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Chapter Author: Richard Nelson

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THE RATE AND DIRECTION OF INVENTIVE ACTIVITY: ECONOMIC AND SOCIAL FACTORS

Introduction

RICHARD R. NELSON
THE RAND CORPORATION

The Background for the Conference

THE papers collected in this volume were presented at a Conference held at the University of Minnesota in the spring of 1960, and sponsored jointly by the Universities-National Bureau Committee for Economic Research, and the Committee on Economic Growth of the Social Science Research Council.

The developing interest in inventive activity which is reflected in the many papers presented at the Conference has stemmed from several roots. The growing body of research findings on productivity[1] turned the attention of economists interested in economic growth to the process of technological change. These articles showed that only a small fraction of the total increase in output per worker which had occurred in the American economy since the late nineteenth century could be explained by increased capital per worker. The lion's share had to be attributed to something else: to increased productivity or efficiency. The term increased productivity covers a wide number of different elements, and the operations by which increased productivity is defined and measured obscure a variety of economic phenomena. Better allocation of existing factor supplies (the process of dynamic adjustment) and capital formation in human beings (education, health, etc.) are two of the most important. But it seems obvious that technological change has also been an important ingredient.

Some of the crucial conceptual problems relating to the measurement and analysis of technological change were considered at a Conference on the Quantitative Description of Technological Change, held at Princeton in 1951 and sponsored by the Social Science Research Council. The 1951 Conference was concerned with innovation and diffusion as well as invention; its proceedings were not published as

[1] See for example: J. Schmookler, "The Changing Efficiency of the American Economy, 1869–1938," *Review of Economics and Statistics*, August 1952; M. Abramovitz, "Resource and Output Trends in the United States Since 1870," *American Economic Review*, May 1956; R. Solow, "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics*, August 1957; J. Kendrick, "Productivity Trends, Capital and Labor," *Review of Economics and Statistics*, August 1956; B. Massell, "Capital Formation and Technological Change in U.S. Manufacturing," *Review of Economics and Statistics*, May 1960.

such although many of the papers were later published independently. This 1960 Conference was more narrowly focused, concentrating on inventive activity.

A second source of the heightened interest in inventive activity has been the cold war and the growing awareness that our national security may depend on the output of our military research and development effort—organized inventive effort for the purpose of creating more effective weapons. Closely related to the interest in military R and D is the growing concern with the technological race to which the Soviets have challenged us. The interest in inventive activity which stems from interest in defense and the space program has tended to be more micro-oriented than the interest stemming from concern with problems of economic growth. The studies generated have tended to be normative—analyses of conditions of efficiency (how resources should be allocated), rather than analyses of factors determining the actual allocation of inventive effort.[2]

A third source of the interest in inventive activity is the changing way that economists are coming to look at the competitive process. Increasingly the focus is on competition through new products rather than on direct price competition. And concurrently, normative considerations are shifting toward conditions of long-run growth rather than fixing on short-term Pareto optimality. In a sense these developments represent a renaissance of Schumpeter.[3]

Fourth, but strongly related to all the preceding points, the establishment of the National Science Foundation has been very important in focusing the attention of economists on R and D (organized inventive activity), and the statistical series the NSF has collected and published have given social scientists something to work with.

As the varied sources of interest in inventive activity suggest, the papers in this volume show a wide diversity of focus and method. All of them, however, are concerned with either the supply of factors which are allocated to inventive effort, the output of inventive effort (inventions themselves) or the input-output relationship (the production function). Social scientists studying the factors determining the

[2] See for example: B. Klein and W. Meckling, "Application of Operations Research to Development Decisions," *Operations Research*, May-June 1958; "Research and Development—Background Testimony," Hearings Before a Subcommittee on Government Operations, House of Representatives, 85th Congress, Government Printing Office, 1958.

[3] See for example: J. K. Galbraith, *American Capitalism—The Concept of Countervailing Power*, New York, Riverside Press, 1952; A. Berle, *Power Without Property—A New Development in American Political Economy*, New York, Harcourt Brace, 1959.

rate and direction of inventive effort are exploring territory which has been previously visited by only a few pioneers. The past few years, however, have been marked by the publication of a number of articles and books which have added considerably to our stock of knowledge about inventive activity. Both Schmookler and Nelson[4] recently have attempted to survey certain aspects of this literature. As a bench mark against which to judge the contributions made by the papers presented at this Conference, it seems useful to state briefly the conclusions reached by earlier authors.

