptualization, and which point in certain interesting directions.

1.1.2 *Eclectic Research On Productivity Growth.* The neoclassical picture of the firm is stark and simple. While many economists were using this basic theory of the firm, other scholars were studying a variety of factors bearing on the productivity and productivity growth of firms while entertaining different and more complex views of their nature. Such variables as the style of decision making, background of the managers, and the character of labor management relations were considered. See Charles Perrow (1979). Still other scholars focused their attention on differences in productivity among firms in the same industry. An early classic study is by Lászó Rostas (1948); more recent examinations of U.S.-U.K. differences are reported in Richard Caves (1980). While this research has not definitively established any robust correlations, it has provided evidence that neoclassical variables do not account for all of the differences among firms in productivity and related variables.

At the same time that some scholars were including R&D in a neoclassical production function, others (sometimes the same scholars in a different guise) were exploring more pragmatically the microeconomics of technological advance. The research of Edwin Mansfield and his colleagues (1968, 1971, 1977) has been especially fruitful. Two key findings should be highlighted here. One is the substantial uncertainty that surrounds efforts to create, or evaluate, new technologies. The other is the considerable variation among firms in the technologies they create and adopt, particularly in industries where technology is advancing rapidly; this fact is partly the consequence of uncertainty, but stems in part from the fact that much of technological knowledge is proprietary. More generally, the assumptions built into the simple form of the neoclassical model—that technological knowledge is a public good and that growth is an equilibrium process—would appear to be inconsistent with the mechanisms that draw forth new technologies in capitalist economies.

Other scholars refocused attention on resource reallocation from low to high productivity sectors (see e.g., Charles Kindleberger, 1964; Simon Kuznets, 1966, and John Cornwall, 1977)—a phenomenon highlighted in earlier writings, but repressed in the macro-neoclassical formulation. Various multisector neoclassical models were developed and techniques developed to estimate the contribution of resource shifts to growth within a growth accounting framework (Denison, 1962 and later volumes). But resource reallocation surely reflects and involves discrepancies between factor returns in different sectors. While it is simple to extend the neoclassical model to include many sectors, the basic logic of that model is committed to continuing equilibrium, not resource reallocation driven by prevailing disequilibrium.

That model also is committed to relatively sustained full employment, and indeed relatively full employment and considerable macroeconomic stability marked the hey-day of rapid growth during the late 1950s and 1960s. Angus Maddison (1967) and Andrew Schonfield (1965), among others, ascribed a good share of the credit for rapid productivity growth to sustained full employment, and inquired into the conditions responsible for that state of affairs which contrasted so sharply with the depression years. Both gave part of the credit to adoption by governments of Keynesian policies. Many scholars have noted that the post-1973 productivity growth slowdown has been accompanied by higher average unemployment and inflation rates, and stop and start economic policies. Economists divide on the explanation, but Maddison (1980) and James Tobin (1980) seem not to doubt that inadequate policies are at least in part responsible for macroeconomic instability and slow growth.

Other scholars focused their attention on social, political, and economic institutions. Abramovitz (1979), among others, has stressed that international trade in goods, capital movements, and flows of technology, proceeded much more rapidly in the post World War II era than earlier. Various scholars contrasted the educational systems in various countries, noting the longstanding weakness of British training of engineers compared with the German and American (Keith Pavitt, 1980). It was observed that the U.S., Canada, and Britain were marked by significantly more strike activity than Germany, Sweden, or Japan. During the 1970s, when productivity growth rates began to decline, scholars began to focus on changing institutional structures as a possible cause. The rise of regulatory environments was one such possibility (Denison, 1979; Paul MacAvoy, 1979, and Kendrick and Grossman, 1980). Other scholars focused on the institutions of the welfare state (Robert Bacon and Walter Eltis, 1976, and Assar Lindbeck, 1974).

One might consider that these lines of analysis are not inconsistent with the neoclassical growth accounting formulation, but are attempts to widen or deepen it. Still, the questions being asked, the variables being considered, and the relationships explored, are different from those out of which the standard model is built. At the least, their consideration poses the analytic problem somewhat differently. But it is also possible that the canonical neoclassical formulation not merely oversimplifies but obscures some of the central features of productivity growth. If so, it might be worthwhile to consider some significantly different theoretical formulations.

1.2 *Limitations and Tensions.* The main reason for entertaining more eclectic or even radically novel approaches to understanding productivity and productivity growth is that research within the orthodox framework is not answering certain questions adequately, and where answers are provided, these raise still further questions. This is so for each of the three roughly separable kinds of questions that have been explored. What lies behind a particular country's growth rate and its variation over time? What explains differences in levels and rates of change of productivity among countries? Why do certain industries experience much faster productivity growth than others?

The first kind of question probably has received the most attention. It is noteworthy, therefore, that despite all the effort to make the "residual" go away it still is very much with us: see e.g. Denison (1962, 1974, 1979). And despite all the effort to give substance to its interpretation as "technological advance," or "advance of knowledge," that interpretation is far from persuasive. Everybody knows that the residual accounts for a hodge-podge of factors, but these are difficult to sort out. If this "measure of our ignorance" is not completely mysterious, it certainly is not well understood.

If anything, the research attempting to explain cross-country differences in productivity levels, and in productivity growth rates, has been even less conclusive. Differences in capital-labor ratios, and in educational attainments, may explain a portion of the macro-productivity level differences, but a "residual" plays a large role in the cross-country analysis. Again, Denison's work (1967) is representative. Differences across countries in their post World War II productivity growth rates are not correlated with intercountry R&D spending differences. They are, however, strongly connected with two other variables—their initial productivity levels (or distance from the U.S. productivity level) and the rates of growth of their physical capital stock. As a general rule, countries that started with low productivity levels closed some of the gap, and the gap was closed faster by countries that had high investment rates. See e.g., John Stein and Allen Lee (1977), and Abramovitz (1979). But there are some nagging exceptions. The considerable difference in initial productivity levels itself is something which is not well explained by neoclassical growth theory. While the different experiences during World War II explain part of the U.S. productivity advantage in the 1950s, Maddison's data (1979) show that the U.S. was the productivity leader by 1913. Why? Britain's productivity growth record has been poor relative to other countries since World War I. Why?

The research on cross-industry differences in productivity growth focuses on a phenomenon repressed in the macroscopic models—that very significant interindustry differences in fact exist. R&D spending is an important explanatory variable in cross-industry analysis. For a review see Richard Nelson and Sidney Winter (1977). By and large the industries with rapid measured "technological advance" are heavy R&D spenders themselves, or their suppliers of inputs and capital equipment are heavy R&D spenders, or both. But how does one explain why certain industries are so much more R&D intensive than others?

As recounted above, scholars not bound by the details of the neoclassical perspective have put forth a somewhat richer one, and one which diverges from neoclassical assumptions in certain important respects. The remainder of this paper reviews and examines in more depth heterodox literature bearing on three different but related topics touched on in the earlier discussion.

The first is the nature of the variables affecting productivity at the level of the individual firm, and the sources of differences in productivity among firms. As suggested, there is a substantial body of literature which does not see a firm simply as a profit seeking "chooser" of inputs and technology operating within a framework of widely available technological knowledge, and known factor prices. Rather, it sees a firm as a "social system," which motivates its members in greater or lesser degree, and which influences how managerial decisions are carried out, and how alternatives are perceived and evaluated. Several studies of inter-firm productivity differences have found social systems related variables, as well as neoclassical ones, to be important. In addition, these studies document significant differences in technologies employed by different firms, differences not readily explained on neoclassical grounds. These topics are explored in Section II.

The second is the character of technological advance. Standard theory sees it either as an exogenous datum—a set of publicly available new opportunities that firms exploit, having regard to factor prices—or as the result of an accumulation of knowledge gained by investment in R&D guided by prospective returns. Uncertainty and the particular incentives provided by patent rights are ignored in most treatments of the connection between R&D and productivity growth. Research on the microeconomics of technological advance has, however, highlighted that the effort devoted to the discovery and exploitation of new technology is strongly influenced by uncertainty, and also is a function of the property rights that invention creates. Also, there is an interaction between exploitation of knowledge and learning itself. Government, universities and many other agents, beside user firms, play a part in technological advance. This literature is reviewed in Part III.

The third is the connections among and the factors behind the proximate sources of growth treated in growth accounting. It is apparent that these sources interact strongly. Capital accumulation and education support technological progress. At the same time, the returns to physical investment and increased education depend on technological progress. This suggests that, in deepening analysis of growth, we ought to consider not only forces that affect the proximate sources singularly, but also more general features of the economic environment and of political and social institutions that support all three sources and the growth they promote. We are, therefore, led to a concern with international differences and intertemporal changes in the economic environment and institutions—tentative forays into which are the subject of Section IV.

Some of the features stressed in the heterodox literature are easily incorporated in an extended neoclassical theory, others are most difficult to assimilate. However, while the heterodox view is more complex than the neoclassical one and differs in certain fundamental respects, it is amenable to its own simplifications and abstractions. To the extent that innovation involves considerable randomness, and to the degree that the processes that screen and select new technologies take time to work out, evolutionary models of productivity growth may be more appropriate than neoclassical ones. The essay concludes by sketching some recent attempts at evolutionary modeling.

