Innovation and U.S. Research

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

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Problems and Recommendations

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Based on a symposium

sponsored by the

Industrial Research Institute

and the ACS Divisions of

Industrial and Engineering Chemistry

and Chemical Marketing and Economics

at the 178th Meeting of the

American Chemical Society,

Washington, D.C.,

September 9–14, 1979.

ACS SYMPOSIUM SERIES **129**

AMERICAN CHEMICAL SOCIETY

WASHINGTON, D. C. 1980

Library of Congress CIP Data

Innovation and U.S. research.
(ACS symposium series; 129 ISSN 0097-6156)

Includes bibliographies and index.

1. Technological innovations—United States. 2. Research, Industrial—United States.
I. Larson, Charles F., 1936- . II. Smith, William Novis, 1937- . III. Industrial Research Institute, New York. IV. American Chemical Society. Division of Industrial and Engineering Chemistry. V. American Chemical Society. Division of Chemical Marketing and Economics. VI. Series: American Chemical Society. ACS symposium series; 129.

T173.8.I565 607'.2'73 80-16172
ISBN 0-8412-0561-2 ACSMC8 129 1–267 1980

PRINTED IN THE UNITED STATES OF AMERICA

FOREWORD

The ACS SYMPOSIUM SERIES was founded in 1974 to provide a medium for publishing symposia quickly in book form. The format of the Series parallels that of the continuing ADVANCES IN CHEMISTRY SERIES except that in order to save time the papers are not typeset but are reproduced as they are submitted by the authors in camera-ready form. Papers are reviewed under the supervision of the Editors with the assistance of the Series Advisory Board and are selected to maintain the integrity of the symposia; however, verbatim reproductions of previously published papers are not accepted. Both reviews and reports of research are acceptable since symposia may embrace both types of presentation.

PREFACE

Contained in this volume are thirty-one papers presented at the "Symposium on Innovation and U.S. Research," during the 178th A.C.S. National Meeting, September 1979, in Washington, D. C. One other paper not presented at the symposium has been included because it provides significant additional insight. Co-sponsored by the Industrial Research Institute and the A.C.S. Divisions of Industrial and Engineering Chemistry and Chemical Marketing and Economics, the Symposium brought together nearly three dozen distinguished and knowledgeable speakers representing, we believe, a cross-section of the best current thinking on industrial innovation. Most aspects of the innovation process were covered, with detailed analysis of problems and recommendations for change both internal and external to the corporation. The authors represented industry, government, and academe; we admit to seeking somewhat more input from industry because the process of innovation is carried out for the most part by industry, not by government or universities. This volume gives an excellent picture of innovation, what its nature is, where it stands, and what can be done to stimulate it in the United States.

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November 13, 1979.

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INTRODUCTION

It is encouraging to note that innovation is receiving major attention by industry and government policy makers not only in the United States but in most other industrialized nations as well. Among other benefits, innovation is seen as a way to create new jobs, increase productivity, and reduce inflation. Due to a combination of circumstances, U.S. innovation has been lagging somewhat behind its past outstanding performance. Current statistics, such as our continuing trade deficits, with no hope of a surplus in the immediate future, illustrate the seriousness of the current situation. By no means, however, is innovation dead in this country, nor will it be in the future.

The terms invention, research, and innovation need to be clarified. Invention is the discovery of a new material, process, or device; it is the identification of something new. Research is carried out to discover something new, sometimes purely for the sake of new knowledge, and other times for commercial application. Innovation, on the other hand, is the entire *process* of recognizing a need, identifying a new solution (usually through applied research), developing an economically attractive process, product, or service, and then marketing that process, product, or service. Stated more simply, innovation is the process of developing and commercializing new technology.

Inventors differ from innovators in that the former are involved in the conception or discovery of something new, whereas the latter take this concept or discovery all the way to commercial reality. The important point is that R & D, even though only a part of the innovation process, can be the critical first step in this process, whether the innovation is in response to market pull or technology push. As pointed out in this volume, a healthy climate for R & D is crucial to a healthy climate for innovation and business in general.

There are, of course, other factors that bear heavily on innovation, such as new knowledge and the supply of well-trained, creative graduates from our universities. Government regulations also have a particularly strong influence on the rate and direction of innovation in the private sector.

Donald Rumsfeld, President and Chief Executive Officer of G. D. Searle & Co., and formerly a four-term Congressman, Ambassador to NATO, White House Chief of Staff, and Secretary of Defense, pointed

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out the pervasiveness of government regulations by stating in *Fortune* (Sept. 10, 1979) that, "When I get up in the morning as a businessman, I think a lot more about government than I do about our competition, because government is that much involved."

Recognizing the need to stimulate innovation, the White House in April 1978 initiated a Domestic Policy Review on Industrial Innovation, coordinated by the Department of Commerce. Results of that review were sent to Congress by President Carter on October 31, 1979. Proposed action to stimulate innovation is also evident in the form of several bills before Congress. We look forward to even more action and indeed one purpose of this volume is to keep industrial innovation at the fore.

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Overview of U.S. Research and Development

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I am basically optimistic about the present structure and future health of our national technical enterprise. Some recent trends provide cause for concern, and there are very real and complex problems that face us today. But there are underlying strengths and there are constructive actions being set in motion now, so that the tools for steady progress are available. I would like to develop these points in this paper.

By our "national technical enterprise," I refer to those activities in the United States included in the roughly $50 billion to be spent in 1979, supporting the efforts of approximately 600,000 scientists and engineers. I have been asked to present an overall picture of this vast system of government, university, and industrial R&D. This obviously cannot be done in a reasonable time by a straightforward review of the technical progress and plans of all the organizations involved.

I propose, therefore, to consider the total U. S. technical effort in terms of three broad criteria which can serve as measures of how we stand and where we have to go. These can be stated as:

1. Our national technical enterprise must be in equilibrium within itself, i. e., it must possess an internal balance among the different forms of R&D and among the functions performed by government, industry, and university.

0-8412-0561-2/80/47-129-003$5.00/0

2. Our national technical enterprise must be in equilibrium with U. S. national objectives, i. e., the allocation of resources and priorities should be compatible with the expectations of society from R&D.

3. Our national technical enterprise must demonstrate increasing productivity.

I would like to comment briefly on our status and trends from each of these three viewpoints.

INTERNAL BALANCE

At any given time, there is a division of technical effort among basic research, applied research and development. There is a division of our technical community among government, industry, and university personnel. There is an educational system geared to producing a mix of scientists and engineers and there is a demand for some mix of those same graduates.

Are these breakdowns of effort and manpower correct, and by what measure? Are there trends and are they in the right direction? And if we want to change the structure, how do we do so?

I would not think any of us are brash enough to say that we know just what the precise distribution of these efforts should be. The best we can do is to spot trends, identify pressures for change, and evaluate the impact.

There is always concern about basic research, partly because it is our foundation for long-term continued advances, and partly because it is indeed somewhat vulnerable to short-term financial pressures. My own concern is not so much with the absolute amount ($6 billion in 1978 is hardly trivial), but rather with the motivations and vigor of the effort.

Data from NSF, pointed out by Professor Albert Shapero of Ohio State University, shows that basic research at universities as a percent of all university research activities went from 43% in 1953 to 69% in 1977. Clearly, the availability of massive government funding did more than sustain normal university research patterns, it <u>produced</u> today's overwhelming emphasis on basic research at universities.

There are some pressures today to have universities expand their efforts in applied research. I do not believe these pressures come from industry, which recognizes the unique strengths of our university system. But can we say that it is better for 70% of university research to be basic than the 43% of 1953?

My own judgment is yes. After all, the universities in 1953 were still evolving from their participation in the military and atomic energy developments of the war years, so that there may well have been too low a level of basic research in the early 1950's. However, I also believe that we should recognize and encourage the growth of "directed basic research," that is, basic research in areas where we have reason to believe that scientific knowledge could lead to desired developments. I will expand on this at a later point.

There is legitimate concern that employment in universities cannot accommodate new graduates. One immediate adverse possibility is that this could lead to a growing inflexibility at the university itself, our principal hope for long-term change. Again, my personal concern is not with the size of university research effort, but its flexibility.

Normally, this flexibility is assured by bringing in new research personnel. If this is blocked by a freeze in university personnel levels, then emphasis can be placed on two other possibilities:

1. Consider mechanisms that will offer constructive professional challenges for senior faculty members which will encourage retirement from the university, though perhaps maintaining office space and contacts.

2. Provide mechanisms, professional and financial, that will encourage constant re-evaluation of university research in order to stimulate changes of research interest when this is desirable. One such mechanism is increased linkages with government and industry in research.

Just for the record, actual employment of R&D scientists and engineers at universities decreased from 68,000 in 1969 to 64,000 in 1973, but has risen steadily since then to about 80,000 in 1979. These numbers represent 12.3%, 12.4%, and 13.1% of the national totals for those years. Thus, the research personnel at universities has continued to increase in absolute numbers and has even shown a slight percentage increase on a national scale. The employment concerns are focussed primarily on tenured faculty and on teaching, with the potential discouragement of careers for new people. These trends have not been reflected in the numbers of professional people conducting university research.

In addition to this concern about university employment, there has been considerable concern expressed about the decline in longer-range programs, particularly basic research, in industrial laboratories. This is regrettable principally because it slows down the accumulation of a knowledge reservoir derived from "directed basic research," and may well have an effect on our industrial productivity ten years from now. This cannot easily be compensated for by seeking the same manpower effort at universities.

Since each company attempts to maintain its own internal balance of R&D with respect to other corporate resources, there is little to be gained in the form of innovation or economic growth by the use of external stimuli to increase basic research within industry. Better business prospects for exploiting R&D will produce both larger total efforts and a rising amount of basic research in those industries where it is appropriate. The disciplines of profit and investment requirements maintain the internal equilibrium for industrial research, whereas other considerations are needed to assure that same balance for government and university efforts.

COMPATIBILITY WITH NATIONAL OBJECTIVES

There are a large number of national objectives to which science and technology can make a contribution. How well are we using our technical resources in meeting these objectives?

Consider how the different parts of our technical community relate to national objectives. Each of the principal sectors -- university, industry, and government--are engaged continuously in activities that fulfill a series of national objectives. Industrial research functions primarily as a mechanism for economic growth. Universities, of course, fill a reservoir of basic research and provide training. Each government agency that has technical component supports R&D related to its particular mission--national security, health, transportation, and so on.

Thus, at any given instance as today, our national technical enterprise consists of organizations each of which is working towards some national objective for which it was established or which evolved over the years by general public acceptance, as in the case of university and industrial research. There is, therefore, an inevitable mismatch between the priorities of existing technical programs and the current priorities of national objectives.

Having said this, I must observe that the total system is more flexible, more in balance regarding national objectives, than perhaps we have a right to expect. While our resources are well-established and structured, our ability to manage those resources for changing objectives can often overcome organizational inertia. Putting this differently, our ability to adapt to changing national objectives may be more a challenge to research management than one of building laboratories and dislocating large numbers of people.

Consider, for example, that industry and university research do react to market mechanisms. Yes, even universities! It is no coincidence that interdisciplinary programs, departments, and institutes in materials science appeared in the 1950's, space science and computer science in the 1960's, environmental and energy research in the 1970's. True, much of this structural change is simply a rearrangement of the ongoing interests and research of the existing faculty at the time that Federal funding and public interest began to favor those fields. But this is precisely the point. A deliberate effort to allocate and manage resources in response to a national objective is in fact a natural and reasonable response of both our university and industrial research sectors. There is a time delay before truly substantive program changes can take effect, and this is much longer for universities than for industry. But there is a direct managerial response possible, and there is a mechanism established which influences the thinking and the motivations of the scientists and engineers involved.

The situation within our Federal laboratories is somewhat more complex. Each department and agency has been established to carry out a particular national objective. Our defense laboratories, the National Institutes of Health, the Bureau of Mines, The Agricultural Research Centers all have their missions. There is little flexibility for these organizations to change with new priorities.

Yet even here, we should view the government technical structure in perspective. To begin with, of all the scientists and engineers engaged in R&D, only a little over 10% are in government laboratories--65,000 out of 610,000 total. Even if we add those in Federally Funded R&D Centers such as the national laboratories, the R&D professionals would amount to 13% of the national total. Thus, inflexibility within government laboratories leaves much freedom of movement nationally.

Further, the scope of activity, objectives, and capabilities of many government laboratories is so broad that there is an inherent technical flexibility which can and does respond to good Federal research management. The Bureau of Mines is involved in some aspects of ocean mining and coal conversion. The defense laboratories pursue electronic research that strengthens our industrial base. A NASA electronics laboratory is transferred to the Department of Transportation. Our oldest and prestigious national laboratory, the Natinal Bureau of Standards, receives about 40% of its total funding from other agencies to assist in their missions, has undergone a major reorganization to better accommodate new needs of our economy and society, and is initiating exploratory programs in cooperative technology and technology incentives.

There are, of course, proper concerns about laboratories whose missions have lost priority. And the bureaucratic difficulties of conversion are such that it is easier to set up a new laboratory for EPA than to convert existing facilities of lesser current importance. We must not be complacent about the apparent inflexibility of R&D missions within the Federal government, but research management can compensate for some of this.

Certainly, this is true for many of the specific national objectives today. Our concern with energy, with natural resources, with environment, with safety and health, with national security--all of these can be, and have been, translated into constructive actions by our technical communities in response to funding, indirect pressures, and to research management.

The more difficult problem is with the broader issues of the domestic economy and foreign policy. There is no convenient technology or discipline that we can identify as "domestic R&D" or "international R&D." These are not problems for research management, but rather for public policy, for the allocation and direction of national resources.

These areas do present a problem, if not of technical incompatibility, then surely of political and economic strain. The critical national objective domestically is to achieve economic

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health, consistent with regulatory objectives. The industrial research structure is the traditional, and the appropriate, mechanism for providing the technical inputs that support these objectives. The level and the directions of each company's technical effort is dictated by, and is in balance with, that company's overall plans and capabilities. Therefore, two areas of strain arise between the national industrial research effort and national domestic objectives:

1. Industrial R&D devoted to meeting regulatory requirements subtracts from the industrial R&D available for new products and processes, i.e., the conventional path for economic growth.

2. Industrial research is geared to perceived business opportunities and business climate, so that current activities indicate some shifting to shorter-range programs and to processes intended to lower costs.

This overall industrial picture has aroused much concern about our national innovation capability and reduced efforts towards economic growth. To the extent that this results from an adverse climate for business investment, including the complex effects of increasing regulatory activity, the concern is probably correct. However, for anyone to infer that more conservative or shorter-range industrial R&D has put us in a reduced innovative positive would be to reverse completely the actual cause-and-effect relations.

There is, then, some incompatibility between what the Federal government would like to see accomplished in the domestic economy through R&D and what the industrial research sector can actually do in the face of broad constraints on the business and investment climate. Government actions to initiate those desired R&D activities are at best inefficient if industrial R&D does not become involved through incentives which permit results to be exploited by the conventional resources of the private sector. We have not yet closed this gap.

Similarly, in foreign policy, several of the principal national objectives include cooperation with developing countries, relations with centrally-controlled economies, and our trade position with western industrialized countries. Science and technology can contribute to all of these. Our government is

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often in a position where it is discussing, planning, or negotiating conditions for the transfer or the use of technology which belongs to the private sector. Again, mechanisms have not been developed by which government policy and private capabilities can work together effectively, thus leaving some incompatibility in this field between the national R&D effort and broader national objectives.

PRODUCTIVITY OF R&D

Finally, I turn to my last criterion, namely, that our national technical enterprise must demonstrate increasing productivity. I really do not want to be any more precise in defining productivity in this sense, except that our technical efforts should provide benefits to society for our domestic or foreign needs, including advancement of basic science. Numbers of patents and technical articles are indications of activity, but productivity to the general public means results--some indications of new products, new processes, or scientific advances that come from the $50 billion annual investment.

This results-oriented measure of productivity helps to identify three primary factors that determine how effective we are in using a given amount of resources to produce the optimum output of science and technology. These are:

1. Whatever our choice of R&D and of national objectives, there should be a steady pressure to conduct the R&D at minimum cost. This is the classic approach to improving productivity by the best mix of professional R&D personnel, research assistants, and equipment.

2. We must be sure we choose the right things to work on, taking into account the technical opportunities, the national needs, and the ability of our total system to put the technical results to use.

3. We must improve the mechanisms for cooperation and transfer of scientific and technical advances between sectors of our national technical enterprise, and from technical results to useful applications.