Quantitative research on inventive activity had focused on patent statistics, R and D expenditure and employment, data and on counts of "important" inventions.[5] For a wide range of industries the cumulative time series of patents was found to be S-shaped, showing definite retardation as an industry matured. Further, the time path of the percentage of total patents issued which relate to a particular industry was bell-shaped, showing that inventive effort tends to shift its focus from industry to industry. The data showed a secular shift in inventive activity away from industries based on craft and simple mechanical engineering and toward industries based on physics and chemistry,[6] although the concept of an industry based on a certain type of knowledge was not clearly defined. The data also showed a significant increase in the proportion of patents granted to corporations as opposed to private individuals, reflecting the growing importance of industrial research and development. However, patent data and invention counts also indicated that the private inventor still is playing an important role.[7] Several writers were approaching the conclusion that the birth of new firms was an important part of the invention-innovation process.[8]

[4] Schmookler, "A Critique of Patent Statistics and a Review of the Literature" (awaiting publication, 1961); R. R. Nelson, "The Economics of Invention: A Survey of the Literature," *The Journal of Business* of the University of Chicago, April 1959.

[5] Schmookler, *ibid.*; Simon Kuznets, *Secular Movements in Production and Prices*, Boston, Houghton Mifflin, 1930; Robert Merton, "Fluctuations in the Rate of Industrial Invention," *Quarterly Journal of Economics*, 1935.

[6] A. B. Stafford, "Is the Rate of Invention Declining?" *American Journal of Sociology*, May 1952.

[7] Schmookler, "Inventors Past and Present," *Review of Economics and Statistics*, August 1957; Nelson, "The Economics of Invention"; and J. Jewkes, D. Sawers, R. Stillerman, *The Sources of Invention*, London, Macmillan, 1958.

[8] W. R. Maclaurin, *Invention and Innovation in the Radio Industry*, New York, Macmillan, 1949; R. Schlaifer and S. D. Heron, *The Development of Aircraft Engines and Fuels*, Harvard Business School, 1950; and A. A. Bright, *The Electric Lamp Industry: Technological Change and Economic Development*, New York, Macmillan, 1949.

The shifts in inventive activity which have been observed could be partially explained by changes in "demand" or, as some writers put it, "social need," although the verification of this relationship consisted primarily of examples. Economists writing about invention stressed the link between demand and profitability and were approaching a market theory of inventive activity. Sociologists and psychologists writing about invention tended to stress nonpecuniary incentives generated by social need. Although several writers seemed to hold these alternative views to be conflicting, more recent writers recognized that they were complementary.[9]

It was generally perceived that the number of people skilled in the appropriate arts and sciences, and the state of knowledge, were two of the most important factors determining the supply curve of inventions in particular fields.[10] However, major difficulties in defining the "state of knowledge" led to considerable confusion and prevented any useful test of this relationship. Writers who used as their examples the inventions of the nineteenth century tended to argue that formal scientific knowledge was unimportant to invention—what was important was general know-how about a technology.[11] Writers who used as their examples more recent advances in chemical and electronics technology tended to argue that, though scientific knowledge may not have been particularly important in the past, formal science was playing a major role in recent inventive activity. In a general way it was becoming recognized that the state of knowledge, however defined, was a very important factor determining the cost of making an invention.[12] Economists writing about invention were beginning to focus on the state of knowledge as affecting the probability calculations of inventors. Sociologists writing about invention were tending to stress the social aspects of knowledge. Some authors were beginning to treat invention as the creation of information, and were exploring feedback relations between information output and subsequent input.

[9] Schmookler, "The Level of Inventive Activity," *Review of Economics and Statistics*, May 1954; and S. C. Gilfillan, *The Sociology of Invention*, Chicago, Follet, 1935.

[10] Schmookler, "The Level of Inventive Activity"; Nelson, "The Simple Economics of Basic Scientific Research," *Journal of Political Economy*, June 1959; W. F. Ogburn, *Social Change*, New York, Viking Press, 1933; and C. Carter and B. Williams, *Investment in Innovation*, London, Oxford University Press, 1958.

[11] Gilfillan, *The Sociology of Invention;* Yale Brozen, "Research, Technology, and Productivity," in *Industrial Productivity*, L. R. Tripp, editor, Madison, Wisconsin, 1951.