II. *The Determinants of Productivity at the Level of the Firm*

Economists have not engaged in much empirical research on the determinants of productivity of individual firms. Interest in productivity differences among firms has been mostly focused on inter-country differences in industry averages. In part, this neglect is due to the fact that economists, generally, are interested in data aggregated at least to the level of an industry. In part it reflects that fact that, from the neoclassical perspective, there are few interesting empirical questions that can be explored or resolved by studying particular firms or by considering differences among individual firms in similar market conditions.

From the neoclassical perspective the productivity of a firm at any time is simply determined by available technology, and market conditions (primarily factor prices). There may be reason, however, to back off from the strong presumptions contained in this analysis. In the first place, large business firms are complex organizations. If this fact is recognized, certain difficulties with the simple neoclassical theory of productivity emerge. In the second place, the assumption that technological knowledge is public, to be obtained and exploited freely, which is implicit in this analysis, is suspect even as a simple first approximation; indeed, the presumption of public technological knowledge may preclude effective analysis of the processes by which new technologies are generated, screened, and spread. In this section I consider, first, some of the literature on the relationships between firm organization and productivity. I then turn to some of the studies of inter-firm productivity differences.

2.1 *The Firm as an Organization.* The neoclassical theory of the firm contains two strong presumptions. The first is that "technological knowledge" is the basic determinant of the input-output possibilities available to a firm. The second is that management "choice" among clearly defined options determines what a firm does. The implicit image is of a firm as a machine, with some human parts, with management controlling the action by making choices which are implemented through direct command, perhaps mediated by a tight hierarchical structure. These presumptions may be useful as first approximations, or they may not.

To begin with, recognize that most firms contain many people, and generally have a management group distinct from the individuals who actually carry out production. This calls attention to complications repressed in the neoclassical theory of production. One is the need for mechanism to coordinate action. Given division of labor, jobs must be compatibly designed and appropriately meshed. A network of information flow is needed so that the whole job gets done smoothly. This problem of organization would exist even if all individuals shared the goals of top management. But, in general, the employees of firms do not automatically share the same objectives as managers. So there is a requirement for motivation and monitoring. The literature on organization in its relation to productivity, mostly outside of economics, contains both these themes.

James March and Herbert Simon (1958) distinguish two broad lines of development of what they call "classical" organization theory. One, deriving from the work of F. W. Taylor (1911), is concerned with physical activities involved in production. Its hallmark is concern for "scientific management" which means, largely, the design of a particular task, the flow of material among stations, etc. A second, flowing from the work of L. H. Gulick and L. Urwick (1937), and Max Weber (1947), is focused on problems of organizational structure—on such questions as whether certain widely used services should be organized under one service department, or decentralized to the various using departments. Both traditions are concerned immediately with coordination (although in different ways), and also with motivation schemes. Thus Taylor wrote about incentive pay schemes. Weber discussed the advantages of career ladders. But both pictured the organization as a machine with human elements, and saw the management problem as one of designing a machine so that it worked well.

Something like this image of organization lies behind the standard theory of the firm. The human actors are classified as "labor," but consideration of problems of coordination and control is repressed. In certain more complex models, the organizational aspects of production may be admitted by recognizing that resources are involved in coordinating and controlling, in addition to those involved in "producing." The state of coordination and control "technology" may even be admitted as a variable, like production technology. But given these constraints, management is still viewed as *choosing* what is to be done. This characterization is in the spirit of the Jacob Marschak-Roy Radner theory of teams (1972) and is consistent with recent work on agency. See Steven Ross (1973).

But few contemporary scholars of organization now view behavior in organizations as did the classical organization theorists. The famous Hawthorne works experiment (F. Roethlisberger and W. Dickson, 1939) conducted nearly fifty years ago, led organization theorists to abandon the notion that an organization was like a "machine" that could be programmed and tightly controlled by top management, and to recognize explicitly that an organization is a social system which may be resistant or unresponsive to management commands. Scholars like George Homans (1950) and Charles Perrow (1979) have outlined such a view on organizational behavior.

Technology, in the sense of well-articulated blueprints, defines what is to be done only within broad limits; there is considerable room for variation in effort, attention, and cooperation. Careful "work design" can narrow the range, but not eliminate it. Similarly, management cannot effectively "choose" what is to be done in any detailed way, and has only broad control over what is done, and how well. Only a small portion of what people actually do on a job can be monitored in detail.

Given the perhaps considerable range of flexibility left by technology and managerial instructions and overview, the social system of work sets norms, enforces them, and resists pressures or commands from management that are inconsistent with those norms. The lower levels of representatives of management, such as foremen whose function is to monitor and discipline performance, are at least partially co-opted into the social system. Consistent with classical organization theory, certain ways of doing things and certain performance levels will be established and adhered to, but contrary to the teaching of classical theory, these will be influenced as much by the social structure as by management directions and pressures. On the other hand, these procedures and norms can be influenced by the sentiments and attitudes of the workers, and by the tone of the organization more generally. Management may have a good deal to do with what that tone is. How workers feel about their job, about their fellow workers, about management, and about the organization, may be more important in influencing productivity than is the particular way they are instructed to do their work, the formal organizational structure, or even financial incentives.

It is natural that, given this view of things, the variables stressed by Taylor and Gulick and their followers would appear to be relatively uninteresting and unpromising as management tools. Scholars of organization who accepted the new "social system" view looked in other directions. A number of different research traditions developed.

Chester Barnard (1938), and later Simon (1947), stressed that top management is limited in the number of things it can control or attend to in any detail, and explored the functions of management in a more constrained setting. Three broad functions were identified: to fix long-term firm strategies that provide guidance to lower level decision making; to establish a social context and incentive schemes so that lower-level decision makers act in the firm's interests; and to deal with exceptional cases and problems that cannot be handled routinely or delegated.

Other scholars—Christopher Argyris (1962) is an important example—concerned themselves with decision-making styles and procedures. The key questions they asked were whether better information was developed, whether better decisions were made, whether implementation was more effective, under participatory modes of decision making or in a hierarchical regime in which decisions are made at the top, with little participation from below.

Other traditions were concerned with worker morale and loyalty to the organization. One group of scholars focused on the fact that workers brought to their work feelings and problems from outside their jobs, and proposed that, by neglecting these, management caused alienation. Various forms of grievance procedures were studied to understand how these affected how workers felt about their jobs and how this, in turn, influenced their absentee rates, strike rates, and productivity. Other scholars studied the way the design of work influenced worker satisfaction and interest. Richard Hackman and Greg Oldham (1980) provide an excellent review of these lines of research.

This sample of questions explored by students of organization is not meant to be exhaustive. However, the questions are illustrative of the wide range of topics opened when a firm is recognized as having a social system, which influences how "technologies" in fact are operated, and how "managerial decisions" are translated into action.

It would be an impressive, and rewarding accomplishment if students of the human relations and social organization of firms were able to identify and document well-defined stable relations between variables under management control and the effectiveness of workers' performance. But my reading of the results of fifty years of research, one consistent with the evaluation of several review articles by scholars in these fields, is that few such stable relations have yet been found. See Hackman and Oldham (1980), and Victor Vroom (1976) for critical reviews. The newer research tradition has been persuasive, I believe, in casting doubt on the machine model of firm organization. But it has not been able as yet to identify and measure the key organizational variables and their influence.

In some experiments, greater worker participation in making decisions increases productivity, and in others it decreases productivity, and in others it doesn't matter. In some experiments, "job enrichment" makes workers more content and productive, in others more content but not more productive, and in still others less content but not less productive. It could be that such variables, omitted in the standard economic model, should simply be treated as introducing a random element. Or it could be that there are stable relations to be found but that these are more complicated than those who initially did the experiments contemplated. For example, the desire of workers to participate in decisions may depend on the extent to which the issues involved are viewed as scientific and technical, and not particularly relevant to their well-being, as contrasted with being germane to their well-being and within their ken (A. W.

Gouldner, 1954). Job enrichment may be preferred by workers if it doesn't involve working harder, but not if it does (R. B. Goldman, 1975).

It may be that the bearing of such considerations is more limited in some contexts than in others. Thus some technologies may impose rather tight control of the pace of work—for example, chemical process technology is embodied in equipment which to a considerable extent controls the flow of materials. In contrast, in many mechanical operations, technologies lend themselves to a degree of worker control (Joan Woodward, 1965). Some market environments are loose enough to permit slack performance; others are strongly competitive and force both management and labor to toe the mark (T. Lupton, 1963). Organization theorists are now coming to recognize these complexities. In any case, economists who have themselves neglected these kinds of questions bearing on productivity can hardly complain about the slow advance of knowledge regarding them.