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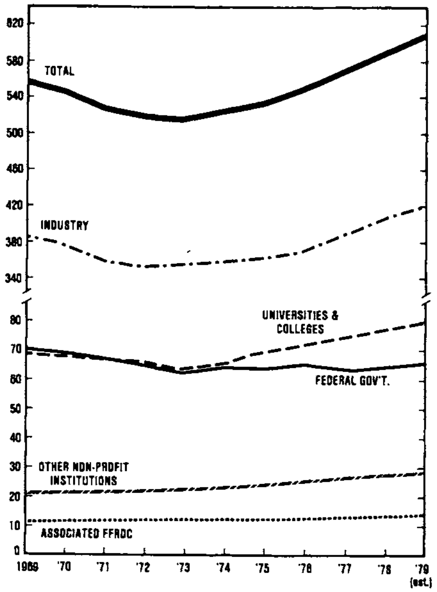

National Science Foundation

Figure 1. Number of R & D scientists/engineers (in thousands) (full-time equivalent)

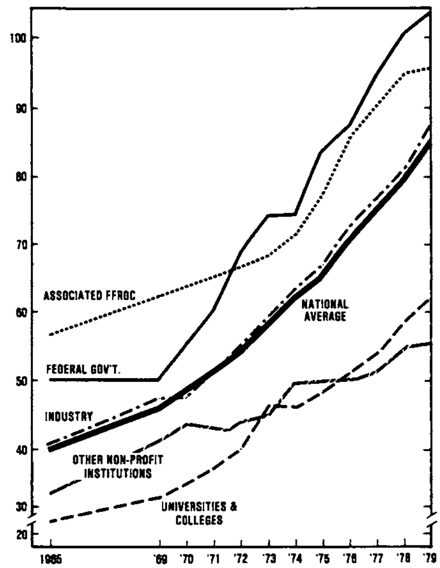

Figure 2. Cost per R & D scientist/engineer (in current thousands of dollars)

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Let me comment briefly on each of these factors simply to put them in perspective. Figure 1 shows the growth of full-time equivalent professional R&D personnel for each sector and the national total, according to data of the National Science Foundation. University personnel are separated from those of associated Federally Funded R&D Centers such as the national laboratories.

Since 1973, there has been a steady increase in numbers for each sector, despite inflation, budgetary pressures, declining student enrollments, and so on. In the six years from 1973 to today, this total national increase is just under 18%. Industrial R&D personnel, comprising about 70% of the total, shows the same increase. The other sectors, however, differed radically. Federal government R&D personnel went up by barely 5%, less than 1% annually. University research personnel, on the other hand, increased by 25% in this same time. Thus, despite inflation, the numbers of people engaged in R&D has increased steadily, most noticeably in universities. For completeness, the FFRDC's went up by 25%. To the extent that output relates to professional R&D people, there should have been a healthy growth in recent years.

But now let us examine some of the cost figures. Figure 2 shows the cost per professional person for each sector in current dollars. Not surprisingly, this has risen steadily. The national average of about $85,000 is controlled largely by the dominant industrial component, averaging $87,000. Government at $106,000 and FFRDC's at $93,000 are the high figures, balanced by universities at $63,000 and other non-profits at $52,000.

The figures tell more about the nature of the work than of effectiveness. More technicians, more services, and unique research facilities will raise the figure, while simpler organizational structure and prevalence of one to three person research projects tend to lower it. Othe points show up within each sector when we look at Figure 3, which shows the cost per professional person for each sector in constant 1972 dollars. On this basis, each sector has declined. Since 1973, the true industry cost per R&D professional has gone down by about 5%, the government by 7%, and universities by about 14%.

These figures really tell us little that is conclusive about productivity. Are we actually getting the same results per professional person for less 1972 dollars? Or are we economizing by

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providing less support personnel, less equipment, and less fringe items such as travel in order to keep within a total budget that has just stayed slightly ahead of inflation?

As one example of where these questions lead, consider the university picture. There is legitimate concern that improved instrumentation and modern research tools are need in university research programs. Special studies by NSF have addressed this issue. If the R&D personnel at universities dropped to the 1977 level of 75,000 instead of the estimated 80,000 today, keeping the total dollars constant, the cost per R&D professional would rise to $67,000 in current dollars and to $40,000 in constant 1972 dollars. This would raise the true per capita expenditure level back to the 1972-1974 period, and provide for about $200 million for research equipment.

This is a complex example, since university teaching is intertwined with research, so there are reasons to select people over instruments even at the expense of research results. I simply intended to point out that, focussing only on research, there are hard management choices to make among the resources available, and the actual productivity of the national R&D effort depends on how these choices are made. Undoubtedly, all sectors will sacrifice some equipment needs in favor of strengthening staff, particularly over a short-term difficulty. When this is practiced over a long-term period, there can be marked effects on output. More intensive studies on such allocations and their impacts are called for.

The two other factors in productivity are probably even more critical, less painful in terms of budgets and personnel, but much more difficult in terms of public policy. I am referring to how we select the "right" things to work on, and the ability of the different sectors to cooperate and to transfer results from laboratory to use.

These questions are meaningful for only a part, but an increasingly significant one of our $50 billion R&D effort. Defense and space expenditures make up about $17.6 billion and within this area, the Federal government both plans and implements results. Likewise, the $24 billion of R&D funded by industry is integrated within the total capabilities of the private sector, and kept in balance by the financial disciplines of profits.

The problems of priorities and application are thus of concern for about $9 billion. These funds are primarily for government

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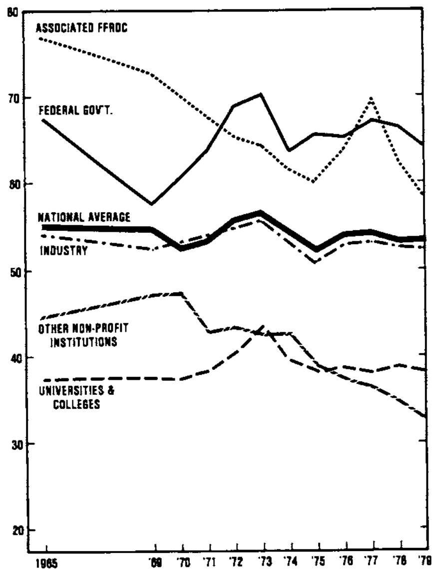

Figure 3. Cost per R & D scientist/engineer (in constant 1972 thousands of dollars)

and university efforts intended to support the civilian sector of our society.

The output of this R&D must enter our society through the private sector. Manufacturing and distribution require private decisions--decisions to invest and decisions to buy. The productivity of our national technical enterprise depends not only on the successful research results, but on successful manufacture and sales.

It is therefore essential that the choice of programs and the transfer to use be compatible with the capabilities and strategic plans of the private sector. This requires mechanisms for exchanging inputs among government, university, and the private sector, mechanisms for improving reasonable awareness of R&D in progress. The critical challenge to increasing R&D productivity is to develop such mechanisms without constraining the independence of each sector in carrying out its proper function. We have not yet done so.

And so, let me summarize this somewhat rambling, yet abbreviated, view of our national technical enterprise.

First, the internal balance among the different sectors, and among the types of research, has not changed appreciably. University R&D has actually increased, particularly in basic research.

Second, there is reasonable flexibility within our system to adjust to most changes in national objectives, and this can be expedited by good research management. There are difficulties in our ability to coordinate our total technical resources to address those national and international problem areas in which public policies must be implemented through the private sector.

Finally, I believe the real problem area is the need to increase the true productivity of R&D. There are opportunities to improve our allocation of resources. There are even greater opportunities to improve the effectiveness of our national system by choosing the right things to work on, cooperating among the several sectors, and developing policies for transfer from laboratory to use, particularly from government and university efforts to the private sector.

In short, our $50 billion and 600,000 R&D people constitute a strong, healthy, well-balanced national effort. There are some problems of balance and productivity, but solutions are available. We should recognize that these solutions are partly through management, partly through procedures, but most importantly, they are largely matters of public policy.

RECEIVED April 28, 1980.

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Chemical Industry Research and Innovation

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I. Definitions and Purpose

The term "chemical industry" as employed in this article stands for a widely diversified series of product manufacturers (defined in the Standard Industrial Classification Manual as "Chemicals and Allied Products"), which include chemicals of all kinds, paints, pharmaceuticals, soap and detergents, perfumes and cosmetics, fertilizers and other agricultural chemicals, plastics, synthetic rubber and fibers, photographic supplies, explosives, miscellaneous chemicals and specialties, etc. However, in recent years the pharmaceutical segment has acquired a special set of characteristics, and although some of the discussion herein includes reference to it, it is difficult to provide a complete examination; it deserves rather a separate treatise of its own. In 1979 chemical industry sales will be about $140 billion, and its employment is slightly over one million (not counting that in downstream industries such as plastics fabrication, textiles, tires, etc., which is much greater, probably approaching six million).

The term "research" means both research and development expenditures, and therefore extends to both basic and applied investigation. It is commonly abbreviated as "R&D." It is a *cost* against operations.

"Innovation" is an often misused word. Economists have defined an innovation as the first commercial application of a new or improved process or product.[1] Nowadays, we should extend this to include a service or a system—the supermarket, time-shared computer, satellite communications, etc. I have discussed the nuances of the words innovation, invention, entrepreneurship, etc., and their interrelationships in a recent article.[2] Therefore, if the innovation is in an area which must be preceded by inventive investigation of the R&D type, the innovation comes into being when the results of the R&D are first commercialized, usually by investing capital, thus converting the *cost* of the R&D into an *economic benefit* (lower manufacturing costs, higher profitability, new or improved products, etc.).

It is the purpose of this paper to examine the state of innovation in the U.S. chemical industry and to study some relationships within that industry bearing on its R&D. It is also a purpose of this paper to compare these aspects with other industries of the U.S., and thereby to seek to view the comparative position of the chemical industry.

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II. The "High-Technology" Industries

It is commonly considered that industries which perform a relatively large amount of R&D and which, it is further assumed, commercialize a material proportion of their R&D, are technologically intensive, or high-technology industries. "Science Indicators-1976," published by the National Science Board in September 1977, states (on page 97) that six manufacturing industries reported R&D expenditures over the billion dollar level in 1974, and together they account for *85%* of total industrial R&D spending. (While absolute numbers have changed since then, these industries' leading position has not. More recently, petroleum R&D has joined the billion dollar ranks. No other industry is anywhere near these seven in total R&D expenditures.)

Further examination shows that some of these industries primarily spend government funds for R&D, while others are almost entirely privately financed. The data for the breakdown between these two sources of R&D funding are not yet available for years after 1977, but assuming that the distributions in 1979 are the same, Table I gives the pertinent figures for these industries. Table I includes not only "Chemicals and Allied Products," but also gives the data for petroleum and rubber products. These two latter industries are included in the total R&D of the "chemicals industry" for this table to illustrate a point, because while the R&D statistics cited by McGraw-Hill for the chemicals industry[3] are consistent with Chemical Manufacturers Association (CMA), SRI International and National Science Foundation (NSF) data, as reported for Industry Grouping 28, they do not include the chemical R&D done by oil and rubber companies. While petroleum companies do research for refining and exploration as well, and the rubber companies do research of a non-chemical nature, nevertheless it is helpful to include their R&D expenditure in this table as chemicals oriented. Furthermore, many other industries engage in chemical R&D, unreported here (for example, General Electric, Pittsburgh Plate Glass, United States Steel and similar companies do chemical R&D which does not get listed because the majority of their company products are non-chemical). No better data are available, but by such approximations one can judge that the chemical industry (as broadly defined herein) may well be the largest private spender of R&D funds, or at least one of the four "big guns" of such industries, along with machinery and motor vehicles, and electrical equipment and communications.

III. R&D in and the Macroeconomics of the Chemical Industry

We now turn our attention more specifically to R&D in the chemical industry, expressed by various indices. Data have been obtained from McGraw-Hill[4], the Chemical Manufacturers Association, SRI International, and *Chemical & Engineering News* (Facts & Figures Issue of June 11, 1979; also R&D Facts & Figures in issue of July 23, 1979). Tables II–IV summarize some of these important relationships.

It should be noted in Table II that another way of gauging the change over the last ten years is to observe that, in constant 1969 dollars, R&D spending by this industry has not changed appreciably, despite its greater size today and the substantial capital invested since then (about $59 billion in current dollars), so that relatively, R&D spending has been going down.

It is also pertinent to note that the capital, income, sales, and R&D figures on which these relations are based do not include that portion of the petroleum industry which went to petrochemical production, as noted above, but the exact data are difficult to break out. It is known from McGraw-Hill data that the petrochemical section of the petroleum industry spent $1.4 billion of capital in 1977, and in that year the petroleum industry spent $913 million on R&D of all kinds, but it is not known how much of this figure was solely for

TABLE I

INDUSTRY	SIC GROUPING	R & D* EXPENDITURES IN 1979 ($ BILLION)	% FEDERAL** FUNDING (1977)	ESTIMATED PRIVATE R & D EXPENDITURES 1979 ($ BILLION)
Aerospace (aircraft and missiles)	372, 376	9.5	54	2.2
Electrical Equipment & Communication	36, 48	7.7	45	4.2
Professional and Scientific Instruments	38	1.8	11	1.6
Machinery	35	5.7	14	4.9
Motor Vehicles and Other Transport	371, 373-5, 379	5.0	12	4.4
"Chemical Industry"				
Chemicals and allied products	28	4.0 }	9	3.6 }
Petroleum refining and extraction	29	1.3 } 6.0	n.a.	— } 5.4 est.
Rubber products	30	0.7 }	n.a.	— }
Total U.S. Industry		**40**	**43**	**23**

Sources: **McGraw–Hill* data on R & D expenditures[3]
**Data compiled from Research & Development, AAAS Report IV–FY 1980

TABLE II

Approximate Proportion of R&D Spending to Other Spending by the Industry

	1969	1979
as a % of sales	3.5	2.9
as a % of capital spending	53.5	48.7
as a % of net profits	44.0	40.0 (approx.)

TABLE III

Purposes of Chemical R&D

	1978	1979
% for improving existing products	58	62
% for new processes	16	20
% for new products	26	18
(% for pollution control	5	4)
(% for energy related	4	3)

TABLE IV

Capital Spending
as Related to Net Profits

	1969	1979
Capital Spending as % of Net Income	86	89 (approx.)

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petrochemical R&D. Close study of the IO-K reports to the SEC by petroleum companies could possibly shed more light, but the variability of both R&D and capital spending among petroleum companies is very great.

The chemical industry employs close to 90,000 scientists and engineers in its R&D establishment, but the Industrial Research Institute points out that nearly 60% of all professionals engaged in all industrial R&D have chemical or chemical engineering backgrounds. The next single largest professional group has a mechanical engineering training, with about 10%!

It is evident from these figures and data that the chemical industry is characterized by an R&D spending which is high in relation to net profits (technology intensive), that its capital spending is high relative to net profits (capital intensive), that it is not itself labor intensive, and the great majority of its R&D goes (and historically has gone) for new or improved products.

These are some indicators of the technological inputs (costs) of the industry. What have been the results? Does all this private R&D and capital spending pay off economically to the firm? And to others? To the country? Curiously, direct evidence is hard to come by. Let us look at a few more statistics, i.e., some macroeconomic data.

1. **Profitability of the chemical industry:** From Figure 1 it can be seen that profitability is below its peak and barely equal to the value in 1968, before the large capital investments of the last decade. Return on stockholder equity (in 1978 it was 15.8%) is also below its peak, but slightly above that for all manufacturing (which was 15.1% in 1978). For motor vehicles it was 17.5%. Some examples of the profitability of less technologically intensive industries are steel, whose return on equity in 1978 was about 8.8%, while that for paper was 12.8%, and petroleum and coal products was 13.5% (despite the billion dollar R&D spending of this industry, in terms of percentage of sales, its R&D effort is small enough so as to permit calling the petroleum industry as a whole less technologically intensive, although this varies from company to company).

2. **Productivity and unit labor costs:** As shown in Figure 2, the productivity improvement of the industry is declining, although not as rapidly as all manufacturing, and unit labor costs are going up, but not quite as rapidly as all manufacturing. These data do not address the changing *quality* of the production, which is virtually impossible to measure except by such facts as export balance (if that measures international competitiveness to any degree—see below). Yet, it is clear that most R&D which goes into improving existing products is designed to enhance quality, rather than sheer quantity alone.

   There can be no question, for example, that the great innovations of the chemical industry in the post-World War II years have come in synthetic fibers, plastics, and rubbers. It is further indisputable that polyester fiber today, for example, with its greater dyeability, its texturizing and other physical improvements, its blending characteristics, its surface finishing, etc., is a very much better and more sophisticated product than the original Dacron or Terylene materials were in the early 50's, the result of prodigious amounts of R&D and capital investment. Yet, DuPont's price index for this and other synthetic fibers is almost exactly equal to that prevailing in 1967! Clearly, there are important structural and strategic problems here which have not been solved. The polyethylene of today is not the polymer invented 45 years ago.