[12] Nelson, "The Simple Economics of Basic Scientific Research"; Galbraith, *American Capitalism—The Concept of Countervailing Power*, p. 91.

It was generally agreed that inventive activity was a form of problem solving and, as such, was characterized by a considerable degree of unpredictability.[13] In this context, demand or social need was recognized as an important factor determining what problems people tried to solve, and the state of knowledge as affecting how, and with what success, people went about solving them.[14] The writers that stressed the unpredictability of problem solving behavior tended to argue against the possibility of a predictive theory of inventive activity. The writers that stressed the social and economic mechanisms for problem selection and solution tended to argue that general tendencies, if not specific inventions, could be predicted. Most writers who had examined inventive activity in any detail agreed on the sequential groping nature of the process and several people argued that a normative theory, or a positive theory based on rationality postulates, would have to take this phenomenom into account explicitly.[15]

Some Problems Treated in this Volume

Due to the large number of papers included in this volume and their diversity, it seems more useful to provide a guide to the reader by discussing some of the issues treated and some of the different points of view expressed than to present an annotated bibliography. In the discussion which follows a number of papers will be considered under two or more topic headings, and the order of treatment will follow the chapter sequence only roughly.

THE CLASSICAL ECONOMICS APPROACH AND THE BLACK BOX

Almost all the papers in this volume were written by economists and tend to reflect the economists' interest in economic growth and in problems of efficiency. This is certainly so of the papers in Part I, which deal with Problems of Measurement and Definition. Both Kuznets and Sanders are interested in defining inventive activity so that the outputs, "inventions," somehow measure an important contribution to technological change, and so that the inputs, resources directed toward inventive activity, may be fitted into a more or less

[13] Klein and Meckling, "Application of Operations Research," p. 24.

[14] A. P. Usher, *A History of Mechanical Inventions*, Cambridge, Harvard University Press, 1954.

[15] Nelson, "The Economics of Invention"; F. R. Bichowsky, *Industrial Research*, Brooklyn, Chemical Pub. Co., 1942; Schlaifer and Heron, *The Development of Aircraft;* Nelson, "The Economics of Parallel R and D Efforts," Research Memorandum RM-2482, The RAND Corporation, November 1959; Klein and Meckling, "Application of Operations Research."

classical economic analysis. Although the two authors differ quite markedly in the extent to which they believe that convenient and useful measures of inputs and outputs exist, the papers are very similar in point of view.

This point of view is essentially that of classical economic analysis, and many of the papers presented at this Conference are similar in that they are attempts to analyze inventive activity with the traditional tools of economics. Machlup's paper examining the supply curve of inventions and Fellner's paper on the profitability of various sorts of inventions certainly fit this mold.

Kuznets and Machlup point out, however, that there are some difficult problems involved in applying classical economics to inventive activity. One particularly important problem results from the fact that there may be great differences in the creativity and productivity of different inventors. How many average inventors does it take to equal one Edison? This fact seriously complicates the analysis of the supply of inventions and indicates that psychological and sociological data may be urgently needed for economic analysis of inventive activity.

MacKinnon's study indicates that such data may be obtainable and useful. MacKinnon examines the intellect and motives of a group of inventors and compares his results with existing data on other creative groups. His findings may have considerable bearing on the extent to which there is a sizable group of potential inventors which might be tapped by an increase in rewards, and hence on an analysis of the supply of inventions.

Minasian's paper presents encouraging evidence that classical economic theory can be applied fruitfully to inventive activity. Minasian's dependent variable is the one which is of real interest to most economists concerned with inventive activity—technological change. His independent variable is the one many economists would look to as the conveniently measured input to inventive activity—expenditure on R and D as defined by the National Science Foundation. He finds that a quite strong relationship exists between R and D expenditure and subsequent increases in productivity.

Save for analysis of the incentives of individual firms within competitive industries, the link between increased productivity and increased profits can be a quite complicated one. However, Minasian finds a strong relationship between increased productivity and subsequent profits for a firm. This result suggests that for some purposes economists may be justified in treating the allocation of resources to inventive activity within essentially the same framework as has been used to treat the allocation of production inputs. Fellner does just this. He is interested in how market incentives tend to "slant" inventions toward various factor saving configurations. Do high wage rates tend to stimulate inventions that are relatively labor saving? High interest rates, inventions that are relatively capital saving? Although he aks the question in terms of aggregative factors and factor prices, his analysis can easily be generalized in much greater factor detail. And although his conclusions are generally negative, his framework of analysis implies that inventors or R and D managers can predict the outcome of a particular inventive effort in considerable detail. Indeed they are able to predict what the new production function will look like. The assumptions Fellner requires are much stronger than the evidence provided by Minasian.