In recent years a number of economists have begun to design models of firms where people reside as individuals, not as automatons. The behavioral theory of Richard Cyert and James March (1963) obviously fits this mold. So do the analyses of Oliver Williamson. Williamson (1970) has shown how the organization of a multi-product firm influences the decisions reached by management just below the top. He suggests that the multi-divisional form leads to better decisions (and higher productivity?) than the older unitary structure. More recently (1975), he has been concerned with the effect on profitability (productivity?) of a firm's decisions regarding what is to be done "inside" the firm and what is to be done through market arrangements. Harvey Leibenstein (1966, 1976, and 1979) has proceeded from the proposition that human beings do not automatically work their hardest, or think fruitfully about what they are doing (both of these themes are recognizable in Taylor). He has been particularly concerned with the role of competition and pressure on the firm to keep what he calls "X inefficiency" under control.

Peter Doeringer and Michael Piore (1971), and more recently Richard Freeman and James Medoff (1979) have drawn attention to the way internal labor markets shape the workings of intra-firm society, and to the role of the union (along with management) in defining internal labor markets and other aspects of the firm's internal society.

In the last few years, there has been increasing recognition among economists and other scholars, and lay persons, of the significant differences in organization and decision-making styles among firms in different countries. Thus, Ronald Dore (1973) has contrasted the structure of large post-World War II Japanese firms with that of British firms, noting significant differences in hiring policies, tenure provisions, decision-making style, and social characteristics. Spurred by Japan's continuing rapid growth, American scholars have recently turned to consider differences between American and Japanese firms. The aim seems to be to encourage American firms to move closer to the Japanese model: see e.g., Vogel (1979).

But the relations are complex and poorly understood. It is worth noting that Japanese productivity grew very rapidly prior to World War II, and that "lifetime employment," and the related cultural characteristics of modern Japanese firms, were not the norm prior to World War II, but are largely a development of the 1950s. It also might be recalled that, only a few years ago, scholars were touting the flexibility of the American system, the ability of scientists and engineers to set up small new firms, the movement of engineers from firm to firm, as the reason for our technological leadership in such fields as semiconductors (Charles River Associates, 1980).

2.2 *Intra-Industry Productivity Differences Among Firms.* As stated above, the interest of economists in productivity differences among firms (in the same industry) has mostly been focused on international differences, and most of the empirical research has been concerned with data at the industry level. However, there has been some research based on data for individual firms. Some of this research has compared firms in different countries, some has compared firms in the same country. Not surprisingly, the international comparisons show considerable differences in productivity. It may be more surprising that there is considerable variation in productivity among firms in the same industry in the same country.

Neoclassical theory would explain international productivity differences by differences in factor intensities associated with dissimilar factor prices, and might admit, as well, possible capital vintage effects. Intra-national differences would have to be explained largely in terms of vintages, although local variations in market conditions also might play a role. While the firm by firm comparisons do generally show these variables to be significant, studies suggest that differences in internal organization are also important, and knowledge about and access to technologies as well.

Of the studies of differences in productivity levels of firms in different countries, a sizeable fraction has been concerned with the low productivity of British firms relative to firms in other countries. There have been two waves of such studies: one, just after World War II, focused on United Kingdom and United States comparisons; the second more recent one, concerned with Britain's lagging productivity relative to Europe as well as the United States.

Rostas' study (1948) is perhaps the best known of the earlier wave. Written prior to the theoretical developments that came to dominate economic thinking about productivity (and growth) after the 1950s, Rostas' examination of the factors behind measured productivity differences is relatively undisciplined theoretically, but is pragmatic, sensible, and sensitive. He identifies the variables that later come to dominate thinking—differences in capital intensity (which he measures by horse power) and in the quality and vintage of the equipment employed. Perhaps because American plants are so much larger than British plants in most industries, Rostas is concerned with possible scale economies, and with the relationship between the ability to exploit scale economies and the size of the market. But he also considers Taylor-like variables such as the layout of work in the factory and the general quality of management. Rostas also lists a variable which increasingly came to attract attention in studies trying to explain the low productivity of plants in Britain—the attitudes and work practices of labor.

C. F. Pratten's studies are representative of the second wave. In one (1976*a*) he compared plants of the same international company producing similar products, but in different countries, and observed that there was a general rank order, invariant with respect to industry, of output per worker in the different plants. American plants were at the top, mostly followed by German plants; French and British plants were toward the middle, and Spanish plants last. His quest was for the reasons behind the relatively poor performance of the British plants.

When managers of the companies were asked for their explanation of the differences, they sometimes said that their more productive plants had better (newer?) machines than British plants. But they said as well that the British plants were "overmanned." This overmanning extended to both overhead activities, like office work, and to physical production lines. The managers attributed this in part to restrictive union practices and in part to a combination of general union pressure and lack of effective management response. Several respondents remarked on the greater difficulty in getting British labor to accept changes proposed by management, compared with the situation in American or Germany.

In a companion study, Pratten (1976*b*) examined differences in output per worker in Swedish plants and closely matched British plants. This study also showed systematic country differences. Swedish plants had higher output per worker in virtually every industry where a paired plant comparison was made. The reasons put forth by Pratten include greater mechanization in Sweden, better labor relations, and more technically sophisticated management.

D. T. Jones and S. J. Prais (1978), in their study of productivity differences among U.S., German, and U.K. auto plants, come up with a similar list of factors. The authors emphasize overmanning in British plants. They also report more "downtime" due to machine breakdown plus union-imposed constraints on repair manning, work slowdowns, and strikes. The authors stress as well that British plants tend to be smaller and to have shorter production runs than West German or American plants, and that this is costly in terms of productivity. They propose that the small size of the British plant is not unrelated to the variables mentioned above. Labor-management relations tend to be worse in a variety of dimensions in larger British plants than in the smaller ones, job slowdowns are more common and more difficult to deal with, strikes occur more often, etc. Jones and Prais suggest that these troubles make British managers loath to set up large plants.

Several of the studies discussed above mention that technology in British firms was not as "up-to-date" as in American or Swedish firms. There are various possible reasons. One is quite compatible with the neoclassical formulation. If technological knowledge were public and new capital always embodied the best available new technology, then newer plants would be inherently advantaged relative to older plants. These are the assumptions built into "vintage" models such as those by W. E. G. Salter (1966), Solow, Tobin, C. Von Weizacker, and M. Yaari (1966), and L. Johansen (1972). In some of the comparisons it appears that machinery in the British firm was older than that in its foreign counterpart. But technological knowledge is not completely public. Some is proprietary. Even where not proprietary, information about new technology is not costless to acquire and may require considerable sophistication, and luck, to evaluate properly. More, the technology chosen by a firm in many cases is not determined by management preference alone. The choice may be constrained by legal restrictions to buy from nationals or by other forms of governmental influence. In many cases, technological change is the subject of labor-management bargaining.

The case studies of British industry, contained in the recent volume edited by Pavitt (1980), indicate that the technological backwardness of British industry has less to do with the age of British machinery, than with the low level of technological training of British management and the lack of strong organized R&D in many British firms. This conclusion is consistent with that reached two decades earlier by Carter and Williams (1957).

Studies of productivity differences among firms in different countries often seem written as if firms in the same country had roughly similar productivity levels. However, there are now a number of studies that reveal much intra-country variation.

For more than a half century the U.S. Bureau of Labor Statistics (BLS) has been engaged sporadically in studies of productivity differences among U.S. firms. During the 1920s and 1930s, studies of industries, ranging from garments (1939) to automobile tires (1933), from shoe-making (1923) to blast-furnaces (1929) were made. While these differed slightly in format, invariably they contained the following elements. The overall production processes of the industry were broken down into a large number of detailed sub-processes, and "best practice" was identified. Evolution of best practice over time was described and changes in labor productivity using "best practice" tabulated. In general, the BLS studies also presented data on productivity levels of firms not using best practice. There was considerable dispersion at any time, and a large gap between average practice and best practice. Quite often a number of firms operated at productivity levels less than half of best practice.

Not all the studies attempted to explain this variation, but a number did. Many of the variables mentioned are the same as in the studies focused on international differences—differences in degree of mechanization, vintage of the equipment and technologies employed, differences in the layout of work. Differences in labor-management relations were not mentioned.

By contrast, Freeman and Medoff and their colleagues have recently considered the effect of unionization on productivity in several American industries (1979). Unionization would appear to be a variable different in kind from those conventionally treated by economists, and the exploration of its effect amounts to an hypothesis that internal organization matters. The authors consider whether a firm is unionized or not as a dichotomous variable in a regression that also contains a firm's capital-labor ratio and other more conventional factors. They interpret their regressions as showing that unionized firms are more productive than non-unionized firms in the furniture and cement industries, but less productive in the underground bituminous coal industry. They identify the cases where unionization increases productivity with situations where there is room for a mutually advantageous deal between management and labor and where the presence of a union facilitates the making of that deal. They identify the negative cases with situations where the conflict is more basic and unionization simply strengthens labor's hand. The questions raised by Freeman and Medoff are important, even if the answers presently put forth are not particularly compelling.

Salter's study (1966) is one of the few that explicitly recognizes the productivity dispersion revealed by the BLS data. He focuses on differences in technology associated with different ages of plants. Lars Wohlin (1970) analyzed productivity dispersion and productivity growth in the Swedish pulp and paper industry, using Salter's model. Since the main interest of both authors was in productivity growth in the industry as a whole, not inter-firm productivity differences *per se*, neither author tested to see the extent to which vintage differences explain productivity differences. Griliches and Vidar Ringstadt (1971) attempted to explain differences in productivity among Norwegian firms on the basis of (regional) factor price differences (they did not consider vintage differences). Not much of the productivity dispersion was so explained.