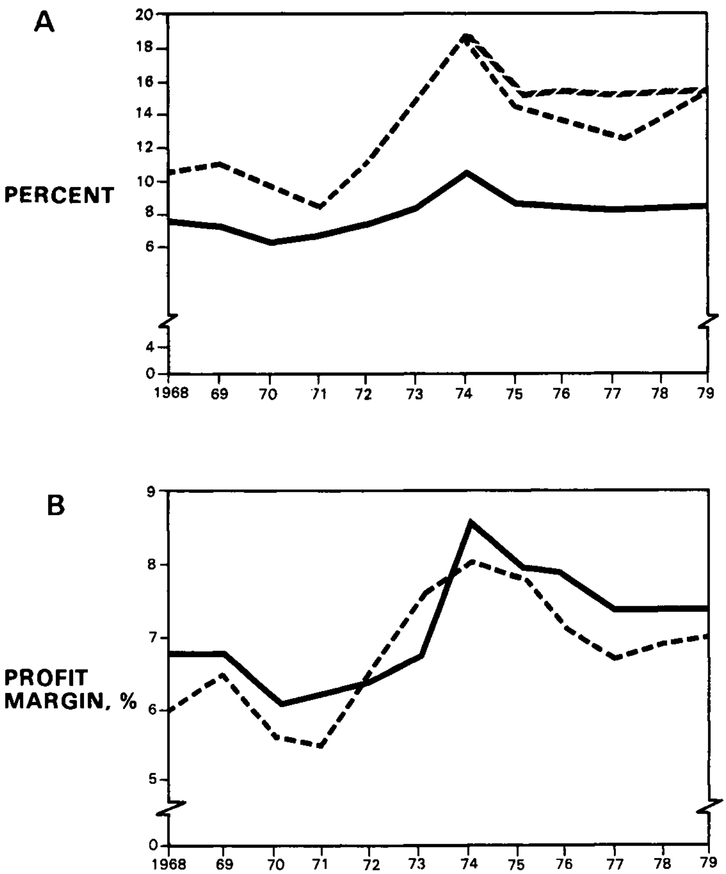


Figure 1. Graphs of after-tax earnings. After-tax earnings as percentage of stockholders' equity or total assets (A). Total chemical industry return on total assets (——), Chemical Manufacturers' Association. Return on stockholders' equity for the 40 largest industrial chemical companies (– – –), Chemical & Engineering News, *June 11, 1979. Return on stockholders' equity for total chemical industry (▬ ▬ ▬),* Chemistry and Industry, *June 2, 1979. After-tax earnings as percentage of net sales (B). Total chemical industry (——), Chemical Manufacturers' Association. 40 largest industrial chemical companies (– – –),* Chemical & Engineering News, *June 11, 1979. (Note: 1974 and thereafter data for all industry calculated on a new basis and not directly comparable with previous years; data for 1979 estimated; all these data are in current dollars and therefore do not reflect inflation.)*

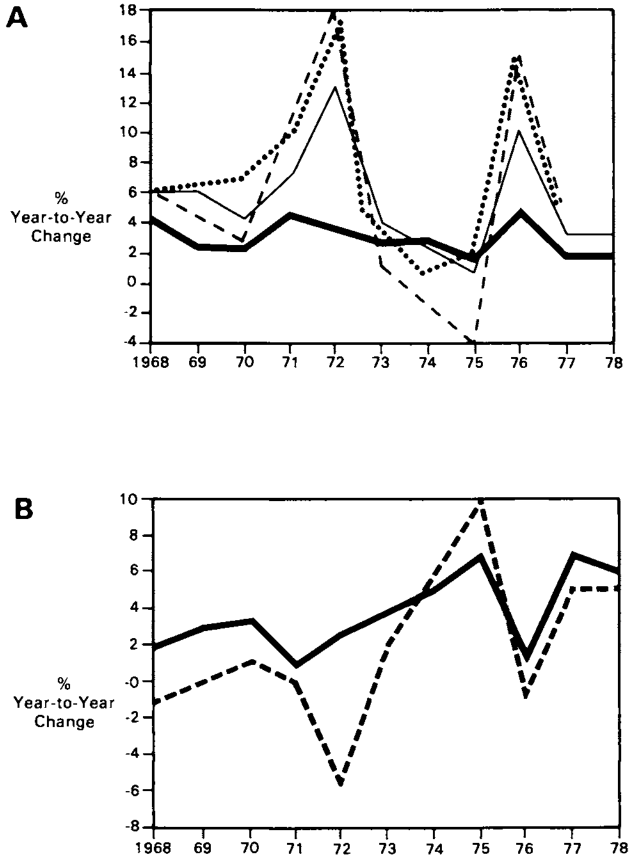


Figure 2. Graphs of economics of chemical industry. Productivity (A): all employees (– – –), production employees (· · ·), derived from Chemicals & Allied Products–SRI International; chemicals and allied products (——), all manufacturing (▬▬), from Chemical & Engineering News, *June 11, 1979. Unit labor cost (B): all manufacturing (▬▬), chemicals and allied products (– – –), from* Chemical & Engineering News, *June 11, 1979.*

The urethane foam industry is vastly improved and serves a much wider market than did the original products of the early 50's. Even monomers, like styrene, vinyl chloride, maleic anhydride, propylene oxide, ethylene glycol, etc., are much purer and more reliably polymerizable than were the earlier products made often by more primitive or less sophisticated technology, although some of this represents competitive pressure and not necessarily the changing technical requirements of the subsequent polymerizations.

The pharmaceutical industry has introduced an extraordinarily valuable spectrum of drugs in addition to the well-known antibiotics, such as tranquilizers, anti-hypertensives, birth control pills, and many others.

Often, when a company builds a plant for an improved product, it also converts or modernizes the older plants, so that production indices alone cannot truly convey the astonishing range, of developments fostered by this industry.

In some cases, it is true, as with certain formulated detergents, there may be a question whether "new, improved" as the commercials have it, are really all that much better than the predecessor formulas, but this is cited merely to underline the absence of quantitative criteria for the effects on "productivity" of R&D and the related capital investments. And this remark in no way is meant to diminish the importance of the quality breakthrough which the introduction of synthetic detergents represented and continues to represent over the older soaps and other cleansing agents, as any housewife or traveler can testify.

3. **Export performance:** As Figure 3 shows, on a current dollar basis, the chemical industry has enjoyed a favorable trade surplus for a number of years (rising from 2 billion in 1968 to over 6 billion in 1978 and estimated to be 6.8 billion in 1979), contributing thereby one of the strongest components to the U. S. trade balance which, overall, is heavily negative. However, there are a number of reasons for this, apart from whatever technological advantages the U. S. may have, such as:
   (a) The huge size of the internal U. S. market, permitting building of large world scale plants which can be nearly fully loaded internally and exports based on marginal production.

   (b) The value of the dollar relative to other currencies.

   (c) Relative tariff barriers.

   (d) Greater aggressiveness in the past by American companies in building overseas plants, which are preceded by an export-based preparation of the market before local production begins. This trend may be changing, as currently the profitability of the U. S. chemical investments overseas is significantly lower than their domestic profitability.[5] The reasons are complex, and may well be due to the current basic capital formation problem, which then forces a domestic producer to ration his ongoing overseas investments. These, however, can only prosper with a long-term growth commitment.

   (e) Various cultural, political, and governmental factors in other countries.

   (f) Price controls by governments, such as U. S. controls on hydrocarbon raw materials which are used as feedstocks for a large number of chemicals.

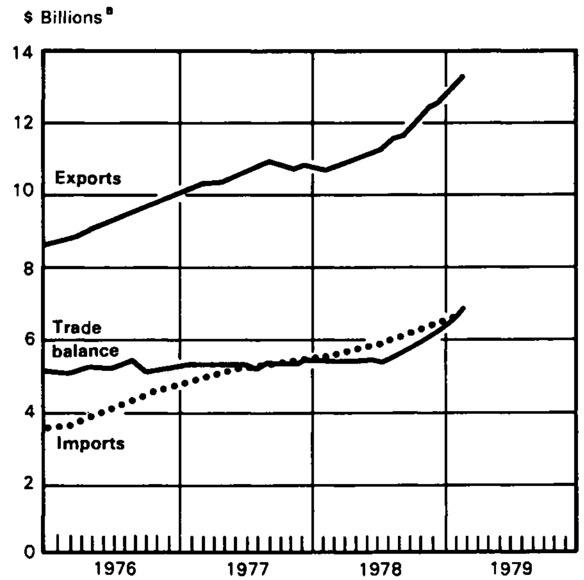
   (g) Relative inflation in different countries.

In order to understand the technological competitiveness of the U. S. chemical industry, it would also be necessary to examine the patterns and results of investments

$ Millions	1978	1977	1976	1968
Chemical exports [c]	$12,618	$10,827	$9,958	$3,289
Chemical imports [b]	6,427	5,432	4,772	1,135
Chemical trade balance	6,191	5,395	5,186	2,154

b General imports. Starting in 1974 reported as FAS value. Prior to 1974 reported as foreign value, which is within 1% of FAS value.

c Exports of domestic merchandise, including Department of Defense and Grant-Aid shipments.



a Running 12-month values for U.S. chemical exports, imports, and trade balance.

Figure 3. U.S. chemical trade balance, from Department of Commerce. U.S. chemical trade surplus, from Bureau of the Census.

abroad by American companies[6] and by foreign companies in the U. S.[7] Data on flow of repatriated profits, and royalty income are also positive and meaningful for this industry[8]. The significance of some of these patterns, and the international strategy of the chemical industry have been the subject of a separate paper[9].

It must be remembered that, of course, other countries perform R&D in this industry. Figure 4 primarily exemplifies the growth of chemical and all manufacturing in other parts of the world, which was inevitable as post-war growth there proceeded at a faster pace than here. By itself it does not tell a great deal about American technological or industrial competitiveness.

4. **Growth rate:** Over the last years, chemical industry production has grown at about 6% per year, as against 3% for all manufacturing. This relationship has been noted by Barnes of DuPont[10], who, however, goes on to predict that the next decade will see a growth rate not greater than perhaps 1.5 times the general growth rate, which itself will be slowing down. Clearly, he says, problems associated with inflation, energy, and regulation, among others, are behind such slowing down of the relative growth rate. Again, we must note that production indices do not measure quality changes. A more alarming development for the future would seem to be the shift away from new product development, and from basic research, as well as to less relative research as a whole. Some comments on these trends are made later.

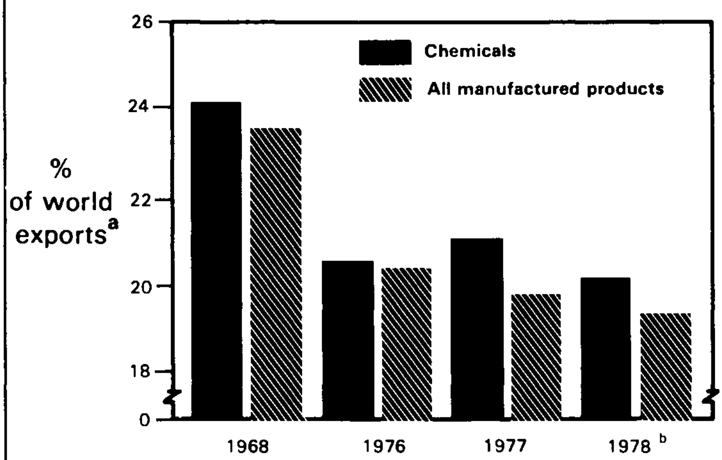
IV. Relationship of R&D to its Economic Benefits in the Chemical Industry

Based on such macrostatistics alone, it is indeed difficult to say unequivocally that the R&D expense by the chemical industry has had a satisfactory economic return, or how much. Professor Edwin Mansfield at the University of Pennsylvania[11], based on studies of a number of *individual* chemical firms, concludes that in this industry the average private rate of return on R&D (i.e., to the firm) may be about 25% pre-tax, or 12.5% after tax. Of course, this return rate will vary tremendously from company to company; it is higher for our company. Although this may have been satisfactory enough in a stable economy, in the inflationary era of today with the prime bank lending rate at 15% or higher and other indices equally astronomical, it is by itself not sufficient justification for any individual company's R&D effort or mix, which after all involve significant risk-taking.

This consideration is important in light of Professor Mansfield's further findings from studies of chemical firms that the cost of the first commercialization (the completion of the innovation) is usually much more than the cost of the R&D that led to it—often, as in the case of process innovations, the R&D is only 10% of the total cost to commercialization, while for highly sophisticated new products it may be well over 50%. The average for the chemical industry is probably no more than one third, and this can be confirmed by the experience of many chemical companies. It must then be clear that for managements to authorize a particular R&D program, risky enough though it may be, they must look down the road at the prospects of commercializing the fruits of that R&D, with all the regulatory and legal uncertainties added to the commercial hazard, which therefore represents a much greater risk, for all these reasons. In short, the lack of predictability is the key problem in assessing the risks. As I will attempt to show later in this paper, such prospects have also been dimming, particularly for first-of-a-kind plants or products. Hence, managements have exercised an increasingly greater control over their R&D spending.

$ Millions	1978	1977	1976	1968
Exports [a]	$143,575	$121,150	$114,807	$34,063
Imports [b]	172,026	147,685	120,677	33,226
Trade balance	—28,451	—26,535	—5,870	837

a Exports of domestic and foreign merchandise, excluding Department of Defense and Grant-Aid shipments. FAS value (free alongside ship). b General imports. Starting in 1974 reported as FAS value. Prior to 1974 reported as foreign value, which is within 1% of FAS value.



a Based on export-weighted exchange rates. World exports are defined as exports from 15 major industrial countries which account for about 80% of exports to foreign markets (excluding to the U.S.) of manufactured products: Austria, Belgium, Canada, Denmark, France, Italy, Japan, Luxembourg, the Netherlands, Norway, Sweden, Switzerland, U.K., U.S., and West Germany. b Average of first two quarters. Starting in third quarter, statistical reclassification precludes comparison with past data.

Figure 4. U.S. trade balance. U.S. share of world chemical market, from Department of Commerce

But it should be remembered that these returns refer to applied research and development, which generally has a purpose. There is no real way of measuring returns for basic research, which must have a very long time horizon, and for this reason is the first to feel the effects of budget-cutting. If there is a role for direct national R&D policy at all, it is in this area of basic research, perhaps in the form of a tax credit to companies which invest in new basic research at universities.

Certainly, however, while paying great attention to these realities, the large number of individual chemical firms which decide to spend money on R&D have made such a decision because it is worthwhile, perhaps as much for defensive reasons as any other, for the alternative of technological stagnation is international and domestic non-competitiveness (as witness Japan's progress in iron and steel, or in consumer electronics). Professor Griliches at Harvard[12] concludes that *the amount spent by a firm on R&D is directly related to its rate of productivity growth.* The macrostatistics cannot alone support such a conclusion for the chemical industry as a whole; again, one must remember the widespread qualitative changes that have taken place.

But Professor Mansfield in his previous research papers and in the present volume also maintains that the social (or society's) rate of return is generally *much higher* than the individual firm's private rate of return on its R&D. No one can measure the loss to society of innovations that are *not* made. From such considerations he concludes that perhaps some (smaller?) firms and certainly many industries or possibly the entire country are probably underinvesting in R&D. But, for the reasons mentioned above, this must be related to how managements and entrepreneurs see the changing conditions affecting the translation of R&D results into economic benefits for their firms,[13] [14] [15] as will be further discussed below.

Professor Nathan Rosenberg of Stanford University, another distinquished specialist in the economics of technology, puts the following perspective on the high social rate of return which commercialized chemical R&D (i.e. innovations), has generated in the past![16]

> "The accurate perception of the economic benefits of technological innovation is further obscured by the difficulties involved in completely identifying the growth in productivity associated with a given innovation. Specifically, many of the benefits of increased productivity flowing from an innovation are captured in industries other than the one in which the innovation was made. As a result, a full accounting should, in principle, encompass all of these inter-industry relationships. In practice it is difficult to identify, much less measure, these benefits... The availability of plastics has had wide-ranging effects in raising productivity in many sectors of the economy, including 'old' industries. For example, although plastics are more expensive than wood per unit of weight, they are much easier to shape and to mold.
>
> "As a result, the use of plastics in the furniture industry has made possible very significant increases in labor productivity. Since the 1930's the building industry has been the recipient of numerous new plastic products which have found a wide range of uses—not the least of which has been cheap plastic sheeting which made possible an extension of the construction year by providing protection on the building site against inclement weather. The sharp increase in the utilization of commercial fertilizer inputs in American agriculture can be entirely explained by the decline in fertilizer prices. This decline, in turn, was to a considerable extent the result of technological change in the fertilizer industry. Agriculture has in fact become highly dependent upon the purchase of inputs from the non-farm sectors—not only fertilizer but herbicides, insecticides, machinery and equipment, fuel, etc.