Several of the papers of Part V, particularly the Marshall-Meckling paper and the Klein paper, throw serious doubt on the ability of inventors to predict as closely as is required by the Fellner model. The concern of these papers is primarily with R and D efficiency, and the authors have attempted to look quite deeply at the insides of the black box—at the R and D process itself. The Marshall-Meckling paper shows that, in military R and D at least, the ability to predict the cost, performance, and development time of new inventions is sorely limited. Klein argues that this fact, plus the fact that as development progresses estimates get better, imply that the whole strategy of maximization in R and D may be different from that in production. If these conclusions are generally correct, prediction models based on the assumption of expected profit maximization, that is, models which attempt to explain changes in allocation by assuming optimal strategies on the part of entrepreneurs as a function of prices, etc., might well consider a wider class of behavior than is treated in classical economic analysis.

THE CONCEPT OF PARALLEL INVENTIVE EFFORTS

Klein argues that the type of uncertainty inherent in R and D implies that decision makers might be wise to run several R and D efforts in parallel. Since the concept of parallel inventive efforts, as formulated by Klein, Meckling and Marshall, and Arrow, and as described by Marschak, has few close analogies elsewhere in economic theory, it seems worthwhile to spell out the logic behind it.[16] Assume that a

[16] Nelson, "The Economics of Parallel R and D Efforts," *Review of Economics and Statistics*, November 1961.

certain value (a function of demand and cost variables) is attached to the successful invention of a device which meets specific requirements —say a long-range aircraft or a high quality soundscriber. Assume that a company or a group of inventors is interested in developing such a device and knows that there are a number of different possible designs that are likely to meet the requirements more or less adequately if enough inventive time and effort are expended. The utility, production cost, and invention cost of the different possible approaches are likely to differ significantly, but presently it is not at all clear which approach is best. However, it is expected that as work proceeds on any particular approach a great deal will be learned about its prospects and cost. Information and work accomplished are joint products.

It can be shown that it may be good strategy for the group of inventors initially to diversify their efforts and undertake parallel work on several alternative approaches—run them in parallel. Then, as information accumulates and more reliable rankings of the alternative designs are obtained, the effort should narrow down to the more promising designs. This conclusion is certainly intuitively reasonable, but the proof of it can be quite complicated.

Under certain assumptions it can be proved that the number of alternatives which should be run in parallel is larger (1) the greater the payoffs from successful invention, (2) the greater the rate of "learning," (3) the lower the costs of the initial stages of effort, and (4) the greater the "differences" in the alternative approaches.[17]

The concept of parallel inventive efforts has been studied formally only in the context of normative analysis for a company or organization. The extension to normative analysis for a society has not been undertaken, and the framework has not been used formally as part of a positive theory. However, the concept does suggest certain positive implications.

In particular, it might well be that a rightward shift in the demand curve for a particular product would have its major impact by increasing the number of independent efforts to invent close substitutes or reduce production costs. Schmookler's study of inventive activity in four industries supports this conjecture, and he presents an analysis of the incentive mechanism at work. Machlup also deals with the multiple effort nature of inventive activity and points out that an increase

[17] The rate of "learning" is defined as the rate of reduction in the expected squared error of estimate of a relevant parameter; the "differences" in alternative approaches are defined in terms of correlation coefficients.

in the number of parallel efforts might result partly in a greater number of new products or processes accepted by the economy, partly in greater speed in the achievement of a satisfactory breakthrough, and partly in a higher quality of inventions the economy finally accepts. One implication of this might be, as Machlup suggests that, as inventive activity in an area increases, the ratio of patents issued to resource inputs will fall because an increasing fraction of the resulting inventions will be duplicates, or near duplicates. And it well might be that by exploring just what *sorts* of responses are likely to occur as a result of an increase in expected profits, the predictive value of the theory could be significantly enhanced over the simple statement that inventive effort will increase.