Neoclassical models of course ignore organizational variation of the sort considered by Freeman and Medoff. As stated above, they ignore as well differences among firms in access to and knowledge about new technologies, and the complex values and processes often involved in making decisions about what technologies to adopt. While intra-country differences regarding technological access and choice might be expected to be smaller than inter-country differences, they still might be considerable. The only direct test, that I know about, of the extent to which new capital systematically embodies better technology than older capital is by R. G. Gregory and Denis W. James (1973). They found that, in Australian industry, firms with new capital on average did have higher productivity than firms with older capital. There was considerable productivity variation, however, among firms with new capital.

2.3 *What Explains Productivity Differentials?* While augmentation of the production function framework to recognize capital of different vintages has brought within the compass of neoclassical theory a significant portion of the factors behind productivity differences among firms, there certainly is more to the story. Cross firm variation in productivity at any moment of time is an interesting phenomenon in itself. But is there any reason why such variation ought to be recognized in analysis of productivity growth, at an industry level, over time? I think the answer is yes, and for two reasons. First, to the extent that firm structures and decision-making style are important variables influencing productivity, this fact in itself cautions against thinking of the determinants of labor productivity simply in terms of the quantity of complementary inputs, and technology. A richer set of variables is involved. These variables may, and likely do, influence productivity in the average firm, as well as the extent of inter-firm dispersion. While some of the added set may reasonably be treated as constant, others may not. Second, to the extent that differences across firms reflect differences in the technological bets they have made, or differences in access to certain technologies, this fact may reflect important aspects of the process of technological advance. Since virtually all scholars now agree on the central role of technological advance and productivity growth, it clearly is important to have an adequate conceptualization of the way the technological advance occurs and of what determines its rate.

2.3.1 *Organizational Aspects.* It is clear that variables relating to the differences in individual or organization capabilities enter prominently in many of the above-mentioned studies. The two such variables most often cited are the character of labor-management relations, and the skills of management. Were this survey widened to include comparisons of firms in developed and less developed countries, worker skills and experience would also show up as important variables. See R. Nelson, P. Schultz, and R. Slighton (1971). While in principle the production function framework can be stretched to count any input that is differentiated from another in any way as a different input, differences in skills and organizational effectiveness would appear to have a different logical standing than, say, differences in the amount of machinery of a given type. They can be best interpreted in terms of what is accomplished by given inputs with a given "technique," not in terms of different quantities of inputs employed in that technique.

While not absent within a country, differences in labor-management relations, and managerial and worker skills enter most prominently in the comparison between firms in different countries. One is tempted to argue that relatively systematic and durable national differences in institutions and general socio-economic climate lie behind these differences. The studies of British productivity certainly are consistent with the proposition that fractious labor-management relations, and management deficiencies in technical training, have been the rule, not the exception, in Britain for a long time. On the former, see Caves (1980); on the latter, C. F. Carter and B. R. Williams (1957) and Pavitt (1980). These variables certainly need to be considered in analyzing productivity differences. To the extent that they influence innovativeness, they may also be important for understanding productivity growth rates. This, of course, raises the question of how durable these characteristics are. At least some scholars who have pointed to these variables have done so with the hope that, if their costs were better comprehended, they might be changed. I return to the question of institutional change in Section IV.

2.3.2 *Technological Competence.* While vintage models do capture certain features of the processes of technological advance, they repress others. Vintage models assume that, in their decisions regarding new technologies, all firms face and know about the same set of alternatives. Differences in choice then reflect differences in factor prices and other market conditions. The proprietary nature of many new technologies, and the time and cost involved in learning about them and in learning to use them, are assumed away.

Accept the proposition built into vintage models that today's distribution of productivity levels among firms is in part at least the cross-sectional consequences of technological advance, where today's best new technology is not adopted instantly and completely by everybody. But change (or augment) somewhat the assumptions of the vintage model to admit that some firms today are not aware of, make wrong bets about, and maybe even are blocked off from access to today's new technology. Recognize that, if innovation is at all risky or costly (because of R&D or other resources involved) it is imitation lag that yields the return to the innovator. If all firms were fully informed about and had full access to new technology created by one firm in an industry, that firm would have far less incentive to develop and introduce new products or processes.

Then today's cross-sectional dispersion, its width and its expected durability, should be recognized as an essential element of the productivity growth process, even if there were no strict "embodiment" requirement. One would not expect that all firms would be on the same production function, vintage effects included or not. Some of the variation, not explained by orthodox variables, could be treated as random noise. But part surely reflects that some firms have systematically gained a head start over their competitors. The internal organization, or the R&D spending, of a firm might then be systematically related to its average technological lead, or lag, compared with the pack. This part of the variation surely should not be treated as random noise. It is what drives the growth process. I turn now to survey some literature on the process of technological advance.

III. *The Dynamics of Technological Advance*

Virtually all scholars of productivity growth now agree on the central role of technological advance. Over the past two decades, a considerable amount of research has been done on the processes involved. Much of that work has been within the intellectual framework provided by neoclassical growth theory, but some has proceeded along other lines. These alternative lines of research have revealed some serious difficulties with the treatment of technological advance within the orthodox framework.

The neoclassical model oversimplifies the connections between an industry's R&D spending and technological advance, and its implicit view of the links between market conditions and profit opportunities for R&D spending contains an internal contradiction. The model also oversimplifies the way that new technology is spread throughout an economic sector. Inter-sectoral and inter-industry differences, which are considerable and important, are repressed. I consider these topics in turn.

3.1 *The Generation of New Technology.* As recounted in Section I, the neoclassical formulation has progressed from treating technological advance as an unexplained residual, to consideration of technological advance as the result of an accumulating R&D capital stock. In turn, R&D investments by firms have been treated as subject to the same profit maximizing calculations as other investments. Most such models relate profit opportunities for R&D investments directly to the market conditions facing an industry, in particular to product demand (price or quantity) and factor prices.

This model of R&D and technological advance is consistent with certain observations. In cross-industry analysis, differences in R&D spending by industries and their suppliers are associated with differences in measured rates of technological advance, in the manner that the model would lead one to expect. There are a large number of studies showing that R&D funding, and patenting, are sensitive to economic variables that plausibly influence the profitability of R&D. Schmookler (1966) and others, have accumulated a great deal of evidence that shifts in the pattern of demand for goods and services lead to parallel shifts in inventing. The predictions of induced innovation models regarding the effects of changes in factor input conditions on inventing are, by and large, borne out. See Binswanger and Ruttan (1978).

There are, however, four aspects of the processes by which new technology is generated that are repressed or ignored in these models. (1) There is considerable uncertainty involved. (2) There usually are multiple undertakers of R&D. (3) When R&D is done competitively, the regime of property rights in technologies significantly influences, and warps, R&D incentives. (4) In many technologies, learning by doing is an important complement, or substitute, for R&D.

(1) Virtually all case studies of R&D aiming to create a technology significantly different from established practice reveal considerable uncertainly at the start of the endeavor. For a discussion of some of the implications, see Burton Klein, (1962). Firms are unsure how much expense and time will be needed to achieve a satisfactory new design; they do not know the exact form that design will take, or how the technology will perform. In recent years, some investigators have attempted to quantify these uncertainties by measuring the accuracy of forecasts of R&D costs and time required to complete a project (Mansfield, 1968, 1971, 1977). But these studies do not focus on perhaps the most significant form of R&D uncertainty—uncertainty about which of a vast set of potential designs or solutions will prove the best. Uncertainty may be the wrong word. Humans engaged in inventive efforts simply do not, and in the nature of the case cannot, comprehend the set of alternatives that they face. The set is fundamentally vague. This is an essential feature of R&D and technological advance. Any model that attempts to relate productivity growth to past R&D, or to predict how R&D allocation will shift as a result of changed market conditions, ought to recognize that the generation and selection of ideas for investigation involves a major element of chance. This random element in the execution of individual projects by single firms takes on special significance in a context of multiple R&D decision makers.

(2) In general, a large number of independent R&D decision-making units are involved in exploring opportunities for technological advance in an industry. The number may include firms in the industry in question, other firms that supply materials and capital equipment, users of products, private inventors, potential entrants to the industry, sometimes governmental laboratories and universities. This pluralistic R&D system generates a portfolio of projects. Generally, there will be some duplication or near duplication within that portfolio but also considerable diversity.

This diversity is socially valuable. The batting average of scientists and engineers, economists, government officials, and businessmen in predicting the most important future technological developments has been abysmal. Experts very often are wrong both in what they predict will happen, and in what they predict won't happen. It is fortunate that there are many different experts who lay their bets in different ways. But the diversity also means that there will be winners and losers in the R&D game.

(3) In an optimal portfolio there will be individual winners and losers. There is no reason to believe, however, that the pluralistic portfolio is likely to be optimal or even efficient, either in terms of maximizing expected industry profits, or social welfare. In many sectors, pluralism is associated with competition among profit-seeking business firms. In such a setting, the R&D that is profitable, and unprofitable, is strongly influenced by the existing regime of property rights. There are several different kinds of "market failure" associated with an industry structure, involving a number of competing firms, each doing R&D, in which the firm that achieves an invention first receives a patent that prevents direct copying (Nelson, 1980).