"Often, however, an innovation from outside will not merely reduce the price of the product in the receiving industry, but make possible wholly new or drastically improved products or processes. In such circumstances it becomes extremely difficult even to suggest reasonable measures of the productivity impact of triggering innovations because such innovations, in effect, open the door for entirely new economic opportunities and become the basis for extensive industrial expansion elsewhere. For example, the chemical industry has exercised a massive effect upon textiles through the introduction of an entirely new class of materials—textile fibers. The great popularity of these new materials, especially in clothing, is attributable to the possibility for introducing specific desirable characteristics into the final product, often as a result of blending (including blending with natural fibers). Thus, materials used in clothing can now be designed for lightness, greater strength, ease of laundering, fast drying, crease retention, etc.

"Technological change in the chemicals industry has exercised a similar triggering function in other industries than textiles. Thermochemical (as well as electrothermal) developments have resulted in the introduction of an expanded range of new metals and new alloying materials. Such techniques have made possible the reduction of ores of high-smelting metals such as manganese, chromium, tungsten and, most important, aluminum. In the case of the electrical industry, the chemicals industry played a critical role through the provision of refractory materials, insulators, lubricants, and coatings, and provided metals of a high degree of purity for use in conductors. The profound effects of chemicals innovations have had a relatively limited visibility because of the intermediate good nature of most chemical products."

In a critical (unpublished) survey by Professor John M. Logsdon of George Washington University made in October of 1978, an extensive review of these and other economic studies of R&D and innovation is undertaken. He stresses that most economists would agree that the body of findings from the studies reviewed confirm the intuitive notion that technological change is *the* driving force behind economic growth,[17] and has been for the U.S. the major source of such growth and of increases in productivity for a very long time. But he quite rightly points out that it is not yet possible to go from such studies to correlations which would assist decision-makers interested in maximizing the return of R&D investments, or policy makers in helping produce a climate for higher R&D returns (such as improving the social rate of return or inducing R&D expenditure when the private rate of return appears to be too small). This should not be too surprising. Willis Shapley provides some general explanations:[18]

"... First, the horrendous complexity of the problem. Second, the absence of an adequate theoretical structure which reflects the realities of the present U.S. economy [much less any other, differently constituted economy] and the ways in which technological changes affect it. Third, the difficulty or impossibility of getting the data needed—accurate data, current data, and data that are disaggregated in ways needed for meaningful analysis. Fourth, the conceptual and practical problems of finding ways to measure outputs of R&D other than by its cost or other inputs. Finally, the problem inherent in learning from experience: does the past really tell us about the future? Will studies of the effects of R&D and innovation on the economy in the 1960s and early 1970s help us deal with the changing economic situations of the late 1970s and early 1980s?"

Rosenberg's citation above is an apt illustration. It thus becomes increasingly important in seeking operationally useful conclusions about the relationship between R&D and innovation, between the *cost* of R&D and its economic *results,* to investigate the *microeconomics* of such decision-making, i.e.,why particular firms decide to spend what they do, and what they feel they accomplish with it. Until a better theoretical framework can be established,however, it will be difficult to draw many generalizations from such studies. Nevertheless, as I have indicated above, and as Professor Logsdon also concludes, in order to obtain useful general knowledge about R&D decisions, and the ultimate correlations of R&D with innovation, it is necessary to understand corporate decision-making in general, with regard to growth and capital investment criteria. From individual firms one may then be able to go to whole industries and ultimately to broader sectors of the economy. Yet, it must be evident that individual firms vary greatly from one another, and from time to time. This variability makes inductive reasoning particularly treacherous. However, a study of the IO-K report of the largest companies would indicate that the averages for the industry are not that far removed from the 40 largest firms (as indicated in Figure 1), so that once one obtains a sufficient number of representative cases it may be possible to develop better modeling techniques.

So, although lacking such a general framework today, we are still able to suspect that the chemical industry has been getting a declining return for its investment in technological innovation (R&D coupled with new investment). This is suggested by the profitability figures, the returns on equity and on sales, and perhaps to some extent the decline in productivity improvement. Sometimes observers point to the decline in R&D expense as a percent of sales, or in real dollar terms, or perhaps in patents issued, and assume that these may be correlated with innovation, but, as discussed above, such is simply not the case.

What we seem to know for this industry, however, is that some major components (e.g. DuPont and Union Carbide) have put greater R&D emphasis on improvement of established businesses, with less on new venture development. This comes from statements by their managements. The differing philosophies and strategies of Dow and DuPont, the two most profitable chemical companies, have recently been compared.[19] While the former continues to be basically process-improvement-oriented, the latter, although continuing new product R&D (30% of their turnover is due to new products developed in the last five years), is moving also toward more improvement of existing products and some additional process work, with less new venture development. Their financial, marketing, and capital investment strategies have likewise differed substantially, making any simple comparisons meaningless.

Quantitative measurements over an extensive time interval for the industry as a whole on these matters would be very difficult to extract from available sources. We know, for example, from the McGraw-Hill surveys[20] that the proportion of capital expenditures which goes for new expansion has been declining somewhat, and that for modernization (which deals more with process and product improvements) has been rising:

	1969	1977
% for expansion	64	55
% for modernization	36	45

But the full implications of these changes are not to be found in such statistics. We will take up later some of the factors which seem to have brought about this change of sentiment in one of our most technologically progressive and healthy industries. An excellent recent review of current strategies is presented by Giles.[21]

V. The Differing Types of Innovation

In order to understand better the microeconomics of decision-making, we must first recognize that there are basically two different kinds of innovation. Professor Rosenberg[22] describes the distinction very well as follows:

"The growing interest in the diffusion of technology in recent years has functioned as a partial corrective to the heroic theory of invention. Inventions acquire their economic importance, obviously, only as a function of their introduction and widespread diffusion ... The central theme, on which I wish to elaborate, is that technological improvement not only enters the structure of the economy through the main entrance, as when it takes the highly visible form of major patentable technological breakthroughs, but that it also employs numerous and less visible side and rear entrances where its arrival is unobtrusive, unannounced, unobserved, and uncelebrated. It is the persistent failure to observe the rush of activity through these other entrances which accounts for much of the difficulty in achieving a closer historical linkage between technological history and the story of productivity growth."

He speaks first of complementarities, i.e., technologies seldom flourish in isolation,

"... It is characteristic of a system that improvements in performance in one part are of limited significance without simultaneous improvements in other parts, just as the auditory benefits of a high-quality amplifier are lost when it is connected to a hi-fi set with a low-quality loudspeaker ... This need for further innovations in complementary activities is an important reason why even apparently spectacular breakthroughs usually have only a gradually rising productivity curve flowing from them. Really major improvements in productivity therefore seldom flow from single technological innovations, however significant they may appear to be. But the combined effects of large numbers of improvements within a technological system may be immense. Moreover, there are internal pressures within such systems which serve to provide inducement mechanisms of a dynamic sort. One invention sharply raises the economic payoff to the introduction of another invention. The attention and effort of skilled engineering personnel are forcefully focused on specific problems by the shifting succession of bottlenecks which emerge as output expands."

He then logically treats of the cumulative impact of small improvements, saying,

"... a large portion of the total growth in productivity takes the form of a slow and often almost invisible accretion of individually small improvements in innovations. The difficulty in perception seems to be due to a variety of causes: to the small size of individual improvements; to a frequent preoccupation with what is *technologically* spectacular rather than *economically* significant; and to the inevitable, related difficulty which an outsider has in attempting to appreciate the significance of alterations within highly complex and elaborately differentiated technologies, especially when these alterations are, individually, not very large,"

and he concludes by employing again the interindustry relationships quoted earlier herein.* These are even more difficult to measure. Also, this difficulty makes it even more risky to propose public policies designed to improve innovation in industry,[23] although much can be

*One of the patterns he emphasizes is the "emergence of specialized firms and industries which produce no final product at all—only capital goods. In fact, much of the technological change of the past two centuries or so has been generated by these specialist firms." One of such beneficiaries has been the chemical industry, which without spending significant amounts of its own R&D money, has been able to obtain ever more efficient and improved compressors, materials of construction, pumps, instruments, computers, separation equipment and many other capital goods. Indeed, the chemical engineer, as a result, is the only engineer trained to design his own production factories or plants using such results from all sources including internal R&D and external industry developments. The cost savings and benefits thus accruing help to offset the benefits which, as noted before, the chemical industry confers on other industries, i.e. the social benefits. These effects make any simple effort to relate policy to innovation-improving measures most superficial except in very broad and general ways, even though there is considerable evidence that some of these external benefits are no longer progressing as rapidly as before, or even at all (the absence of direct R&D by the chemical industry in these areas may yet prove to be very costly).

done by paying careful attention to the opinions of entrepreneurs, managers and technologists who have had direct experience in innovation. But it would be a great error to apply to industry the experiences of our successful national policies for stimulating R&D and innovation in agriculture.[24] Professor Mansfield also addresses this issue in this book, and stresses that coupling of R&D to the market is indispensable for long-term benefits to arise in our industrial economy. In short, merely stimulating more R&D expenditures will not lead to more innovation, unless there is a commercial driving force for the application of the new technology thus discovered.

Regardless, then, of how much the social benefit of innovation may prove to be, or the value to society of reducing pollution, increasing safety, or increasing diffusion of technology, etc., it is still up to each individual firm to decide how much it spends for R&D, and what it gets for it (the private rate of return). It acts in accordance with the ground rules prevailing at the time of decision-making, which of course are heavily influenced by government policy. A recent example is found in the "voluntary" price guidelines of the Council on Wage and Price Stabilization, which, by applying historical formulas to allowed price changes or imposing profitability tests, fundamentally opposes the innovative process, or investment for productivity improvement, and converts industrial management thinking into a "utility" type concept of regulated returns.[25] Another type of brake on innovation is a too rapid diffusion of technology, so that the private rate of return may be seen by the firm to be too small relative to the social rate. This is particularly true for unpatentable improvements, which Prof. Rosenberg described above and which I would further like to consider at this point.

Dr. Edwin A. Gee, who spent many years at the senior management level of DuPont, wrote in his recent book[26] about that company's experience with the enormous benefit of small accumulations of knowhow or innovation: "If a rule-of-thumb generalization is drawn from the nine cases [cited in Chapter 8] it would be that 50% reduction in mill cost in constant dollars is an attainable goal in five years from the point of regularized operation, with a further 50% reduction (75% overall) attainable in a further ten years (15 years overall)." He points out that this is usually accomplished by both economy of increasing scale and economy of the learning curve, i.e. progressive technological improvements.

Mr. Robert Malpas[27] has discussed the application of learning curves to the chemical industry, and given some experience by Imperial Chemical Industries, where he served as an executive director until becoming President of Halcon International.

The power of such a cumulative learning curve is not only beneficial to the firm (if it can retain possession of the knowhow long enough), and justifies much R&D (probably most): it also explains why the real technological breakthrough (which is usually patentable) becomes more difficult the longer the competing product or technology has been in commercial operation. Figure 5 shows a typical learning curve, in which the cost of production in cents per pound is plotted against the cumulative production. (This kind of logarithmic plot has been shown to be valid for an astonishing number of goods, from automobiles to plastics to commodity chemicals, when plotted in constant or real dollars. It should be remembered that such a curve ought really to apply to a fixed or standard product, but as mentioned before, much R&D is devoted to improving product quality, so that a simple curve cannot alone express all the benefits to the firm of cumulative small improvements.)

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

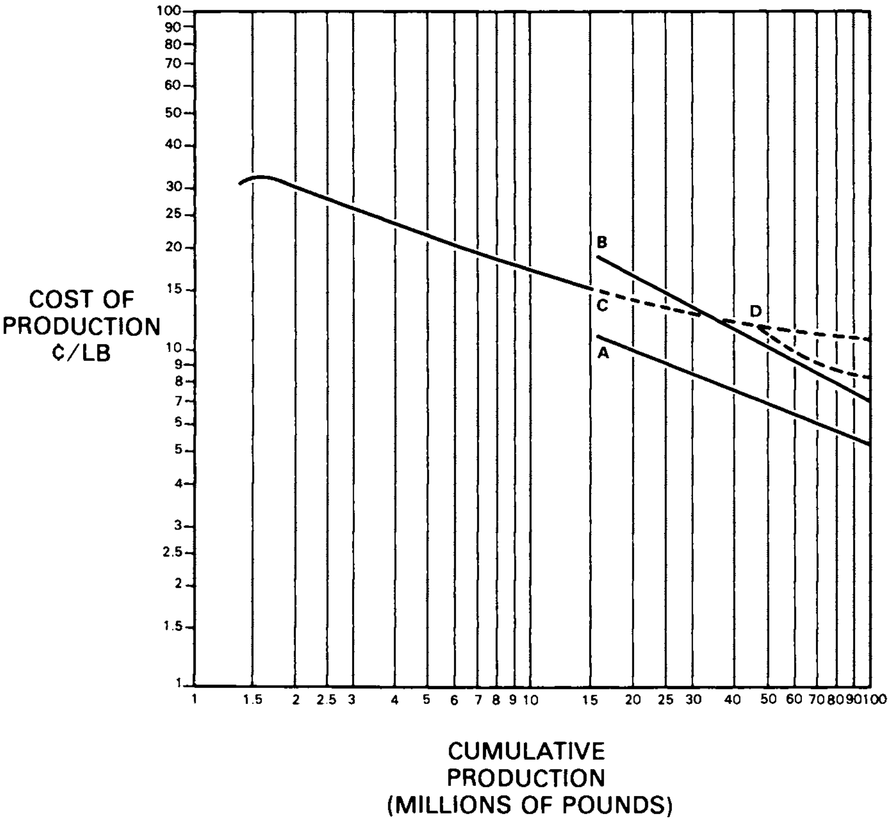


Figure 5. Typical learning curve

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

Let us suppose that at point C a real technological breakthrough occurs, and a new curve could be commenced from point A. Clearly, the new technology will be expected to replace the old, as its learning curve accumulates experience. However, life is usually not that simple for managements: the new technology may involve an initial cost at B *higher* than C. Nevertheless, if it follows its expected slope, its learning curve should eventually cross over below the curve where C would be if continued, and sooner or later B will take over. But it is a real act of courage and faith for a company to commit to an investment for B when the same company has plants at C, and with even a chance that a further minor technological breakthrough such as D might improve the slope of the learning curve so that B might hardly or never catch up! Mr. Malpas, in an address delivered at the Society of Chemical Industry meeting in New York in October and to be published by *Chemistry & Industry* shortly, has addressed in a most penetrating way some of the factors that far-seeing managements must take into account in making their decisions affecting the application of new technology. In particular, he stresses the long-term view which is necessary if a company is to remain technologically progressive and internationally competitive.

The current world-wide inflationary trend also means that capital investments required for new "world scale" plants are now enormous, being usually $100 million or more (often, much more) so that every incentive exists to "ream out" existing plants by debottlenecking or other short-term improvements. Furthermore, in such a high-inflationary era, the worst inflation comes in the capital cost of new plants, as compared with the consumer price index. In addition, the time to build such plants has substantially lengthened, so that the time cycle mentioned by Dr. Gee is probably considerably longer now. This combination results in expected returns, especially for complete or grass-roots plants, based on a commonly used method such as the discounted cash flow (where the time value of money is important), which look increasingly threadbare, compared, for example, with the advantages of buying an existing company. Only the small incremental improvements would continue to show satisfactory discounted cash flow rates of return under these conditions, and this explains why for many companies a major part of their capital budgets consists of such improvement projects costing just a relatively few million dollars each. Other projects are often mandated energy-or pollution-related. These conditions also account for the current perception by many in the Congress and the business community that the proposed Capital Cost Recovery Act of 1979 (providing for accelerated depreciation) is one very important step to improve the discounted cash flow returns for new and larger projects. High inflation has also meant low price-earnings multiples on Wall Street, and acquisition fever consequently runs high.