PROFITS FROM INVENTIONS

The papers of Schmookler, Enos, Peck, Marschak, and Nelson indicate that, as a first approximation, one might ignore the complications suggested by Klein and try to explain the allocation of inventive effort by a quite simple maximization model. Schmookler is able to explain a considerable proportion of the variation in patenting in his four industries by variations of demand, and profitability. Enos finds that in the field of petroleum refining invention was extremely profitable, both ex ante and ex post. Peck finds that the different kinds of inventions in the aluminum industry were supplied by those groups of firms we would expect to be most likely to profit from them. Marschak finds that Bell Telephone Laboratories had a pretty good idea of what it wanted when it set out to develop a new communications system, and that the decision was quite rational (cost reduction oriented). Nelson shows that, even in a field with so complex a set of motives and controls and so uncertain an environment as basic research, similar circumstances prevailed. Thus the inventors of the transistor were looking for an amplifying device, among other things, and there were good reasons for their belief that a solid state amplifying device would yield significant practical payoffs.

Although these examples suggest that expected profit may be a very useful independent variable in a model explaining the allocation of inventive activity, they also suggest that a quite detailed and sophisticated analysis is required in order to understand where profit opportunities lie in the fields of invention. For example, in Marschak's study it is clear that the demand curve for communications capacity was shifting to the right, but the scarce factor whose opportunity cost was rising was the unused portion of the frequency band. The inventive effort was directed toward designing equipment to use previously unused frequencies. Although the initiation of the development is easily explained using the conventional language of economists, only someone quite familiar with the communications industry would think of frequency bands as a factor of production.

To further complicate the problem, Rubenstein's paper suggests that organizational factors may be very important in determining a firm's perception of, and reaction to, profit opportunites.

In order to have a useful theory relating inventive activity to perceived profit opportunities we must be able to answer the following kinds of questions: What factor costs are relevant to the profits from successful invention? Do the shapes of the supply and demand curves figure in an important way? What are the complements of invention? The substitutes?

The Thompson and Worley data reflect our present lack of understanding of the conditions underlying high R and D profitability. Thompson relates the geographical distribution of persons receiving patents to the extent of urbanization and to industrial structure. Worley explains the changing composition of the 100 largest R and D employers by relating R and D employment to the size of the firm, and to the industry involved. It is clear that some industries are much more R and D intensive than others but the reasons are not apparent. To say that in these industries R and D is extremely profitable is to beg the question. Brozen relates R and D profitability to past expenditure on basic research, but it seems worthwhile to ask why some industries have in the past spent more on basic research than others. To explain the differences we can fall back on institutional and cultural variables, or say that some industries are linked more closely to fundamental science than others. But what do we mean by that? It is not at all clear.

Schmookler's analysis suggests that invention and new capital equipment may be complementary relative to variable factors of production. This is scarcely a surprising result, but an important implication is that economists had better be wary in making any sharp conceptual split between capital formation and technological change as factors increasing output per worker. Clearly it will require a quite sophisticated type of analysis to disentangle the factors that contribute to high R and D profitability.

Adding to the difficulty of predicting and explaining where profitable opportunities lie is the problem of external economies, discussed by Arrow and others. This problem is more appropriately discussed under the topic "Invention and Policy," but it should be said here that, to the extent that different market structures and institutions affect R and D profitability, a predictive theory must consider these variables.

NONMARKET FACTORS

In his analysis of problems of public control, Markham raises the point that a very large fraction of our R and D effort is at least partially divorced from the incentives and controls of the market. On the demand side, the source of over half our R and D demand is the federal government. On the supply side, much R and D activity is conducted in organizations (universities, government laboratories, etc.) whose goals include many variables other than profits. It is important to understand these nonmarket controls and incentives.

Cherington's paper is a description of how military R and D decisions are made. It is a study of how a complex organization, attempting to maximize a welfare function involving many variables not easily measured by money and operating in an environment of great uncertainty, gains information and advice and comes to make choices.

Merrill's paper examines organization and the decision making process in basic science and in several other sectors that are linked only loosely to the market. He finds that the allocation of effort in basic academic science is determined in part by the interests of individual scientists and in part by the professional judgment of an elite who have considerable control over resources and rewards. The "welfare function" being maximized involves the conceptually vague but seemingly quite operational concept of promise to advance understanding. Nelson, in his study of the Bell Telephone Laboratories, shows that the mechanisms described by Merrill work in industrial basic research laboratories as well as in universities. Merrill also examines the structure of incentives and controls in medical research, in university engineering research, and in governmental agricultural research, all sectors where allocation is not directly guided by a market.