First, there is a simple positive externality problem. If patents prevent direct copying, but there is a "neigborhood" illuminated by an invention that is not foreclosed to other firms by patents, some of the returns to innovation leak away. Second, there are a set of problems akin to those occurring when there are multiple independent tappers of an "oil field." If patents are strong and wide a competitive race to get there first, may waste R&D inputs. And, given that one firm gets there first, there are incentives for another firm to develop a substitute technology even if it is worse than the best one, provided it is better than the one it has and the best is blocked by patents. The imitation threat deters R&D spending. The competition race and blocking problem may spur R&D spending, but toward socially inefficient allocations.

The unlikelihood of social optimality of course carries implications, if subtle ones, regarding government R&D policy. But it carries predictive modeling implications as well. While it may generate relationships that square qualitatively with some empirical evidence, a model which assumes that industry R&D is determined so as to maximize industry (expected) profit, or social (expected) value, is fundamentally mis-specified.

(4) In many industries learning-by-doing, or by using, is an important part of the process by which new technology gets created, modified, and broken in. Learning-by-doing is in part a substitute for, and in part a complement to, learning through R&D, and is the source of certain important phenomena repressed in the orthodox formulation.

The learning-by-doing aspects of a technology tend to be difficult to articulate in a manner that can be "transferred" easily. Thus, even in a non-proprietary context, there is a certain "privateness" to technological knowledge. Where such tacit knowledge is important, one firm can learn from another, but such technology transfer usually involves personnel exchange, example setting and teaching. See W. H. Gruber and D. G. Marquis (1969); G. R. Hall and R. E. Johnson (1970), and David Teece (1976, 1977). The costs and time involved can be considerable.

Industries and technologies apparently differ significantly in the importance of learning by doing (or operating experience more generally) and, relatedly, in the limits of what can be learned in distinct deliberate R&D activity. In some technologies, deliberate R&D is very important—pharmaceuticals, aircraft, and electronics are good examples of industries where R&D, as a specialized activity separate from production, is very powerful. In some activities, it would appear that very little can be done in R&D that goes beyond learning-by-doing or using—violin making and education are cases in point. It is noteworthy that technological advance—both as measured by growth theorists and as recounted by historians and technologists—has been much more rapid where R&D is effective than where learning-by-doing is dominant. This is one reason for the correlation between an industry's R&D spending and its technological progress. But, it is a reason that does not imply that more R&D would significantly increase productivity growth in industries where, presently, such growth is slow. In some of these, at least, R&D is low because it is not particularly fruitful.

Why might this be? A number of scholars have pointed to the great difference in strength of the underlying sciences or of engineering in the former technologies as contrasted with the latter (Rosenberg, 1976). An inference might be drawn that a reasonably strong science or engineering base is required to make separate R&D—staffed by people with special training—more fruitful than the simple natural experimentation and learning that occurs in the course of production itself. The issues here are important and clearly in need of further exploration.

Even where R&D is an important source of technological progress, there appears often to be strong interaction between learning through experience, and through R&D. Learning curves, reflecting reductions in unit production cost as experience accumulates, are steep in the production of aircraft and semi-conductors. See Harold Asher (1956) and Charles River Associates (1980). This partly reflects growing practical experience that leads to smoother, better coordinated action on the part of labor, better management understanding, and more effective work design and job layout. But part involves experience feeding back to generate redesign of certain aspects of product and process. The study by Samuel Hollander (1965) of productivity growth in DuPonts' rayon plants, and by Carl Dahlman (1979) of a new Brazilian steel plant, show intricate connections between learning by doing and R&D. Eric Von Hippel (1976) and Nathan Rosenberg (1980) have pointed to the role of user learning and feedback to R&D in the evolution of certain products.

R&D itself is an activity that involves learning through experience. Thus, in many industries, technological advance is characterized by an occasional major technological breakthrough involving a significant change in operating principles, followed by a series of improvements and variegations. These follow-on advances may, in cumulative impact, be as important as the original breakthrough. John Enos (1962) has described this phenomenon for petroleum technologies, Ronald Miller and David Sawers (1968) for aircraft, and Devendra Sahal (1981) for tractors and other items of mechanical machinery.

In these cases, it makes sense to think of accumulating "knowledge capital." The knowledge capital builds up within a particular technological regime, and becomes obsolete when a radically new technology is introduced and comes to dominate. But the variables and relations involved are not well pictured by the simple neoclassical formulation.

3.2 *The Screening and Spread of Technology.* In the original neoclassical formulation, new technology instantly diffuses across total capital. In the later vintage formulation, technology is associated with the capital that embodies it and thus adoption of a new technique is limited by the rate of investment. But in this latter formulation, as in the original one, uncertainty and the proprietary nature of some new technologies are repressed. Once uncertainty is recognized, the trial in actual practice of new technology can be seen as an extension of the research and development process, another stage in the progressive winnowing and refining of ideas spawned by dreamers and inventors. Somewhat peculiarly, however, almost all research on the screening and spreading of new technology has been concerned with new technology that turned out to be productive. The mistakes and aborts, of which there are plenty, have been neglected.

These are two conceptually distinct kinds of mechanisms by which the use of a profitable new technology is spread. One is the diffusion of a new technology from firm to firm. The other is the growth of firms that use a superior technology relative to those that do not. The relative weights on these different mechanisms differ from sector to sector, and from technology to technology.

There is a large literature on the diffusion of (generally non-proprietary) new technology among potential users. Among economists, Griliches' work on the diffusion of hybrid corn was pathbreaking (1957). Mansfield has conducted extensive studies of diffusion of new technology in industry (1968, 1971, 1977). Scholars from other disciplines also have studied diffusion. Griliches' work on hybrid corn followed on a longstanding tradition of research on diffusion by rural sociologists. See, for example, Ryan and Gross (1943). The sociologists Coleman, Katz, and Menzel were early students of diffusion of new practice among physicians (1957).

More recent research has amply confirmed a central result of these early studies. When a technology is new, there is considerable uncertainty among potential users as to its merits. There is some disagreement among economists about the sophistication of users' judgements. Contrast Griliches (1957), who assumes that farmers in general judge competently the merits of hybrid corn, with Ray (1974), who reports that the calculations made by firms often are quite haphazard or arbitrary. But it is clear enough that firms (managers) differ in the speed with which they evaluate new options, the judgements they arrive at, and even the range of options of which they are aware.

Information about a new technology grows as more firms employ it and as their experience accumulates. Firms may rationally decide to delay adoption of a new technique until they have information about the experiences of other firms. Several scholars have noted that, under such conditions, a "contagion" model might apply to diffusion. See e.g., Griliches and Mansfield, above. Such a model, even were there no requirement for new capital to embody new technology at any time, would lead one to expect a significant gap between average and best practice of the sort we have observed in the preceding section. Further, there is no guarantee that new capital will embody the best new technology. See Gregory and James (1973).

In most of the diffusion studies, the source of the new technology lies outside the industry or sector where its use is spreading. Thus, hybrid corn was developed by government laboratories and seed companies, not farmers. Mansfield's studies were of the spread of new equipment, produced by a supplying firm, among using firms. The mechanism for spread of an innovation clearly is different when one of the firms in the industry is itself the source of the innovation. In such a setting, the innovative firm may have incentive to restrict its use by other firms.

When innovative firms are able to expand their capacity and market share at the expense of their rivals, this competitive mechanism, rather than (or along with) diffusion may be a principal one by which a new technology comes to replace an older one. Indeed, the ability to shield a new technology from one's rivals (at least temporarily) and to expand one's market share, provide strong incentive for a firm to undertake research and development. The extension of use of a new technology so developed tends to involve the growth of the capital and market share of the innovating firm. There have been only a few studies explicitly concerned with the relation between a firm's innovative successes, and its growth or decline. One is by Mansfield (1968). He found that innovating firms do, in fact, tend to grow more rapidly than the laggers. Almarin Phillips, studying innovation in the civil aircraft industry, also found that the market share of an innovating firm tended to grow rapidly (1971). Studies of competition in the pharmaceutical industry (David Schwartzman, 1976) and in the semi-conductor industry (Charles River Associates, 1980) show that the market share of different companies is closely connected to their innovative successes.

Even in industries where an innovating firm can significantly expand its market share at the expense of its rivals, diffusion also plays a role in the spread of new technologies. In the first place, innovating firms are seldom able to shield their technologies from their rivals completely, at least not for very long. Patented innovations can be copied, or the protected process by-passed by some substitute. A study by Mansfield *et al.* (1980) shows that these costs may be considerable, but not insuperable. In the second place, capital goods and material suppliers often are important sources of new technologies, and these sources have an interest, not in the restriction of their new technologies, but in their rapid spread among the potential users in the industry.