A good example of this situation may be seen in our company's innovative activity with Atlantic Richfield through the Oxirane Group in the field of propylene oxide. We made the basic invention in the early '60s; the first plant was started up in January 1969. Meanwhile, the only other commercial technology is the chlorhydrin process, invented around the time of the First World War, and obviously very far down its learning curve. That was why we failed to interest any existing chlorhydrin producer in our technology, and why two "outsiders" like ARCO and Halcon finally took the plunge. Our account of this important development is contained in two papers.[28] A new development may not look very promising when first invented (i.e. it may fall at B), compared with its already highly developed competitor, and it takes bold long-range strategy to capitalize on it. We succeeded, because our technology was superior, and thereby established a strong market position.

But in retrospect, this history shows that if someone *does* have the guts to gamble on new technology, then in time it chokes off the old, and the stand-pats lose position; however, their managements of the day probably have already retired! Such breakthroughs and risks are only justifiable if the patent protection available can give a reasonable head start. And, looking backward, if investments continue to be made in the new technology, and its learning curve improves, it becomes much harder, particularly in inflationary times, for new entrants to come in later with the highest capital and operating cost plants which require full depreciation, and with no possibility of averaging returns on historic or partially amortized capital, unless they, in turn, make a new technological breakthrough, and take the big risks!

We may now return to the question of what may really be happening in the chemical industry to change the character of its innovative activities. It is a function of the above realities and the developing *political-economic climate* of the last 20 years, and has been extremely well summarized by Professor Peter Drucker[29] as follows (remarks in brackets are mine):

> "One reason for this is the increasing pressure, especially in an inflationary period, to produce results, fast. An inflationary period, by definition, is one that erodes and destroys both industrial and political capital. In an inflationary period the existing value of future results is subject to the exceedingly high discount rate of inflation which, in effect, means that no results more than a year or two ahead have any present value whatever, whether value is defined in economic or in political terms. It is, therefore, not a period in which either industry or the policy-maker can take risks.
>
> "Thus, both industry and the governmental policy-maker in an inflationary period concentrate on small, but sure, and immediate, payoffs; that is, on what can be calculated with high probability ... " [i.e., the learning curve improvements]. "More important perhaps—or at least more insidiously deleterious over a longer period of time—is taxation. The tax system adopted by the United States in the last 20 years or so penalizes basic research and the adaptation of basic research to technology. Worse, through the combined working of corporation income tax and capital gains tax, the system greatly favors short-term, immediate gains and makes long-term investments in an uncertain future unattractive and unrewarding.
>
> "Equally inimical to investment in research and innovation is the increasing burden of regulation. It is not primarily that regulation adds cost, but that it creates uncertainty. Whether in respect to the environment, to safety, or to new drugs, regulation makes investment in research irrational, not only increasing the odds against research producing usable results but also making research into a crooked game.
>
> "Tax laws and regulations also push industry away from technology focus and toward financial conglomeration. Under the tax laws of the United States—laws which in this form do not exist in many countries—the proceeds of liquidating yesterday are considered profit and are taxed as such both to the company and to the investor. Hence, businesses, instead of liquidating the obsolete have to find new investments in new businesses for whatever cash is being released by the shrinkage of an old technology, an old product line, or an old market. And this, in effect, imposes conglomeration on them. This policy makes it increasingly difficult to shift resources from low and diminishing areas of productivity to areas of high and increasing productivity and this impedes innovation. It also shifts businesses from a technological to a financial focus. It makes management increasingly a matter of finding the right financial investment" [and thereby puts more power into the hands of financial analysts and the large financial institutions they serve, who have no other primary criteria] ... "This constant pressure of the tax laws, which results in a swerve from the scientific and technological toward the financial and from the long term toward the short term, is then aggravated by the antitrust laws, which probably are responsible more than any single factor for turning American history away from building on a technological, science-oriented base and toward the financially based conglomerate." [The recent FTC suit against DuPont on TiO_2 is a good example of the chill which these attitudes have put into technology-based companies generally. Some interesting recent studies of this and other anti-trust decisions of technological importance are presented by

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

Baker.[30] Although an administrative law judge of the FTC has just found in favor of DuPont, the litigation is not necessarily ended.]

"In the world economy, even businesses that are very large on the national scene are becoming marginal, if not too small. The 'big business' of 1938 or even 1958 is a small, if not a marginal business in the 1979 world economy. Yet our antitrust laws frown on the scaling-up of businesses except through the formation of conglomerates, which, however, lack the fundamental core of technological unity. This conglomerate is focused on financial rather than on technological results. Hence, investment in long-range research and in the application of scientific knowledge to economic production becomes difficult in the conglomerate. People who are good at building and running conglomerates are financially oriented people. Yesterday's business, with its unified technology, organized around a process, such as making glass, was basically technologically oriented and therefore looked to science for its future. The conglomerate, which comprises everything from tin cans and electronics to fast-food restaurants and dress shops, from airlines to banks and toys, is, of necessity, financially oriented. *Research becomes a cost center rather than a producer of tomorrow's wealth.*"[emphasis added.]

Clearly, big companies perform the bulk of the R&D in the chemical industry, and they have been adopting a more cautious approach toward risk-taking both in R&D and in its application to innovation as a result of all these factors. The highly capital-intensive, high-technology nature of this industry makes it virtually impossible now for significant new entrants to appear except from other industries, and these are rare, for the reasons mentioned. But the big companies respond to the external forces cited by Prof. Drucker (and recently also by Alan Greenspan[31]), and the result is that fewer technological breakthroughs or long-term risk taking can be expected. Indeed, with a few exceptions, the great period of new product development ended about 25 years ago. As the patent life expired on the great inventions and replacement of natural materials by synthetics waned, more competitors entered, when entry costs were lower, and their prices could not rise as fast as inflation replacement costs because of over-capacity. Technology became available to any would-be entrant either from contractor-engineering firms or from foreign manufacturing firms who saw no opportunity for investing themselves. It was not until the early 70's, with the oil price rise, that chemical pricing for some products began to catch up with real costs, and the profit margin erosions were stopped and perhaps partially improved.

Nevertheless, during this 25-year period there have continued to emerge a significant number of "breakthroughs." In the next section I propose to analyze their nature and occurrence, excluding pharmaceuticals and specialty chemicals.

VI. Important Innovations in the Chemical Industry since 1953

Figure 6 shows the first half of this period—a time when major commercialization was accomplished for important young plastics such as polyurethanes, high density polyethylene and polypropylene. It should be noted that a large segment of this period's development included significant commercialized process improvements for precursors of plastics developed in earlier years—maleic anhydride, terephthalic acid, KA oil (cyclohexanone-cyclohexanol mixtures), vinyl chloride, acrylonitrile and hexamethylene diamine (HMDA). The last half of this period, shown in Figure 7, shows less development in the higher tonnage plastics, but on the other hand the commercialization by DuPont of the more sophisticated and higher-priced, lower volume, polymers Qiana and Kevlar. Development also continued during this period on precursors for previously developed polymers; vinyl acetate, ethylene oxide and glycol, p-xylene, HMDA and maleic anhydride. It is interesting to note that several of the developments during this period involved a switch in raw materials that showed a lower cost and/or future promise of greater feedstock economy; these products include vinyl acetate from ethylene, acetic acid from carbon monoxide and methanol, acrylates from propylene, HMDA from butadiene, and maleic anhydride from butane.

Figure 8 shows recently-announced but not yet commercialized large chemical projects. Again, the emphasis is on plastics and lower cost raw materials.

As stated above, most of these developments were created by the large chemical companies, or chemical arms of oil companies, with a noticeable fraction, however, coming from U.S. specialized process development companies, such as our own. These figures, therefore, list the "Big Leagues" of chemical development. But at the same time, there continue to be many small companies—particularly in the specialties or biomedical field—who are making very important contributions to technology and to employment. They have special problems in the present inflationary era of inadequate venture capital, stiffening regulation, and a very uncertain economic climate; but the scope of this paper, which deals with the entirety of the chemical industry, prevents further examination herein of the problems of the smaller entrepreneur or innovator.[32]

I have reorganized the information shown on the last three figures in order to emphasize the source of development. Figure 9 shows the previously listed developments made by individual chemical companies. It is also to be noted that Japan, during this period, was taking by far the most economical route for that country, which was that of concentrating on acquiring technology from the outside, and very successfully improving it, rather than following the painful, lengthy and very expensive procedure of developing and commercializing entirely new chemical processing technology. Of course, in recent years the patent literature has shown Japan to be extremely active in chemical inventions and it would not be surprising if they pick up their full share of innovative chemical processing commercializations in the future.

The corresponding contributions to the chemical processing area of oil companies and other development organizations are shown in Figure 10. It is obvious from these two figures that U.S. chemical and oil companies have been successfully aggressive in this field. Companies such as UOP and Pullman/Kellogg (as well as other engineers-contractors like the Lummus Company and Stone and Webster) have made innovative approaches to the manufacture of olefins, aromatics and other individual hydrocarbons, which I have chosen to categorize as feedstocks for the chemical industry.

It is also interesting to note the important contributions made by foreign companies to the U.S. chemical industry. Professor Mansfield[33] states "...studies of the chemical industry indicate that about 30% of the innovations applied in the U.S. have come from abroad." Some years ago I made another historical analysis of contributions made by foreign entities.[7] Both this latter, and the foregoing figures support Professor Mansfield and show how vigorous is the international technological competition among chemical companies, and the abilities of companies everywhere to commercialize inventions made elsewhere.

I might offer at this juncture what I hope is a modest note of the relatively large contribution made by our company to the area studied here. The reason for this relative success is believed due to the intense concentration of our entire organization, from top management throughout every group, on this one very specialized field, embracing all activities connected with our main goal (such as laboratory, pilot plant, project management, engineering, startup, economics, patents and catalyst manufacture) without the diluent effect of day-by-day responsibility for product development, manufacturing and sales that divert the management attentions of large manufacturing organizations. But another

APPROX. DATE	PRODUCT	DEVELOPMENT	COMPANY
thru-57	ISOCYANATES-URETHANES	URETHANES & FOAMS (POLYETHER POLYOLS: ONE SHOT FOAM: ETC.)	BAYER; HOUDRY; WYANDOTTE
1953 +	AMMONIA	HIGH PRESS. SYN GAS	PULLMAN/KELLOGG
1955	MALEIC ANHYDRIDE	HIGH YIELD BENZENE OXID.	**HALCON**
1958	HIGH DENSITY POLYETHYLENE POLYPROPYLENE	NEW CATALYSTS	MONTECATINI, PHILLIPS. AVISUN
1958	α-OLEFINS	NEW CATALYSTS	GULF. ETHYL. CONOCO
1958 +	TEREPHTHALIC ACID	AIR OXID. OF ρ-XYLENE PURE PRODUCT	**HALCON**; AMOCO
1959	ACETALDEHYDE	VAP. PHASE ETHYLENE OXID.	HOECHST/WACKER
1960-70	OXO ALCOHOLS	IMPROVED CATALYSTS	EXXON; ICI; SHELL; UNION CARBIDE
1964	KA (CYCLOHEXANOL-CYCLOHEXANONE) OIL (FOR NYLON)	CYCLOHEXANE OXID., BORIC SYSTEM	**HALCON**
1965 +	VINYL CHLORIDE	OXYCHLORINATION OF ETHYLENE	GOODRICH; MONSANTO; PPG: STAUFFER
1965	ACRYLONITRILE	PROPYLENE AMMOXIDATION	SOHIO
1965	HMDA (FOR NYLON)	ACRYLONITRILE ELECTRO-HYDRODIMERIZATION	MONSANTO

Figure 6. Major commercial processing developments in the chemical process industry (through 1965)

APPROX. DATE	PRODUCT	DEVELOPMENT	COMPANY
1967 +	VINYL ACETATE	ETHYLENE + ACETIC + O_2, VAPOR PHASE	BAYER; CELANESE; HOECHST; USI
1968	ACETIC ACID	HIGH PRESS. METHANOL + CO	BASF; DUPONT
1969 +	PROPYLENE OXIDE, GLYCOL, TBA	EPOXIDATION W. HYDROPEROXIDE	ARCO/**HALCON**
1969	PHTHALIC ANHYDRIDE	HIGH YIELD O-XYLENE OXID.	BASF
1969	ACRYLATES	PROPYLENE OXIDATION	BP; CELANESE; ROHM & HAAS; SOHIO; UNION CAR.
1969	QIANA	FROM CYCLODODECANE KA OIL	DUPONT; **HALCON**
1970 ±	ETHYLENE OXIDE	CATALYST IMPROVEMENTS	**HALCON**; SHELL; UNION CAR.
1970	ρ-XYLENE	RECOVERY BY ADSORPTION	UOP
1970	METHANOL	LOW PRESS. CO + H_2	ICI
1972	HMDA (FOR NYLON)	BUTADIENE + HCN	DUPONT
1972	STYRENE AND PROPYLENE OXIDE	EPOXIDATION W. HYDROPEROXIDE	ARCO/**HALCON**
1973	ACETIC ACID	LOW PRESS. METHANOL + CO	MONSANTO
1974 +	MALEIC ANHYDRIDE	FROM BUTANE	AMOCO ; **HALCON**; MONSANTO
1974	KEVLAR	HI-TENSILE FIBER	DUPONT
1974	POLYPROPYLENE	VAPOR PHASE	BASF
1978	ETHYLENE GLYCOL (AND VINYL ACETATE)	VIA ACETOXYLATION	**HALCON**

Figure 7. Major commercial processing developments in the chemical process industry (1969–1979)

APPROX. DATE	PRODUCT	DEVELOPMENT	COMPANY
1977	LOW DENSITY POLYETHYLENE	LOW PRESSURE, LOW COST	UNION CARBIDE
1977	PMDI (FOR POLYURETHANES)	NON-PHOSGENE ROUTE	ARCO
1978	METHACRYLIC PRODUCTS	VAPOR PHASE OXID. t-BUTANOL	ARCO; **HALCON**

Figure 8. Major commercial processing developments in the chemical process industry; announced projects

U.S.			
CELANESE	— ACRYLATES — VINYL ACETATE	PPG	— VINYL CHLORIDE
DUPONT	— ACETIC ACID — HMDA — QIANA — KEVLAR	ROHM & HAAS	— ACRYLATES
ETHYL CORP.	-α- OLEFINS	STAUFFER	— VINYL CHLORIDE
GOODRICH	— VINYL CHLORIDE	UNION CARBIDE	— ACRYLATES — ETHYLENE OXIDE — OXO ALCOHOLS — LDPE (ANNOUNCED)
MONSANTO	— ACETIC ACID — MALEIC ANHYDRIDE — VINYL CHLORIDE — HMDA	USI	— VINYL ACETATE
		WYANDOTTE	— ISOCYANATES—URETHANES
FOREIGN			
BASF	— PHTHALIC ANHYDRIDE — ACETIC ACID — VAPOR PHASE PP	HOECHST	— VINYL ACETATE — ACETALDEHYDE (WACKER)
BAYER	— ISOCYANATES-URETHANES — VINYL ACETATE	ICI	— METHANOL — OXO ALCOHOLS
		MONTECATINI	— HDPE — PP

Figure 9. Major commercial processing developments in the chemical process industry; chemical companies

	OIL COMPANIES		OTHER	
U.S.	AMOCO	— MALEIC ANHYDRIDE — TEREPHTHALIC ACID	HALCON/SD	— ETHYLENE OXIDE — MALEIC ANHYDRIDE — CYCLOHEXANE OXIDATION — PROPYLENE OXIDE AND GLYCOL, TBA — STYRENE (VIA HYDROPEROXIDE) — ETHYLENE GLYCOL (AND VINYL ACETATE) VIA ACETOXYLATION — METHACRYLIC PRODUCTS (ANNOUNCED) — TEREPHTHALIC ACID — CYCLODODECANE OXIDATION
	ARCO	— PROPYLENE OXIDE & GLYCOL, TBA — PMDI — METHACRYLIC PRODUCTS (ANNOUNCED)		
	EXXON	— OXO ALCOHOLS		
	GULF	-α- OLEFINS		
	PHILLIPS	— HDPE — PP	UOP	— P-XYLENE
	SOHIO	— ACRYLONITRILE — ACRYLATES	PULLMAN/ KELLOGG	— AMMONIA (HP SYN GAS)
	CONOCO	-α- OLEFINS	HOUDRY	— ISOCYANATES-URETHANES
	AVISUN	— POLYPROPYLENE		
FOREIGN	BP	— ACRYLATES		
	SHELL	— ETHYLENE OXIDE — OXO ALCOHOLS		

Figure 10. Major commercial processing developments in the chemical process industry; oil companies and other companies

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

reason is evident from all of the preceding: most large organizations have for many years spent their R&D and capital in product innovations. This was too costly for us, but at the same time we saw that there was an opportunity to do process innovation because of its relative neglect by such large companies. The oil and process engineering firms, lacking product development capabilities, also spent their R&D money in this area, and many of them were therefore real competitors of ours.