The Schmookler and Nelson papers present quite different evidence on the role that science plays in invention. Schmookler finds little evidence that advances in scientific knowledge contributed much to the inventions of the industries he has studied. To the extent that science did play a role it was a permissive one—as a reference book determining the skill with which persons concerned with practical problems were able to surmount them. Nelson's study shows science in a more active role, with advances in knowledge triggering inventive activity, generating a search for problems to which the new knowledge could be applied. It seems likely that the differences here reflect basic differences in the nature of the industries. The electrical communications industry is much more closely related to fundamental science than is railroading or papermaking. But this statement begs the question of what "closely related to fundamental science" means.

Siegel discusses a number of the relationships between science and invention. He attempts to relate both to the concept of information. A large number of the papers in this volume seem to be approaching the view that research and inventive activity are essentially activities aimed at creating information (see the Arrow comments). One would suspect that, in the future, research on the economics of invention will draw more intensively on the concepts of information being developed by economists, decision theorists, and mathematicians.

INVENTION AND POLICY

The notion that conditions for R and D efficiency may be quite different from conditions for production efficiency is reflected, but only partially, in the Arrow and Markham papers dealing with normative aspects and public policy. Arrow focuses on three important problems. One is the conflict between static conditions and longer-run efficiency conditions raised by the very low social cost of using knowledge, as opposed to the quite high cost of producing it. The problem is an old one in economics and in the past has been argued in the context of such examples as optimum bridge tolls. In R and D, however, certain special and quite complicated problems of appropriability of product seem particularly important. Arrow also is concerned with the welfare implications of the risk in R and D. It can be shown that to the extent that individuals can avert risks and no "insurance" is available, less will be spent on risky activities than is socially desirable.

A third major problem is that of external economies. Arrow, Kuznets, Machlup, Markham, Merrill, and Nelson all present arguments or evidence that, given existing institutions, inventive activity generates values which cannot be captured by the inventor. The problem seems particularly serious toward the basic research end of the spectrum.

Klein might argue that Arrow has not gone sufficiently far in admitting and examining the implications of certain properties of the knowledge producing industries, particularly the nature of the efficiency conditions. The problems raised by the efficiency of running parallel approaches may be particularly nasty. Is it efficient to run the invention industry as a lottery? If only one is to win the prize but each competitor can benefit from the ideas of the others, what mechanisms will generate an optimum flow of information? What of the many situations in which successful inventors and inventions spring from the ruins of unsuccessful ventures? To the extent that technological change builds on itself, what mechanisms can gain for an inventor some share of the profits from subsequent rounds of inventions to which his ideas contribute?

Markham is concerned with the conflict between antitrust policy and policies designed to sponsor a more rapid rate of technological change. The papers of this volume present conflicting evidence on the role of the large corporation. The Marschak and Nelson papers seem to indicate that in R and D size is a great advantage. It is difficult to imagine either the development of the T.H. system or the research which created the transistor being carried out in a small laboratory. These papers show that economies of scale seem to result from the ability of large laboratories to make profitable use of what would be external economies in a small laboratory, their ability to make profitable use of a wide range of expertness (division of labor), and their capacity to carry a large portfolio of projects (reduction of risk).

At first glance, Mueller's study seems to give conflicting evidence. He finds that only a small proportion of Du Pont's major product and process innovations stemmed from Du Pont inventions. (Three important exceptions are Dacron, Nylon, and Neoprene.) However, Mueller's evidence does not clash sharply with the theory that the large laboratory in the large and diversified company has a comparative advantage in many fields of inventive activity, for many of Du Pont's innovations stemmed from inventions of (other) large laboratories. Effective public policy certainly depends on better understanding of the economies and diseconomies of scale and diversification in the invention industry.

The organization of papers in this volume is significantly different from the order of presentation at the Conference. Further, because of duplication of content, or because the material is being published elsewhere, the following papers have been compressed considerably from their Conference versions: Brozen, Cherington, Machlup, MacKinnon, Rubenstein, Sanders, Siegel, and Worley. The more extensive versions of these papers can be obtained by writing to the authors.