Diffusion is the dominant mechanism for the spread of a new technology in sectors where the firms are small compared with the market as a whole and where for a variety of reasons, they are unable to expand their market shares rapidly. Farming is the archtypical example. Residential construction, and many service industries, are other examples. Physicians' services fit this mold. Many public sector activities have this characteristic; education, firefighting, and refuse collecting are examples. In such activities, firms are not rivals, and there are no strong disincentives to sharing technological knowledge. In these circumstances a network of information exchange about technology develops. Journals that publicize relevant information appear. Professional societies and conferences play important roles in disseminating information, and managers consult with their fellows.

These also are industries and activities where firms have little or no incentive to engage in R&D on their own. These sectors, therefore, are dependent for their technology upon suppliers, upon cooperative R&D mechanisms, or upon government financed R&D. Thus, while doctors and non-teaching hospitals rarely do R&D on their own account, pharmaceutical companies do and the government supports significant medical R&D largely through the medical schools. Farmers do not engage in research but seed and equipment suppliers do, and the government funds agricultural R&D at the land grant colleges.

I have written as if the spread of a new technology, and its development, were separate processes; in many cases they interact strongly. As stated, one reason why potential users wait before adopting is lack of adequate information to form a judgement. As use spreads, information feeds back not only to potential users, but to the designers of the product and their competitors. The learning phenomena described in the preceding section proceed along with diffusion, the product is redesigned to improve its performance, and production costs drop. Some potential users may choose to wait for the second or third generation of a new technology to appear before the plunge. As the product improves, and versions better suited for particular classes of users appear, more and more potential users find it profitable to adopt. See Paul David, (1975). Then a significantly different, new design may come along. The product cycle begins again.

3.3 *Differences Among Sectors.* The discussion above has identified important structural differences among economic sectors which determine who does the R&D, the relative roles of R&D and learning by experience, and the mechanisms by which new technology is carried into widespread use. The system that generates and spreads new technology in agriculture differs from the system in pharmaceuticals. The aircraft industry is not the same as firefighting. For some industries, Schumpeterian competition would appear to be a good model: for others, cooperation.

It would be interesting if one could associate certain industry characteristics with rapid technical change and productivity growth, and others with slow technical change and productivity growth. But the causal connections would not appear to be simple.

The progressive industries are all characterized by significant R&D activity either by firms in the industry, by supplying firms, or by government funded programs. In technically progressive industries marked by oligopolistic competition, firms in the industry generally are major sources of innovation. In technically progressive atomistic industries, technological progress is dependent upon the work of outsiders. But it remains something of a puzzle as to why certain oligopolistic industries are actively engaged in R&D and others not, and why government has developed programs of R&D support for some industries but not for others. One reason why R&D has not become an established feature in some industries may be that the scientific and engineering basis of a technology is weak and R&D is not productive. Another reason may be that the policies and institutions that support R&D have not formed.

An extensive literature has developed about the structural conditions needed for an industry to support considerable R&D, and to conduct it efficiently. See Nelson, Peck and Kalachek (1967) and Morten Kamien and Nancy Schwartz (1975). Much of the analysis has been concerned with the Schumpeterian hypothesis that, in general, relatively concentrated oligopolies generate more technological progress than less concentrated industries. It now is apparent that this hypothesis is too simple and, as stated, not generally valid. Particularly in new industries, or in industries where the existing technology is relatively new, small firms and often new entrants are important sources of new technology. See John Jewkes, David Sawers, and Richard Stillerman (1969) and Charles River Associates (1980). In such a context, small scale R&D is often productive. The ability of a new firm to enter the industry and to grow then may be vital to rapid innovation. As a technology matures, experience begins to count more and the effort needed to make further improvements often becomes more expensive. See Dennis Mueller and John Tilton (1970), and William Abernathy (1978). Entry becomes more difficult. Large size becomes a requirement for the support of efficient R&D.

But even where the structure of an industry is appropriate to support the relevant kind of R&D, successful innovation is far from an automatic result. The risks that surround R&D, and the uncertainty about the appropriability of results, mean that it may not be at all obvious to a firm whether it is more profitable to try to forge ahead or merely to try to stay abreast of the technological developments of competitors. If all firms make conservative judgments, an industry may be marked by very little R&D. Even where R&D is potentially fruitful, a firm which decides to innovate may be a failure if new markets are hard to crack, or if imitation is relatively easy. Even where innovation pays, the market positions of established firms may be relatively sheltered and it may take a long time before it becomes clear that the nature of competition in the industry has changed, and that the requirements of economic success and viability have been modified. This appears to be the case in several industries where British firms have been slow to realize, or act upon the realization, that a strong R&D effort now is essential for survival. See Pavitt (1980). Hayes and Abernathy (1980) believe that, during the 1970s, in many industries American management shortened their time horizons and cut back on innovative R&D. They suggest that this is one reason why the American technological lead over Germany and Japan has eroded. It may take time for this managerial mistake (if it is one) to be recognized widely and remedied. The efficacy of governmental R&D support programs is difficult to assess *ex ante*, or even after considerable experience has accumulated. Nor are the conditions for political support of government R&D programs well understood. While there are several good histories of the evolution of government support for basic science (see e.g. Price, 1954) no good history of governmental industry R&D assistance exists.

Thus, for analysis of the determinants of industry R&D spending, just as for analysis of the determinants of the kinds of inventions that will be made, the presumption that profitability shapes outcomes takes us one step forward. But there are many other considerations that influence R&D spending, and only a few of these are well understood. There are probably significant elements of historical chance that are unlikely to be reduced to pre-determined events even within a sophisticated analysis. Over time, economic forces stimulate and guide the evolution of particular technologies. Similarly, over time economic competition molds the evolution of private and public R&D policies and institutions. But economic forces here are unlikely to be sharply defining in the short run, and considerable time may elapse before they bring about major changes.

This suggests the importance of the general economic climate of a country and its institutions, which broadly support, or hinder, innovative activity, and other sources of productivity growth. I turn now to this topic.

IV. *The Sources of Growth Reconsidered*

In growth accounting a number of different sources of growth are identified and their contributions estimated separately. It is well recognized that such an explanation of growth has limited causal depth. The analysis can be deepened by exploring the factors determining the magnitude and character of the various sources of growth—e.g., the investment rate—and their variation over time and across nations.

But the intellectual route that proceeds most naturally from the growth accounting starting place is not the only one for gaining deeper understanding. It is apparent that the sources of growth are strongly interdependent. In addition to deepening the analysis by looking for variables that impinge on each of the sources of growth, one might also try to discern broad factors or conditions that foster or hinder a generally stimulating growth environment. Intellectual exploration along this route leads naturally to consideration of macroeconomic conditions and economic institutions as the basic factors molding economic growth, and to examination of institutional inertia and institutional change.

4.1 *The Attribution Problem*

4.1.1 *The Adding Up Problem.* Economists like to take derivatives and to analyse the effect of small changes. The instinct is particularly strong when the focus is on the contribution of different factors of production to output. But when the changes in question are large, marginal analysis may be misleading.

Thus, factor prices measure the contribution to output of a factor at the margin. However, growth accounting usually has been concerned with changes over a considerable interval of time. The fact that the yearly percentage increases in labor, capital, and gross national product are typically quite small should not obscure the fact that, even over a period as short as a decade, the percentage changes are substantial. If there is any curvature to isoquants, the marginal productivity of any factor toward the end of a decade is influenced by the relative growths of the different factors over the decade. This is a well known difficulty with analyses of growth based on a factor-price weighted input index.

The growth accounting procedure implicit in Solow's analysis seems to get around the problem. Factor shares are employed to estimate output elasticities rather than factor prices to estimate marginal products, and input and output indexes are defined logarithmically. Even though the marginal productivity of a factor may fall as it increases relative to other factors along a production function, its share need not. In the special case of a Cobb-Douglas production function, shares are invariant to factor proportions. Aside from the Cobb-Douglas case, factor shares are not invariant to factor proportions and will change over finite time if factors grow at different rates. The Divisia index, in which for each period the then obtaining factor shares are used as weights for a logarithmic input index, has been proposed to cope with the possible empirical problems. See e.g., M. Richter (1966). In fact, this is what Solow employed in his 1957 formulation. But while the Solow proposal recognizes curvature, it doesn't obviate the implications of curvature. If factors are complements, growth is super-additive in the sense that the increase in output from growth of inputs is greater than the sum of the increases in output attributable to input growth, calculated one by one, holding other inputs constant at their base level in each sub-calculation. The growth of one input augments the marginal contribution of others. Where complementarity is important, it makes little sense to try to divide up the credit for growth, treating the factors as if they were not complements. See Nelson (1973).

The problem here is the same one that bothered economists at the turn of the century as some tried to extend the evolving marginal productivity theory of factor remuneration to a discussion of "just shares" in the sense of some sort of "average" contribution. One can analyze the contribution to output of a worker, or a machine, at the margin. It does not make sense, however, to try to calculate the contribution to output of all of labor, or all the machines. Or, to take another example, consider the sources of a well made cake. It is possible to list a number of inputs—flour, sugar, milk, etc. It is even possible to analyze the effects upon the cake of having a little bit more or less of one ingredient, holding the other ingredients constant. But it makes no sense to try dividing up the credit for a good cake to various inputs.