At this point I would like to think back on the list of processes I have just reviewed in order to see what "common denominator" might exist that would throw some light on the innovative process for individuals and organizations.

In the first place, most of the developments involved large-tonnage products which (except for the initial years of specialized plastics) involved hundreds of millions, or billions, of pounds per year of product. This provided the economic incentive for process innovation.

In the second place, almost all the cited developments depend on new catalysts, and in a number of cases on new chemistry as well, so that intensive cooperation is required between the chemist, who generally is the inventor of the basic process, and the chemical engineer, who is involved throughout its further commercialization. Some of the more important activities of the chemist and the chemical engineer in our organization are shown in Figure 11. I am sure it is somewhat similar for other organizations. It can be seen that there are many areas in which chemists and chemical engineers must work closely and harmoniously together as a project moves from discovery through market and economic studies, pilot plant, data analysis and correlation, patents, engineering and startup.

All of this requires special attention to motivation and organization. Of course, I know our own organization the best, although I naturally have developed some working knowledge of the many large (and few small) chemical and oil companies that we have worked with over the years. This paper is not the place to enlarge upon this subject, but I have written about my views elsewhere[34] as has our president, Mr. Malpas.[35] However, a brief summary of some of our observations and experiences regarding organization for innovation and strategic planning might be as follows:

> One of the problems of great professionally managed corporations with wide ownership diffusion is to maintain and enlarge an entrepreneurial longer-range spirit and vision simultaneously with the employment of the systematic cost-benefit approach to decision making that is the hallmark of good contemporary professional management. In order to overcome the obstacles Professor Drucker has alluded to, this probably requires the establishment of two different cultures within the same organization, staffed by different types of people. In essence, the large organization must seek to imitate the successful looser pattern of an entrepreneurial smaller company in order to develop similar skills and ultimately successes. Conflict must be avoided between the full utilization and improvement of existing technology and the creation of the really new. The first must above all be adequately profitable, and must finance the second, which is in turn needed for the company as a whole to remain profitable in the long run.
>
> The boards of directors must prod the managements to provide for long-run change,[36] and assist this process by providing incentives for executives which do not depend on short-range financial accomplishments. A portion of the capital budget should be set aside for risky longer-range investments, to go along with a significant percentage of basic research of the more adventuresome kind. The R&D department of a company exists for the very purpose of upsetting the assumptions made by its strategic planning group, since the R&D officer is devoted to technological change

CHEMIST	CHEMICAL ENGINEER
EXPLORATORY RESEARCH	• CATALYST DEVELOPMENT
• CATALYST DEVELOPMENT	ECONOMIC STUDIES
ANALYTICAL CHEMISTRY	• MARKET DEVELOPMENT
ANALYTICAL INSTRUMENTATION	• PILOT PLANT
• PILOT PLANT	DATA CORRELATION
• SAFETY (LABORATORY)	PATENTS
• MARKET DEVELOPMENT	SALES
• PLANT STARTUP ASSISTANCE	PROJECT MANAGEMENT & ENGINEERING
• WASTE AND ENVIRONMENTAL	• SAFETY (LABORATORY AND PLANT)
• MANAGEMENT	• PLANT STARTUPS
	• WASTE AND ENVIRONMENTAL PLANNING
	• MANAGEMENT
	FINANCE

Figure 11. Professional occupations in chemical process innovation. Activities in which professions intersect (●).

whose outcome cannot often be predicted. There is need for a structure closely tied to top management which integrates these divergent cultures into an entrepreneurial strategy (including technology).

But such an arrangement is difficult for many companies, both because the CEO increasingly is becoming financially oriented, and because his tenure is on the whole not very long in terms of the years needed for strategic changes. At the same time he must deal in an increasingly adversarial capacity with the primarily legally trained government officials and politicians. Thus, there is now a three-way tension between lawyer-financier-technologist in each of these centers of intellectual and economic activity which somehow must be bridged by the CEO—whatever his training—together with the board; and despite all the short-term pressures, the company must increasingly have a long-range strategy. A look at the companies in the Dow-Jones averages now versus those 40 years ago will show little repetition. Thus, ultimately, the fate of the company itself is at stake in such strategic planning. A recent article in *The New York Times* about the problems of one such real CEO is most pertinent to the theme of this paper,[37] and should be read also with the comments on the technology aspects of his company cited in [32]. These problems of publicly held corporations are also complicated by the fact that the increasing proportion of outside directors is coming primarily from people of legal or financial backgrounds, rather than from technological activities. Thus, boards have audit committees, pension committees, etc., but very few have a technological audit committee. The company just referred to above happens to be one of them. And although a recent article [38] urges a strategic planning committee of the board to work closely with the CEO, this is not practiced very extensively for similar reasons. Such a situation exists in many companies, even within the high technology industries referred to earlier in this paper.

Innovation cannot be controlled in a rigid time frame; it does not occur on a monthly, quarterly, or annual basis. (The timing of strategic acquisitions is equally resistant to orderly calendarization.)

VII. Conclusions

1. The chemical industry is one of the seven major R&D spenders, and is one of the four largest privately funded R&D industrial efforts. As a consequence, the R&D cost to the chemical industry is exceptionally high when compared to annual profit or capital investment. To a large extent it is the price one pays to stay alive in this competitive world of high technology, and to maintain an edge over newer entrants who have less technology at their disposal. To some fortunate and well-managed organizations, at certain points in history, in addition, it has been the cause of rapid economic advancement and an entrenched position for many years.

2. Reported statistics are not really satisfactory as to identification by business line of chemical R&D costs, sales, productivity and return on investment. "Productivity" is particularly hard to define because of vast improvements in product quality over the years.

3. There is no obvious statistical relationship between R&D costs and any business success index such as profitability or productivity. Price indices in the chemical industry have tended to lag behind cost increases over the years while return on investment is not outstanding compared with other industries, and has changed little. These returns would look even lower if true replacement cost accounting could be employed, especially in an era of high double-digit inflation such as today's. A recent study of inflation accounting[39] indicates that for the chemicals industry in 1978 the inflation-adjusted profits would be 64% of the reported income, and 62% for the period 1974-1978. It is partially due to this perception of lower real dollar profits that the industry has held its real R&D spending at a constant level, which contributes to

the relative decline in R&D mentioned earlier in this paper (for example as a percent of sales). The conclusion is that competition has been fierce, the structure of the industry faulty in many segments, and the game is still inviting to too many new entrants. Also, the chemical industry is probably too broad a category for a macro-economic study of the effectiveness of R&D, since important segments of the business have relatively very high or very low R&D budgets, and many important statistical areas (e.g., rubber and oil companies, chemical arms of non-chemical companies) are not clearly reported.

4. One of the major results of chemical R&D is the benefit by way of improved productivity and quality to many industries that use its constantly improved and diversified products (food, clothing, housing, transportation, medicine) as well as the resulting ultimate social benefit to individual consumers. Therefore, the chemical industry's R&D cost center is to an extent an unpaid, unsung hero (this might well be said of other industrial R&D cost centers also).

5. Because of low growth of the economy, coupled with high inflation, exacerbated by excessive regulation and unfavorable tax structure, there has been a trend away from high-risk, new-product and new-process R&D, towards development and improvement of existing processes and products, which produce a more immediate and less risky return, as well as to acquisitions of established enterprises in preference to building first-of-a-kind innovative plants. New capacity is resisted and market share sometimes yielded in favor of higher profitability. The trend to conglomerates applies even to this industry, with some of the pitfalls mentioned by Prof. Drucker being just as applicable to basic chemical companies suddenly all looking for "specialties," etc.

6. Because of the existence of a large number of fully or partially depreciated plants, built at deflated prices, optimized, debottlenecked and otherwise full beneficiaries of the "learning curve," a new process or product has to be seen by management in the proper long-term perspective in order to claw its way into this competitive arena. Indeed, it is no longer true that the newer plant is the low-cost producer in the industry—quite the opposite is often more nearly the case. In fact, a close reading of history would show that many major developments of today were at the time of their discovery apparently only marginally better than existing technology, if at all.

7. The industry has traditionally had a high R&D expenditure level, but in recent years this effort has slightly declined; there are signs, however, of a welcome tendency to increase selectively R&D spending once again. This is essential for the health and strength of the industry, for there are still unlimited opportunities for existing and new products and processes. The circumstances of lower economic growth, high costs of energy and raw materials plus heavy regulatory burdens are demanding technological change and innovation. Most economists would agree that technological change is *the* driving force behind economic growth, and has been for the U.S. the major source of such growth and increases in productivity for a very long time. But for R&D to be translated into economically beneficial results to the firm in the form of innovations, and for society to enjoy the high social rate of return which seems to accompany such innovations, the government must establish a more favorable climate for capital formation and risk taking by the private sector, which must mean urgent attention to the barriers created by inflation, regulation, taxation and uncertainty. History shows that close coupling of innovation with the market is an essential ingredient to success, and that governments are not good at making the kinds of decisions required. As the

paper on Japan in this book demonstrates, the Japanese methods are different, but in a market economy like that of the U.S., there is no substitute for the creation of a favorable climate for technological individual profit-oriented firms. Professor Mansfield's paper in this book makes the same fundamental point.

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RECEIVED November 13, 1979.

3

Science, Technology, and Innovation in Europe

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During the recent European elections, the preparation for which was likely rather confusing for Americans, I often heard here an interesting definition of the typical European: he would have the even-temperedness of the Irishman, the charm of the Prussian, the imagination of a Belgian, the sobriety of a Luxemburger, the flexibility of a Dutchman, the good nature of the Dane, the punctuality of the Italian, the modesty of a Frenchman, and, last but not least, the love-making ability of an Englishman.

As a modest Frenchman, I am very flattered to have been invited to address this most distinguished group on innovation in Europe, a very fashionable subject now.

In this country, European innovation is continually praised, compared to the U.S. which is viewed as losing its position of technical leadership to Europe and Japan. The paper of C.A. Sears describes what the situation is in Japan, but as far as Europe is concerned, let me tell you that everything is not nearly so rosy as people say, and that Europe, with its usual delay, is now starting to come to grips with problems similar to those that this country began to face several years ago. I shall return to these shortly. In addition, as J. Herbert Hollomon, Director of the M.I.T. Center for Policy Alternatives, points out, science and technology policies in the several countries that make up Europe vary significantly. He goes on to say that Great Britain emphasizes basic research, and France, national independence in some advanced technologies, whereas West Germany encourages the private sector and liaisons between the state, the university and industry. I would add that these science and technology policies, when there is any consistent policy at all, are often contradictory.

The fact is, no one knows yet if and when Europe will become one entity -- politically, economically and industrially -- as well-defined as the 50 states which comprise the United States. But it seems now that economic union will precede political union which, in turn, will precede industrial union.

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Thus, without being aware of it, or at least without reacting, Europe, as did the U.S., entered a completely new situation which contains these four components:

Component No. 1. An irrational and misleading hostility of the public towards technical progress which is blamed for all problems, even though no respected specialist would deny the overriding importance of new technology in the unprecedented and ever-increasing standard of living of this same public. From this hostility springs the enormous proliferation of regulations, some of which are necessary, but many which are exaggerated and even counter-productive. As an example, let me remind you of the oft-cited case in the pharmaceutical industry which I learned myself from Bruce Hannay, Vice President, Research and Patents, at Bell Labs: in 1938, receiving approval for the introduction of adrenalin to the market required two years and a 27-page report; in 1948, an expectorant needed 73 pages; in 1958, the description of a treatment for pinworms took 439 pages in two volumes; in 1962 a contraceptive required 12,370 pages in 31 volumes; and in 1972 a skeletal muscle relaxant needed 456 volumes weighing one ton and taking 10 years to prepare. I leave it to you to imagine what more up-to-date figures would look like ... but I can tell you that some European countries are vying with the U.S. in this area.

Component No. 2. A general and absurd belief that everything has been discovered, even though a simple cursory look at recent scientific progress, and the re-examination of some theories which have been challenged by this progress, underlines the belief that everything is yet to be discovered. This misleading idea is even shared by some of our experts, as it is found to be a major theme in the first report of the Club of Rome.

Component No. 3. There is a difficult economic context on which it is useless to dwell. It rewards the short term over the long term, leading to a drastic reduction of R & D budgets, thereby compromising the future. Instead of development by innovation, business today prefers development by acquisition, a more immediate source of profit.

Component No. 4. A new sociological context, notably with a new balance of desires and possibilities between work and leisure. To illustrate, I only have to mention the astonishment of my American colleagues at the report of strikes in France by employes demanding the generalization of a fifth week of paid vacation.

This dramatic change in the environment makes it imperative for Europe, as well as the United States, to adopt a radically new attitude -- in a word, to innovate, technological innovation

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being only one aspect, although an essential one, of total innovation.

It is useful to measure the possible dimension of technological innovation by examining what has been accomplished in the last 10 or 20 years in Europe, and in predicting what seems possible in the 10 to 20 years to come. This study was carried out with EIRMA (European Industrial Research Management Association), the sister organization of the IRI, by the "Technology 88" committee, chaired by Mr. B. Delapalme, Vice President, Research and Development, Elf Aquitaine. Concerning the technological upheaval of the last few years in Europe, I will only have to cite a few figures: in a quarter of a century, from 1950 to 1976, car ownership in Europe increased twenty-fold, the number of passenger-miles of the European airlines increased thirty-fold, and households with a refrigerator, fifty-fold. In just ten years, from 1966 to 1976, annual European production of color television sets quintupled, whereas the price of the electronic parts needed (and their size as well) were divided by 100, putting this technology within the reach of a much larger public.

The list could be long. But it is regrettable that hardly anyone ever speaks about this in the mass media.

Has everything been invented? All we have to do to realize that the answer is no is to look at the electronics industry which has known the greatest changes in the last 20 years. We are now witnessing a series of innovations at the heart of which is the microprocessor. These innovations sprang from the theory of quantum mechanics, leading to Bohr's atomic model, followed by semi-conductor physics, then the transistor, then integrated circuits. It is in this continuous line of developing technology that microlasers are now being developed. They will make it possible to produce new quantities of information corresponding to the increased capacity of the newer micro-processors, while optic fibers will allow for their transmission, creating a whole communication process. This kind of progress is destined to invade other aspects of life: M. K. Teer, Director of Electronic Systems, Philips Research Center, estimates that the cost of circuits will be one-sixth of what it is today in ten years, whereas the number of bits of information that can be stored per circuit will be multiplied by 100, thus tripling the foreseeable net sales in the sectors where it can be used. It is difficult to know where to turn next to apply the technological advances which are at hand.

The situation is similar in biochemistry in which development should be evident during the next 20 years by its impact on such varied areas as nutrition, health, chemistry and energy. I will just mention in passing genetic engineering. Innovation in this area is advancing rapidly and the outcome is difficult to evaluate today, but it could revolutionize the methods of manufacturing not only pharmaceutical products, but also most intermediates in organic chemistry.

From this point of view, the EIRMA committee I mentioned earlier strongly emphasized the insufficiency of relations between so-called "horizontal" industries which have a great tempo of technical progress, i.e. electronics, biology, chemistry; and "vertical" industries, i.e. transportation, shelter, food and clothing for which the tempo of progress is much slower, undoubtedly because there is insufficient penetration of these new technologies into these sectors. The Japanese have been very successful in two popular consumer areas by applying the latest progress in electronics, to photography and audiovisuals.

It is generally agreed in Europe that the steel, textiles and paper industries are those currently having the greatest difficulties, but at the same time, technical progress in these areas has been relatively slow and R & D expenditures have been very low, often less than 1% of the net sales. On the other hand, there has been considerable progress in the technologies of electronics and aeronautics, and it is exactly in these areas where research spending has been the greatest, often exceeding 10% of net sales. These figures speak for themselves.

In order for the rate of technological progress to remain constant or even to increase in some areas, European governments must both provide incentives and even offer new directions, but of course without giving in to the temptation of taking a place in private industry, nor even imposing solutions which must remain the responsibility of industry itself. This attitude implies a certain confidence which appears to be sorely lacking at the moment.

It is becoming more and more apparent that the trends which seem favorable to the consumer or the businessman for the short run, or in a particular area, are not favorable universally, over the long term, to the nations of Europe, to European scale. European governments, therefore, have a duty to use the considerable means at their disposal to bring these trends into line. The largest proportion of their budgets designated for innovation is often channeled into defense or national prestige, and very little -- often less than 20% -- to consumer areas, the so-called bread and butter industries. National policies, and international as well through the Common Market and the OECD, should take into account more carefully the real new problems which need to be solved, such as inflation, unemployment, and working conditions.

One important element of innovation which might take different forms in Europe and the U.S. will be a greater awareness of the sociological considerations in the changes to be made. This new awareness will make it necessary for social and economic sciences to be introduced in an interdisciplinary approach, this approach which has been talked about so much over the last few years.

In general it is imperative during the coming years that European industry become much more open in various directions -- towards potential consumers in order to understand their real

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needs; towards other industrial sectors as a primary supplier, client or joint venture partner; toward government agencies for the establishment of reasonable regulations; toward other countries such as America and Japan, but also toward the developing countries to find complementary areas of cooperation; and finally toward the people who influence public opinion and the mass media to enable them to understand the true possibilities of industry, an understanding which is sorely lacking at present.

In both the U.S. and Europe, as you have witnessed, the problems are similar. There are, however, additional difficulties for Europe because of its lack of unity. Nonetheless, in both areas we must not underestimate our responsibility as representatives of the scientific community. The new world which is coming into being is presenting challenges which we must meet, challenges which, in many cases, we have the means to overcome. But we must act now and see these changes as opportunities to seize rather than chasms in which we risk disappearing. Remember the quotation from Shakespeare: "There is a tide in the affairs of men, which, taken at the flood, leads on to fortune; omitted, all the voyage of their life is bound in shallows and in miseries. On such a full sea are we now afloat and we must take the current when it serves or lose our ventures."

RECEIVED November 13, 1979.

4

Innovation in Japan

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For the past twelve years, I have had the very stimulating and interesting experience of being closely associated with Japanese industry. Through this period of time, we have negotiated and established technical exchange agreements, licensing agreements and joint activities with a number of Japanese companies. As a result of this experience, I have developed a great deal of respect and, I hope, some understanding of the Japanese, their industrial system, their society and cultural activities, and their general way of life.

The population of Japan approximates 50% of the population of the United States with a total land mass less than many of our individual states. Approximately 25% - 30% of the Japanese population live in a corridor about 350 miles long extending from Tokyo to Osaka. In addition to this apparent resource limitation of land area per unit of population, Japan has essentially no natural resources.

However, even with these limitations, this "island country" has become a major factor in the industrial world of today. Perhaps these very limitations have contributed to developing the strongest resource of Japan -- its human resource. This human resource has brought Japan to its leadership position and this resource could propel this "island country" to an even greater position in the future.

Japan's human resources have more than counter-balanced this country's lack of natural resources, and have required that the Japanese people innovate to become a leader in our industrial society or stagnate and become a "loser".

The course they have successfully followed is readily apparent in world markets.

Japan's success at innovation is legend. For example, Japan has increased their automobile production over 100 times (from 100,000 units to 10,000,000 units per year) in the past two decades.

In addition, Japan has taken the leadership from Germany in camera production; from Switzerland in watch manufacturing, and

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has captured the market in high fidelity systems, radios and TV's from the United States. They have captured the market from Great Britain for motorcycles. They are reputed to be ahead in quality and efficiency of steel production and have surpassed the United States and Great Britain combined in shipbuilding.

Many of the innovations that have lead to Japanese commercial leadership are based on discoveries made in the United States, Great Britain, or Western Europe. Specifically, Sony Trinitron TV is based on technology "discovered" in the United States. Sony innovated a commercial system/product based on this. In the late 1960's, Japanese TV manufacturers adopted solid state systems for their units; United States' manufacturers stated "they would never fly".

Such innovation lead to lower costs and energy conservation - reflected in Japan's taking the lead in the TV industry. The miniturization of multiple function, liquid diode calculators were successfully innovated to commercial products by the Japanese. The basic discoveries were made in the United States. Other examples could be cited, including the quartz and digital watches.

Harvard economist, Dale Jorgensen, has reported that although Western societies are ahead in a number of advanced research fields, Japanese industrial plants had, by 1973, surpassed ours in regard to modern improvements. Their product, process, and marketing innovations, based on discoveries made in other parts of the world, is openly exhibited.

Japanese products and market success have been subject to much criticism, particularly relative to pricing policies. Some of this may be justified, however, let us give credit where credit is due.

It is an accepted fact that Japanese products are of highest quality, but it is not as widely understood that Japanese companies do not generally have what we identify as a quality control department -- their quality control is built into every step of the operation as a part of their "zero defect" program. It is a recorded fact that, generally, Western production failures for quality reasons are 2 - 4 times higher than those of comparable Japanese items.

The effect of this upon costs and resultant pricing options/ policies is obvious. This is truly a part of the innovative process.

Japan's basic dependence on import and export markets -- or the need to think in terms of world markets/supplies -- has created a society with the ability to adapt and innovate to meet these basic needs. This innovative process includes qualities of doing their "homework" thoroughly, of patience to understand, and the ability to adapt and design product or market systems for specific situations.

Japan has proven its unique innovative character. The factors that have contributed to this unique character should lead to Japan's playing an increasingly greater role in discovery and innovation on a world-wide basis for the future.

I am confident that there are many examples that could be cited that would reflect the innovative leadership of the United States and/or Western Europe.

The purpose of this discussion is not to reflect on whether one area of the advanced world is more innovative than the other but to point up those factors that create a very favorable climate for innovation in Japan.

At this point, it may be helpful to define the views accepted for this presentation relative to innovation. I have generally accepted the definition, "innovation is the technical, industrial and commercial process or steps which lead to the marketing of new manufactured products and commercial use of new technical processes and equipment". By this definition, we can include the discovery process with the innovative process or consider discovery as a separate, distinctive process from innovation -- although each is dependent upon the other. We prefer to consider them in a separate sense.

There are at least four key factors that contribute to creating a favorable climate for innovation. These factors exist in any advanced society, but it is my view that these characteristics in Japan result in a more favorable climate that:

1. has lead to Japan's success with the innovative process
2. will continue and strengthen this trend
3. will lead to greater contributions in the discovery process in the future

I would like to consider with you those key factors that contribute to creating a favorable (or unfavorable) climate for innovation and discovery and the particular characteristics in each of these that result in a very favorable climate for future discovery and innovative contributions from Japan. These key factors are:

1. the human resource
2. the management resource
3. the government/political resource
4. the financial resource

Perhaps the most basic element is the nature of the Japanese people and their culture. Earlier we mentioned the human resources of Japan and their importance relative to the lack of natural resources.

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

The Japanese are a closely-knit, highly-motivated, well-disciplined, highly-intelligent society. They take great pride in their respective place in society, and in turn, respect the place and importance of the individual as a part of the whole.

For example, I doubt that anyone who has been to Japan is not impressed by the pride each person takes in his job, his company, his possessions, and those possessions of his company or others.

The taxi drivers, when not driving, are polishing and cleaning their cabs. This character of cleanliness and pride is reflected throughout the society.

There is an esprit de corps in Japanese companies that is enviable. The average worker is not just an employee -- he is the company. This is reflected in their indirect and direct support of the industrial system. The Japanese savings rate is at least 3 - 4 times greater than in the United States. These savings provide funds for re-investment and modernization and play an important role in the fact that Japan has a re-investment rate at least two times that of the United States.

Japan has one of the highest educational levels in the world.

Their crime rate has dropped 50% since the late 1940's and did so despite increasing industrialization and urbanization.

The Japanese average life span is longer than any other nation, reflecting again, the pride, discipline, and recognition of the individual.

An important characteristic of the Japanese is their ability to be "alone". This seems contrary to our observations that Japan is a highly-populated country with relatively small living area and people, people, people everywhere. However, it is just this factor that, I believe, has taught the Japanese to discipline themselves to "be alone" or detach themselves from the masses, even though they physically may be in the center of such masses.

Why is this important to innovation? To innovate requires a kind of "aloneness". This is a first condition for creative or innovative thinking. Those who fill their days with whatever tasks present themselves and continually work in pressure situations,who cannot detach themselves and find an "aloneness" or an "awareness" will probably not innovate or create. They will react -- in contrast to causing reaction.

These socio-economic factors contribute to a stability within the individual and society which, in turn, creates a favorable climate for reflective thinking which, in turn, leads to discovery and innovation.

The role of management or leadership in contributing to the overall health of the group corporation is well-documented. Perhaps in Japan, the key contribution of management has been its ability to create, adapt, and maintain those favorable characteristics that exist in their human resources.

For example, I have discussed with associates in Japan their lifetime employment policies. As you know, the unemployment rate in Japan is normally less than 2% and when it exceeds this there is great concern. Some Japanese question their lifetime employment policy. It is my view that we in the United States have a lifetime employment system, however, the difference is that in Japan it is managed and controlled by the private sector, while in the United States it is managed and controlled, to a major extent, by the public sector through welfare programs, food stamps, etc. It takes little imagination to consider which is more costly to a society, both in terms of dollars or yen and, as important, in pride and utilization of the human resource.

The average Japanese worker is now as highly-paid as in other industrial economies such as the United States and Western Europe. However, Japan's productivity per worker is at least 1½ times that of the United States and their product quality enjoys an enviable position. The cooperation between labor unions, management, government, and the financial institutions are unique to any industrial system and contribute greatly to Japan's ability to maintain a relatively stable system even in light of significant shifts in other sectors of the world's economy.

The resources of government can support or detract from the innovative process. In Japan, the government, generally, is supportive of the innovative process through the Japanese government's direct support of the industrial system. For example, in 1978, sixteen government technical centers, with about 3800 specialists, were funded by MITI. These laboratories are primarily oriented to the individual entrepreneur or the smaller enterprises that do not have large research facilities. In addition, there are about 200 test and research institutes, one in each prefecture and major city, that support an additional 7500 specialists.

Perhaps as important, or even more important, is the Japanese government's attitude toward industry. MITI is a difficult "task master", as is any bureaucracy. However, this agency performs as a focal point to coordinate and rationalize Japanese industry. Their efforts, without fear of antitrust or government control, serve a useful purpose in aiding industry to focus on what is to Japan's best interests short and, particularly, long-term.

For example, through various government and private studies, it was determined (1 - 2 years ago) that there were several structurally weak industries in Japan. Through programs developed by MITI and industry, these industries were restructured by various methods - including shut-down and dismantling of excess capacity (NH_3, for example). Industry was provided proper tax incentives and employees were shifted to new positions. This provided the opportunity for Japan to focus the important resources of capital and people into areas that were, longer-term, more beneficial to their economy and society. This would not have been possible without government's full support.

It is a recorded fact that the Japanese government and Japan's industry have made a joint commitment to obtain a leadership position in the communications industry, including computers. Studies carried out in 1964 and 1970 have shown that the Japanese have developed a superiority in mathematics and related sciences over other advanced societies of the world. This critical resource of technical training will contribute greatly to this national commitment.

It is reported that some informed observers expect that Japan will reach the general level of United States computer technology by the mid 1980's and that by 1985 Japan will enjoy a 6% - 10% share of the United States computer market - worth about $1.7 - $3 billion to the Japanese economy.

This is quite an incentive!

Capital formation and utilization are vital to the free enterprise system and the free enterprise system is the best overall climate for innovation.

Japanese industry is highly leveraged - by our standards. For example, in the United States, an average debt/equity ratio may be in the range of 20/80 to 40/60; but in Japan the reverse ratios are common. We contend that this directly or indirectly favors the innovative process.

You will recall that the average individual savings rates in Japan are about 20% - 25%. These savings generate capital for re-investment and indirectly make the Japanese society an integral part of the capital formation process. We could logically rationalize that the equity/stock system provides the same opportunity to the individual. The fallacy may be that stock ownership is not as widely spread as savings systems.

However, even more important, the equity system creates external pressures on management by many not gifted with an understanding of the business process. The equity system places much greater emphasis on short-term profits, price/earnings ratios, and the other measures of financial success.

Perhaps another way of expressing this is that in the equity system there are many more external pressures, including individual shareholders, the media and various financial institutions.

In the debt system, there is essentially only the banker to answer to. Normally, in Japan, he will be more close to and understand the business. As long as his investment is generating proper interest, his external pressures will be minimal.

This generally leads to more patient money, longer-term projects, and a more favorable climate for the innovative process.

In summary, Japan has created an innovative society. This was needed to survive. Following survival, they have extended this innovative character to become a leader in the world's advanced societies.

In the past, innovation has been sufficient to bring them to this position. In the future, we believe, and many Japanese confirm this, that Japan must assume a greater position in the discovery process as well as the innovative process. There is every indication that Japan will be as successful here as they have been in the innovative process and assume an even greater role in future scientific discoveries and developments.

RECEIVED November 13, 1979.

5

Innovation and Technology Assessment

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The climate for innovation has taken a steady pounding in recent times. By comparison, the climate was salubrious in the early 1960's. Entrepreneurs flourished and venture capital flowed readily to finance new technological initiatives with long-term pay offs. Innovators and entrepreneurs took big chances in an economic environment that encouraged the creation of new technologically based enterprises. The risks were high, but so were the potential rewards.

Since that time, darkening skies have characterized the climate for innovation and they have dampened entrepreneurial and innovative spirit in America. They seem to have come hand-in-hand with the increasing centralization of decision-making in our society and with economic policies that encourage consumption and discourage investment for the future. Although it purports to be able to, a ham-handed federal government has amply demonstrated that it cannot efficiently and wisely handle all of the levers in a $2,300 Billion economy. Stagflation has pulled the rug out from under Keynesian economics and its federal practitioners.

Excessive federal spending and monetary expansionism and rampant interventionism and tinkering with the productive apparatus of the economy have been antithetical to "letting a thousand flowers bloom" in the fields of innovation. As a result, the "Innovation Indicators"--the signs that tell us something about the health of the U.S. scientific and technical enterprise--have taken a decided dip over the past decade.

As you know, the Carter Administration has been engaged in a Domestic Policy Review on Innovation. What you may not know is that this has been a custom of every administration for the past 20 years.

- o In 1961, President Kennedy urged that technological innovation be stimulated and unshackled.
- o In 1965, President Johnson exhorted his administration to do likewise.

- In the Nixon Administration we had the "New Technology Opportunities Program" and, in 1972, the White House sent Congress the first Presidential Message on Science and Technology.
- In March of 1979, the Carter Administration followed suit and delivered its message on science and technology to the Congress.

And we are soon to see, we have been told for many months now, the fruits of the Domestic Policy Review on Innovation.

Critics can be forgiven if they sense a certain disingenuousness in this quadrennial display of concern for the problems of inventors, innovators and entrepreneurs. It all seems to be part of the "Presidential Cycle" . . . and an eye to the next New Hampshire primary.

These cycles of concern about innovation generate a lot of hot air in Washington, lots of political hot air, so that there is a new theory on the uniqueness of Washington, D.C.: "It is the only place in America," a physicist friend of mine has observed, "where sound travels faster than light."

If 20 years of Presidential studies on innovation are a harbinger, it is unlikely that very much of the fine work that has been put into the Domestic Policy Review by Frank Press and his excellent staff, as well as the many outstanding advisory panels that participated in this effort, will survive the Office of Management and Budget and Gerald Rafshoon and Company. My guess is that what survives that process will sound embarrassingly familiar. No new insights will light the way. The sound will probably still travel faster than light up Pennsylvania Avenue.

To old hands, the pronouncements will probably seem a familiar litany of exhortations and admonitions. But in fairness, that misses the point, for the merit of these pronouncements lies not in novelty, but perhaps in a reaffirmation of some basic principles:

- That technological innovation is the key to productivity-improvement and the economic and social health of our society;
- That R&D, while indispensable, is but a prelude to innovation;
- That transforming R&D into new products, systems, and processes is a high-risk venture;
- That the incentives for doing so have to be commensurate with the risks;
- That creative individuals, in Abigail Adams' phrase, do not "fall from the sky like the God-given rain:" They must be nurtured and cultivated;
- And finally, that it is far easier to stifle innovation than it is to stimulate it.

Thesebasic principles were enunciated during the Johnson Administration by a blue-ribbon Panel on Invention and Innovation.

I had the privilege of working with that Panel, which some of you may recall as the "Charpie Panel," named after its Chairman, Bob Charpie. We argued and debated and studied the problems faced by inventors, innovators, and entrepreneurs. For a year we did this, and then it was my job to synthesize all of that into a final report. The title of it was, as some of you may recall, Technological Innovation: Its Environment and Management.

Briefings on the report were held for members of the Cabinet and the heads of the regulatory agencies. It was discussed personally with President Johnson. No one can say whether they were persuaded, but they sure seemed concerned. What killed us, I think, was the paralysis that was just beginning to set in then. Like so many aspects of national life at that time, our recommendations for improving the national climate for invention and innovation were a casualty of the Vietnam War and the "guns and butter" inflation that was beginning to smolder.