It may be fruitful to consider the several sources of growth as being like the inputs to a cake. All are needed. There are two evident kinds of interaction among the three "sources" that have dominated most analyses of productivity growth—technological advance, capital growth, and rising educational attainments. First, they appear to be complementary, in the sense that increase of any one raises the marginal contributions of the others. Second, because of this, forces that lead to the augmentation of any one are likely to stimulate an increase in the others.

4.1.2 *Growth Fueled by Technological Advance.* In a context of strong interaction among factors, if analysis is to proceed it is necessary to focus on the key processes involved and try to see the role of the various factors in these processes. It is useful, I think, to view technological advance as the central driving force. I propose, also, that reallocation of resources ought to be seen as a key process in productivity growth which governs the pace at which potentialities opened by new technology can be exploited. In part, resource reallocation simply reflects differences in income elasticities of demand among products. But it reflects, even more than this, the fact that technological advance destroys the economic viability of certain industries, firms, and jobs, as it creates new ones. Within this context of growth driven by technological advance, and involving significant resource reallocation, capital and education play key supporting roles.

In the simplest of the neoclassical models, new physical capital is treated like any other factor of production; its augmentation relative to labor increases labor productivity according to the logic of linear homogeneous production functions. Within vintage models, and in the view expressed here, a more important role of new capital is as a carrier of new technology. Carrying the logic of interaction farther, to the extent that new capital carries new technology, new investment ought to increase the returns to and stimulate R&D spending. New capital-embodying technologies just out of the R&D laboratory also would appear to be the locus of much learning-by-doing, and using, which in turn feeds back to stimulate more R&D (Rosenberg, 1980). Investment in new physical capital also enables firms with advanced technologies to expand their market shares at the expense of lagging firms. More generally, as Abramovitz (1979) has stressed, physical investment and disinvestment is a principal vehicle by which resources in general are transferred from declining to growing activities and sectors.

In orthodox theory, a better educated worker is treated as simply "more productive" than a less well educated one. From the viewpoint sketched here, this is oversimplified to the point of being misleading. Increasingly, highly trained engineers and scientists have become essential for carrying on R&D. See e.g., Pavitt (1980). A central task of management is to make decisions regarding R&D allocation, and judgements regarding what new technologies to adopt; various of the studies discussed in Part II propose that technical sophistication on the part of managers is a prerequisite for doing these jobs well. There is evidence (Bruce Ryan and Neal Gross, 1943; Finis Welch, 1970) that better educated farmers have an advantage in accessing new technological developments relevant to their practices. Better educated and more recently educated doctors are the early adopters of new pharmaceuticals (Coleman, Katz, and Menzel, 1957). Workers with relatively high educational attainment often are found in the work forces of firms employing new technology; in this context a strong educational background might be viewed as facilitating quick understanding of what is required for learning by doing. To the extent that a broad based education makes a worker flexible and able to learn a variety of different jobs, education may facilitate the shifting of workers between old jobs and new ones, from declining industries to expanding ones. Also, the knowledge and confidence generated by this flexibility may dampen resistance on the part of the work force to technological change.

Just as a high rate of capital formation and a well educated work force stimulate and facilitate technological advance, so technological advance stimulates a high rate of capital formation and motivates young people to acquire formal education. If technological advance were slower, diminishing returns to capital deepening would have less of an offset, and the returns to investment or the investment rate or both would be lower. If technological advance were slower, there would be less demand for scientists and engineers to enable firms to stay competitive with their technological rivals. There would be less need for managers and workers to deal with new situations and to learn new skills.

From this perspective, it would be surprising if one observed many countries where technological advance was rapid, but where investment rates and educational attainments were low. Nor would one expect to find many instances where capital formation maintained a rapid rate, but new technologies were not being introduced and spread through the economy. Societies might find it hard to sustain high educational attainments on the part of young people entering the work force, and not at the same time be moderately progressive scientifically and technologically. In short, there are not neatly separable sources of growth, but rather a package of elements all of which need to be there.

4.2 *The Economic Environment and Economic Institutions.* One way to deepen analysis of growth is to study the forces influencing the various proximate sources. The strong interactions among the proximate sources suggest that another route is to try to identify certain features of the economic environment that have a generally supportive or retarding influence on growth. A significant fraction of recent research on growth might be recognized as following this latter path.

This certainly is so regarding the recent work which tries to link productivity growth to macroeconomic conditions—particularly unemployment, inflation, and stability. As stated in Section I, the neoclassical theory of economic growth was born of an effort to identify reasons for the pessimistic conclusions about balanced growth built into the Harrod-Domar models. The key modeling assumption identifed—fixed coefficients in production—and modified (through the assumption of variable proportions with input mix presumed sensitive to relative-factor prices), balanced growth was henceforth simply assumed in most of the neoclassical growth models. But nothing in the simple neoclassical growth model guarantees that prevailing factor prices will actually be those consistent with full employment of a nation's prevailing stocks of both capital and labor (or other inputs). Nothing in the model guarantees that aggregate demand will always equal aggregate potential supply of goods and services. These conditions define an equilibrium, but to my knowledge at least, no powerful argument, much less empirical evidence, exists that the macro time path is automatically tightly bound to its equilibrium track. Maddison, and other analysts of the rapid growth of the 1950s and 1960s, argued that, with sophisticated application of monetary and fiscal policies, balanced growth was achievable and was achieved. The post-1973 experience calls that belief into question.

Economists clearly are not in agreement about how much of the current productivity growth slowdown stems from the higher unemployment and inflation rates, and from the wide fluctuations that have been experienced, and it can be argued that slow productivity growth is itself one of the causes of the poor employment and price performance of the economies. In my eyes at least, research on the connections among long run growth of economic potential and shorter run macroeconomic performance still has not yet clearly identified, much less quantified, the key mechanisms involved. In part this is because there are so many different and inter-connected mechanisms. From an orthodox point of view, the macroeconomic climate has a direct effect on productivity growth through its influence on investment. To the extent that economic slack involves excess capacity, investment is deterred, the growth of the capital-labor ratio is slowed, and so is the introduction of best practice. A decline in investment may also slow down the pace of advance of technological knowledge, and not merely the rate of which best practice is absorbed into use.

Whether the losses of an economic recession are made up in recovery, or are lost forever, is an open question. When a high rate of capacity utilization is achieved again, will growth of physical capital accelerate sufficiently to make up for trough losses (as implied by some models)? Or will the investment in new plant and in R&D lost because of the recession never be made up (as would be implied by a model in which investment is always a fixed fraction of GNP)?

In any case, it is important to look behind the scenes to identify the reasons why governments have had so much difficulty coping with the macroeconomic problems of the 1970s compared with the 1960s. The surge in oil prices is part of the answer, but why have societies found it so difficult to accept the (temporarily) lower living standards that economists have argued are necessary? Why has it proved impossible to implement the kinds of "income" policies many economists have proposed? Does slow productivity growth, or rather a slower productivity growth than previously experienced, tend to cause an inflationary gap between income growth expectations that people regard as reasonable and just, and what the economy can yield? Why have some countries found it easier to meet these problems than others? Such questions may possibly be the most important ones for economists to answer if they are to understand the forces behind the post-1973 slowdown of growth. But they are not the questions addressed in the growth theory tradition.

The search for answers inevitably will lead to consideration of the bases of conflict in a society, and the mechanisms which contain and resolve, or inflame, these conflicts. Is it happenstance that Britain is marked by both fractious labor relations and stop-and-start economic policies and that until recently at least Sweden had neither? How much of the British problem stems from the particular form of her unions? To what extent is that form deeply rooted, or malleable?

The same kind of questions can be asked about a nation's educational system. Several analyses of Britain's poor performance ascribe a good share of the blame to her schools which, until recently, have lagged in the training of engineers relative to the systems in Germany, the United States, and Japan (Austin Albu, 1980). Such analyses posit that the influences of a nation's educational system are not readily studied in terms of human capital, conventionally defined, but rather are atmospheric, influencing management style, hence innovation, capital formation, and the nature of competition. To some extent differences in educational systems reflect underlying differences in culture and social structure. Until recently at least, academically trained engineers had a hard time finding jobs in British industry. The land grant college system of the United States surely reflects an interest in practical mass education that was evident in this land even before the Republic was established. But, during the late 1960s and through most of the 1970s, engineering enrollments fell significantly in the United States (recently they have come up again). Britain has begun to enlarge and improve her system of engineering education. Why? Differences and changes in rates of return on different educational investments are part of the answer, but not all of it. And these returns themselves reflect institutions, attitudes and government policies.

The greatly enlarged regimes of regulation and the growth of the welfare state also have been identified with developments strongly influencing productivity growth. While some analyses of the effects of these new institutions have focused strictly on their resource absorbing or diverting aspects, other scholars have recognized that their effects are atmospheric, like the microeconomic climate, the state of labor relations, and the character of a society's educational system. Businessmen, discussing their concerns about the regulatory environment, stress the uncertainties involved and their fears that anything they try to do that is new will be prohibited. This fear influences decision making regarding R&D and physical investment. Similarly, it has been argued that the most pernicious effect of the rise of the welfare state is that some young people no longer feel that they should or must work very hard for a living. No persuasive evidence as yet supports any of these contentions. I mention them only to call attention to the fact that they have no place in orthodox analysis.

Social scientists (other than economists) and historians long have believed that variables like those discussed above are important. They have tried to explain them and their effects. Economists, working within an intellectual tradition that values formal theoretical and quantitative precision have tended to view work by other scholars on economic growth as lacking in rigor and in amenability to quantification. Undoubtedly it would prove difficult to make questions and answers, such as those above, rigorous and quantitative—far more difficult than to continue elaborating the orthodox framework. However, can we afford to follow only that familiar path?

4.3 *The Evolution of Economic Institutions.* The durability, and the mechanisms for change, of economic institutions are amenable to study. Increasingly, economists are joining other social scientists in doing so. Research has proceeded both with respect to the evolution of private organizations—in particular the organization of business firms—and of public or society-wide institutional structures.

Perhaps the most interesting examples of such work on the evolution of the business firm have been by Alfred B. Chandler and by Oliver Williamson. Chandler, as the pre-eminent historian of the evolution of the modern corporation, has argued that, prior to the transportation and communication revolutions of the middle 19th century, constraints on information flow and the ability to control operations located at some distance virtually foreclosed the development of firms with geographically dispersed branch operations (1962, 1977). The exceptions were branches run by members of an extended family. The 19th century technological revolutions reduced information and control problems and permitted firms to encompass geographically dispersed branch operations, if they could develop appropriate managerial structures. The modern line and staff form of organization then took shape, with lower tier managers in charge of the dispersed operations and reporting to the center. Chandler also has described the later development by corporations of the independent profit-center idea in response to the increased proliferation of geographical branches or product lines, and the resulting overload on peak management within a traditional hierarchical structure.

Williamson, the theorist, building on Chandler's historical work, has developed an argument, based on transaction cost considerations, to show the economic advantage of these newer arrangements over the earlier structures (1970, 1975). Williamson's general theoretical posture is to consider the transaction cost advantages and disadvantages of different modes of organization under different circumstances, and to postulate that the mode that is adopted is the most efficient one for governing those transactions in the particular context. In recent work he has extended this line of thought to consider organizational innovation more generally (1980). Among the organizational innovations that he has attempted to explain by this class of argument are the rise of wholesaling in the late eighteenth century, and that of chain stores in the twentieth. Lance Davis and Douglas North (1971) attempt to explain the long run evolution of land policy, labor organization, and financial institutions, in the United States, in terms similar to those of Williamson.

Some of the work on institutional change implicitly or explicitly presumes a mixed economy, in which governmental actors play a key role in facilitating, or blocking, privately desired changes. The organizational changes described by Davis and North required public as well as private action. Ruttan (in Binswanger and Ruttan, 1978) has described the way governmental programs in support of agricultural education, research, and extension, evolved in response to changing economic conditions, and to changes in what farmers wanted.

Other scholars have painted with an even broader brush. Years ago, Joseph Schumpeter (1950) predicted that rising capitalist affluence would lead to growing distaste for capitalistic competition, and that some form of socialism would emerge. It is unclear whether he forecast the modern welfare state. Yet that institution clearly is designed to shield individuals and families from the risk and pressures of economic life. More recently, Mancur Olsen (1976) has proposed that the peaceful evolution of a political democracy supports the growth of special interest groups and that interest group politics leads to legislation that protects group interests and inhibits resource reallocation. While Schumpeter held that the safer, more tranquil system, which he foresaw, would be quite capable of sustaining reasonably rapid technological progress, Olsen has proposed that sheltering special interests makes economic change costly and difficult.

With the vision of hindsight it seems that Schumpeter overestimated the extent to which innovation can be "routinized" and made compatible with democratic consensus politics. On the other hand, Olsen's hypothesis cannot easily explain a number of recent political developments which have torn down, or significantly reduced, the levels of protection carefully raised over the years by various interest groups to shield themselves. Simple theories are interesting, and serve to focus attention on certain variables and relationships. But perhaps by now we have had enough experience with simple theories to be ready to entertain a struggle with more complicated ones. There is the story about the drunk who lost his watch at night by the side of the road, who looked under a lamppost where he knew he had not dropped it because there, at least, it was light.

V. *Towards Evolutionary Modeling of Economic Growth*

The view on productivity growth that one can gather from the literature reviewed in the previous three sections is considerably more complex than that of neoclassical theory. However, it is not merely more complex; it is different. At least certain features of growth that the heterodox view identifies as fundamental are difficult, and perhaps impossible, to treat within a conceptual framework that builds from neoclassical footings.

Neoclassical growth theory clearly shows its origins in the neoclassical theory of firm and industry behavior, at rest. One can accept the value of the simplifying assumptions of that theory to address the kind of questions conventionally associated with standard price theory—*viz.* the response of a firm to an increase in the demand for its product, or to an increase in the price of one of its factors of production relative to that of another—although even in these applications there are alternative models that view the response somewhat differently. But one might be skeptical about the extent to which a simple augmentation of that theory to admit shifts in the production function would lead to a framework capable of illuminating the key features of long run economic growth, fueled by technological advance.

The heterodox literature explored in this essay dispenses with, or casts doubt on, the two canonical assumptions of neoclassical theory—that firms literally maximize (expected) profit, and that the industry and economy as a whole are in (moving) equilibrium. The problem with the maximization assumption is not that it connotes a profit motive and intelligent effort to achieve profits, but that it connotes, as well, ability beyond human capabilities to perceive alternative courses of action and compare the consequences of exploring different parts of a previously unexplored terrain. In such a context, human behavior may be purposive, sensible, and even creative, but different people will inevitably focus on different parts of the choice spectrum, and make different evaluations about what is promising and what is not. Similarly, if equilibrium meant only a tendency for the better economic technique, the more effective organization, the more profitable firm, to drive out competitors or to force their reform, there would be no particular difficulty with this concept as a tool for analyzing long run economic change. The equilibrium concept, however, as it is conventionally employed in economics, does not depict such a dynamic process; it presumes the process is (always) complete. This presumption makes it extremely difficult to analyze such phenomena as diffusion, Schumpeterian competition, and resource reallocation driven by differences in returns to factors and firms.

There has been a long tradition in economics of thinking about economic growth as an evolutionary process. Darwin credits Malthus with having provided him with several key ideas. In turn, Marshall was much influenced by evolutionary theory in biology. In the post World War II era, the idea that models styled on evolutionary theory might be appropriate in economics has lingered mainly around the fringe of our discipline, but occasionally has been articulated in a mainline journal. Armen Alchian's 1950 article is a well-known example. Tjalling Koopmans (1957) expressed interest in evolutionary modeling in his third essay.

More recent forays in evolutionary modeling have been published by Sidney Winter (1964), Michael Farrell (1970), Richard Day and Theodore Groves (1975), Day and Indergit Singh (1977) and Gunnar Eliasson and colleagues (1977). Burton Klein (1977) has presented a less formal and more sweeping essay in the Schumpeterian spirit.

In a number of recent papers, Sidney Winter and I have put forth an evolutionary theory of productivity growth (1974, 1977, 1982). In our models, discovery or creation of a new technology is recognized as an uncertain as well as a costly business. Potentially, R&D can be profitable for a firm if that R&D results in a better technology, and if competitors are not able to imitate quickly and easily. Different firms make different technological bets; some turn out to be better bets than others. Over time, productivity grows as new technologies are discovered and applied, as better technologies discovered by some firms are imitated by others, and as profitable firms grow relative to unprofitable ones. The ability of firms to imitate the technologies of other firms and the extent to which profitability of the firm induces its expansion are variables within our model. So also is the relationship between R&D spending and the new technologies that are found or invented.

These models generate dispersion of productivity levels among firms at any time, of the sort that the BLS studies display. They are capable of generating diffusion patterns for particular new technologies that are consonant with the literature on diffusion. The time paths of industry productivity growth are qualitatively consonant with observed time series of real data.

These, and the other recent evolutionary models, do not address the complexities of internal firm organization, or of individual or social psychology. Nor do they treat economic institutions or political processes in a manner much more sophisticated than does neoclassical theory. They provide no good definition of economic climate. They do, however, provide an account of productivity growth that is consistent with what is known about the processes of technological change. This at least would be one step forward, theoretically.

The current state of evolutionary modeling is primitive relative to the advanced state of neoclassical modeling. But enough has been done to demonstrate the feasibility of such models. They are admittedly more complex than those economists studying productivity growth are accustomed to employ, but no more complex than many of the existing large macroeconomic models. Perhaps the most important present limitation on the use of such models in empirical investigation is scarcity of data suitable for use within a model that treats differences across firms at any time, and different growth rates among firms, as essential aspects of productivity growth. Existing data sets do not enable many of the relevant connections among a firm's R&D spending, invention and imitation performance, profitability, and growth to be made. Yet these connections are the heart of an evolutionary model. Were adequate data available, there undoubtedly would be some difficult questions regarding appropriate estimation techniques. And, as stated, present evolutionary models are only one step forward from prevailing theory in dealing with the apparent complexities of productivity growth.

Economists have every temptation to

turn aside from trying to develop more complex models and empirical research methods for studying productivity growth. Let me remind you again, however, about the drunk and his watch.

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