The recommendations in that report covered taxation, venture capital, antitrust and regulation, patents, education, and the special problems faced by new technologically based enterprises. What I remember most vividly, however, was the final recommendation. Let me read it to you:

> "One more recommendation remains and it is, in our view, of key importance . . . .
>
> "For whether we talk about the problems and contributions of a large or small company, a regulated or unregulated industry, or an individual inventor or entrepreneur, there is too little appreciation and understanding of the process of technological change in too many crucial sectors:
>
> "--Throughout much of the Federal Government.
> --In some industries.
> --In many banks.
> --In many universities.
> --In many cities and regions.
>
> "More important, therefore, than any specific recommendation concerning antitrust, taxation, the regulation of industry, or venture capital, is one central proposal:
>
> > "The major effort should be placed on getting more managers, executives, and other key individuals--both in and out of government--to learn, feel, understand and appreciate how technological innovation is spawned, nurtured, financed, and managed into new technological businesses that grow, provide jobs, and satisfy people."

Now, the need for that kind of appreciation and understanding, particularly for those who determine the policies affecting innovation, is even greater today than it was 12 years ago when the Charpie report was published.

And the reason is that all of the "Innovation Indicators" have been going down-hill since that time. I have compared various indicators that have been suggested as measures of the health of the nation's scientific and technical enterprise. Dick Atkinson, the Director of NSF, provided some figures recently, as did Irving Shapiro of DuPont. Others have as well.

Before I get into these figures, let me begin with a caveat: Some indicators can be misleading. For example, if we look at absolute figures and not just rates of change, it is clear that the United States is still ahead of the rest of the world in terms of productivity and investments in R&D. Also, none of these indicators gives us a straight cause-and-effect forecast, but in the aggregate they give a clear signal of changes in the climate for innovation.

As I said, every one of these indicators turned downward about a decade ago.

One rough indicator is R&D spending. As a percent of Gross National Product, R&D funding, both public and private, was down by about 20% in 1978 from what it was in 1968.

A second indicator is refined from the first one: the amount of R&D spending that goes to basic research. That not only tells us something about the reservoir we will be drawing from a good many years hence; it also tells us a lot about the prevailing attitudes toward the future. It's an optimistic country that makes a big investment in its future for the next generation.

What does the record show about our commitment to basic research? The fraction of GNP devoted to basic research was about 20% less in 1978 than it was in 1968--although I should say that in adjusted dollars, the support for basic research is about the same now as it was then.

A third indicator is private spending for R&D. This is the one most closely associated with real economic growth and the ability to compete internationally. From this one comes the technology to create most of the permanent new jobs. The U.S. is now spending less in this column, as a percent of GNP, than either Germany or Japan.

A fourth indicator is corporate profitability, and the key measurement here is not gross dollars, but the actual purchasing power of the dollars left after taxes. After you squeeze out the inflation and put aside enough money to cover replacement at today's prices for the plant and equipment that is wearing out, there is less left to encourage new ventures now than there was 10 years ago.

Walter Wriston, the Chairman of Citicorp, commented on this recently. He objected to government spokesmen who were traveling around the country telling people that the real villains of inflation are the business men who are raising their prices and the labor unions that are raising wages. He observed that "the government's ability to devastate an economy and blame it on

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

someone else can never be overestimated." "The reason we have inflation in this country," he explained, "is that since 1967 the government has caused the money supply to grow nearly three times as fast as the goods and services that can be bought with it."

It is sobering to recall that it was Nikolai Lenin who said: "The best way to destroy the capitalist system is to debase the Currency."

From an inflation rate of 2-3% in the mid 1960's, we are now at 13% and climbing.

A fifth indicator is <u>the burden being placed on the Nation's productive apparatus by government</u>. Given a capital-starved economy, it is little wonder that managements will tend to avoid the longer-term risks for those that are shorter-term and less uncertain. Government regulations have mushroomed over the past decade and, consequently, so too have the perceived risks for investments in innovation.

Now, regulations for health, environmental and safety reasons are a basic mission of government. Many of these regulations have spurred innovations, such as more fuel-efficient automobiles. However, it is also true that regulation, by definition, usually constrains the scope of innovative activity--especially the introduction of new drugs or chemicals.

Consequently, the question is now whether government regulation affects the climate for innovation, it does of course. Nor is the question whether or not there should be government regulation. Of course, there must be.

Rather, the question is how can we provide a more rational basis for government regulation? How can government perform its proper regulatoryrole, while minimizing the barriers to the creative renewal of society? Technology assessment is one of the ways to provide a more rational basis for these kinds of decisions.

In the late 1960's and early 1970's Congress had been put through a technological wringer. Scores of unevaluated and irreconcilable assertions and opinions had handicapped Congress in appraising such highly technical matters as the anti-ballistic missile, the SST, environmental standards, food additives, and advanced rapid transit systems--to name just a few.

It was for this reason that the Congressional Office of Technology Assessment began its work in 1974. Its job is to assess the impacts of technological applications and to identify the advantages and disadvantages of alternative policy options for enhancing the benefits and reducing the costs of such applications.

Some of you may recall that when OTA began its work in 1974, industrialists and others in the scientific and technical community viewed it with strong misgivings. They feared it would be a brake on progress, and some referred to it scathingly as the Office of Technology <u>Harassment</u>. But the record shows that OTA has definitely remained impartial with respect to technology. OTA's job is not to advocate. It is neither pro-technology nor anti-technology.

It is true that some of the most ingenious technologies can go awry or be misused. Everybody has a list: phosphate detergents, thalidamide, Three Mile Island, and so on. However, the concern for technological misapplications goes too far when it becomes a crusade to turn off all technology. Turning off nuclear power plants means turning on coal-fired ones. The risks won't go away. Learning how to cope with risks in a rational way is perhaps the most fundamental challenge to a democratic society. And trying to put a cap on technological innovation is not a rational response to this challenge.

For technological innovation is indispensable to social progress. This was brought home dramatically by Richard Strout of the Christian Science Monitor in an article on world population. Each day, he said, adds a new Toledo, Ohio, to the world: that is to say, 250,000 people each day. That comes to 90 million more people a year, if you keep on adding it up. It is technology that has made these staggering increases possible. And it is the increasing aspirations of this ever-increasing world population that makes technology indispensable.

It is easy to bemoan the problems that have resulted from some applications of technology and to advocate a return to the simpler lifestyles of yesterday, to a society less dependent upon technology. Those simpler times were possible when there were fewer people with more limited aspirations. But today we have no choice but to go forward, striving to increase our understanding of the world around us.

We cannot rely on the crystal-ball gazers, for the future has a way of mocking the futurists. And so, we'll have to rely on good judgment. Some 20 years ago John Von Neumann said that "For progress there is no cure. Any attempt to find automatically safe channels for the present explosive variety of progress must lead to frustration. The only safety possible is relative, and it lies in an intelligent exercise of day-to-day judgment."

That sums up what we can expect from technology assessment. It is not a magic formula and never will be one. It is not even an exact science, although it draws on all sciences. But it is a way of providing a more rational basis for the decisions that governments and societies will make one way or another.

RECEIVED December 18, 1979.

6

Systems of Innovation MACRO/MICRO

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Innovation has been linked to rising productivity, to growth in employment, and to an improved quality of living. It has also been linked to increasing economic growth and to strong positions in export markets and trade. Conversely, a lack of innovation in the face of rising competitive challenges may contribute to inflation, to unemployment and dislocation of labor, to stagnation of growth, and to the rising importation of more attractive or lower priced goods. But understanding this is of little importance unless one understands how innovation occurs and how to influence it.

The central theme of this analysis is that the conditions necessary for rapid innovation are much different from those required for high levels of output and efficiency in production. The pattern of change observed within an organization will often shift from innovative and flexible to standardized and inflexible under demands for higher levels of output and productivity. Different creative responses from productive units facing different competitive and technological challenges may be expected, and this in turn suggests a way of viewing

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Note: The author is especially indebted to William J. Abernathy. Our collaboration over the past four years has led to many of the ideas and findings expressed here. Many others were originated by him and are explored in the context of the auto industry in his recent book The Productivity Dilemma (Baltimore: Johns Hopkins University Press, 1978). This paper is based on work supported by the National Science Foundation, Division of Policy Research and Analysis under Grant No. PRA76-82054 to the Center for Policy Alternatives at the Massachusetts Institute of Technology. Some parts were previously published in Technological Innovation for a Dynamic Economy, C. T. Hill and J. M. Utterback (editors), Pergamon Press, 1979.

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and analyzing the possible policy options for encouraging innovation. [1]

Many alternative definitions and conceptions have been used for various purposes in studies of innovation. One perspective sees innovation as a creative act synonomous with invention; while another sees innovation as a thing, i.e., a piece of hardware and possibly its design and production; and still another views innovation as a choice to use a thing, including possibly the ways which it is used and its diffusion. The first of these definitions focuses on the originality and newness of the innovation; the second, on its tangible form and use in the market or production process; and the third, on marketing approaches to different classes of users. In order to encompass these varied perspectives, innovation has been defined here as a process involving the creation, development, use, and diffusion of a new product or process. [2]

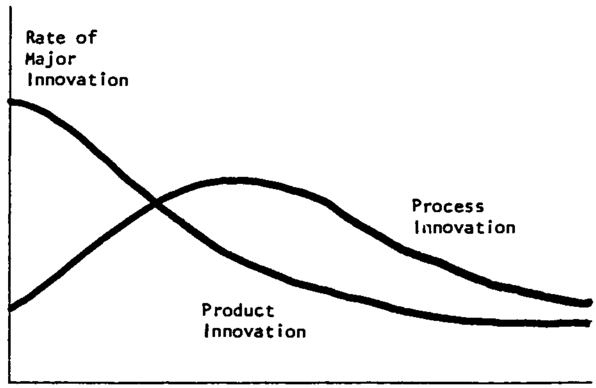
Innovations vary greatly, and some of the differences among them appear to correspond to markedly different patterns in the process through which they arise. In particular, it is important to distinguish between product and process changes, and between innovations which require change in many facets of the firm and those which require only modest change. [3]

A Dynamic Model of Product and Process Change

One way of viewing different types of innovations and their relationships is to think of them as successive steps in the development of a line of business. The business starts through the origination of one or more major product innovations. These are usually stimulated by users' needs through frequent interaction with users of the innovation. Exploration of the product's potentials in different applications follows. Rising production volume may lead to the need for innovation in the production process. Demands for greater sophistication, uniformity, and lower cost in the product create an ongoing demand for development and improvement of both product and process. This means that product design and process design become more and more closely interdependent as a line of business develops. A shift from radical to evolutionary product innovation will usually occur as a result of this interdependence. This shift is accompanied by heightened price competition and increased emphasis on process innovation. Thus, small-scale units that are flexible and highly reliant on manual labor and craft skills and that use general-purpose equipment will develop into units that rely on automated, equipment-intensive, high-volume processes. Changes in innovative pattern, production process and scale, and kind of production capacity will all occur together in a consistent predictable way. [4]

These relationships are summarized in Fig. 1. The rate of major product change is shown to be high at first and gradually

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.



	Fluid pattern	Transitional pattern	Specific pattern
Competitive emphasis on	Functional product performance	Product variation	Cost reduction
Innovation stimulated by	Information on users' needs and users' technical inputs	Opportunities created by expanding internal technical capability	Pressure to reduce cost and improve quality
Predominant type of innovation	Frequent major changes in products	Major process changes required by rising volume	Incremental for product and process, with cumulative improvement in productivity and quality
Product line	Diverse, often including custom designs	Includes at least one product design stable enough to have significant production volume	Mostly undifferentiated standard products
Production processes	Flexible and inefficient; major changes easily accommodated	Becoming more rigid, with changes occurring in major steps	Efficient, capital-intensive, and rigid; cost of change is high
Equipment	General-purpose, requiring highly skilled labor	Some subprocesses automated, creating "islands of automation"	Special-purpose, mostly automatic with labor tasks mainly monitoring and control
Materials	Inputs are limited to generally-available materials	Specialized materials may be demanded from some suppliers	Specialized materials will be demanded; if not available, vertical integration will be extensive
Plant	Small-scale, located near user or source of technology	General-purpose with specialized sections	Large-scale, highly specific to particular products
Organizational control is	Informal and entrepreneurial	Through liaison relationships, project and task groups	Through emphasis on structure, goals, and rules

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Figure 1. A dynamic model of innovation (5)

diminishing as major process innovation increases. Both product and process change subsequently become incremental in a situation marked by production of standardized products in high volume. Competitive emphasis is first on functional product performance, later on product variation and finally on cost reduction. Innovation is at first stimulated by information on users' needs and even by users' technical inputs. As the product line and process develop, opportunities created by expanding internal technical capability increasingly provide the stimulus for innovation. Later, pressures to reduce cost and improve quality are expected to be the major stimuli for change. The initial product line is diverse, often being mainly custom designs. Innovative emphasis will begin to shift when it includes at least one product design stable enough to have significant production volume. The line of business will consist mostly of undifferentiated, standard products when it is fully developed.

Production begins in a flexible and inefficient form, and major changes are easily accommodated. As volume expands, processes become more rigid, with changes occuring in major steps. Ultimately the production process assumes an efficient, capital-intensive, and rigid form, and the cost of change is consequently high. General-purpose equipment, requiring highly skilled labor, will be used at first. Later, some subprocesses will be automated, creating "islands of automation" linked by manual processes. Special purpose equipment which is mostly automatic, with labor tasks consisting mainly of monitoring and control, will be the hallmark of highly developed productive units. Early on, materials inputs are limited to those generally available. Later, specialized materials may be demanded from some suppliers. If specialized materials are demanded, but not available, vertical integration to provide them will be extensive.

As the line of business develops, location will also shift. Early plants will be small-scale and near users and sources of technology. Ultimately, plants will be large-scale, highly specific to particular products, and located to minimize materials, labor and transportation costs. In sum, small-scale units that are flexible and highly reliant on manual labor and craft skills using general-purpose equipment will develop into units that rely on automated, equipment-intensive, high-volume processes, which are highly productive but correspondingly less flexible. In this setting, major product or process innovations will tend to be viewed as disruptive and will tend to originate through invasion of the line of business by new entrants.

As a unit moves toward large-scale production, the goals of its innovations change from meeting ill-defined and uncertain targets to meeting well-articulated design objectives. In the early stages, there are many product performance requirements which frequently cannot be stated quantitatively. Their relative importance or ranking may be quite unstable. It is precisely under conditions where performance requirements are ambiguous that users are most likely to produce major product innovations and where manufacturers are least likely to do so. One way of viewing regulatory constraints in the later stages of a product's evolution, such as those governing auto emissions or safety, is that they add new performance dimensions to be resolved by the engineer--and so may lead to more innovative design improvements. They are also likely to open market opportunities for innovative change of the kind characteristic of entrepreneurial firms in such areas as instruments, components, and process equipment.

The stimulus for innovation changes as a unit matures. Initially, market needs are uncertain, and the relevant technologies are as yet little explored. Uncertainty about markets and appropriate targets is reduced as the unit develops, and larger research and development investments are justified. At some point, before the increasing specialization of the unit makes the cost of implementing technological innovations prohibitively high and before increasing price competition erodes profits with which to fund large indirect expenses, the benefits of research and development efforts reach a maximum. Then, technological opportunities for improvements and additions to existing product lines become clear. A strong commitment to research and development is characteristic of productive units in the middle stages of development. Such units invest heavily in formal research and engineering departments, with emphasis on process innovation and product differentiation through functional improvements.

Although data on research and development expenditures are not readily available on the basis of productive units, divisions, or lines of business, an informal review of the activities of corporations with large investments in research and development shows that they tend to support business lines that fall neither at one extreme nor the other but are in the technologically active middle range. Such productive units tend to be large and to have a large share of their markets. [5]

Units in different stages of evolution respond to differing stimuli, or respond differently to the same stimuli, and therefore, undertake different types of innovation. This idea can readily be extended to the question of barriers to innovation, and probably to patterns of success and failure in innovation for units in different situations. New entrepreneurial firms tend to view as barriers any factors that impede market aggregation, while firms with stable products and markets tend to rank uncertainty over government regulations or vulnerability of existing investments as more important disruptive factors. [6]

Sources of Radical Change

Radical innovations occur in quite a different manner than the normal evolutionary pattern described above. A radical change is one which can create new businesses and transform or destroy existing businesses. Substantial portions of the capital stock will essentially be swept away and replaced.

Innovations which serve the same purpose as a familiar product, but from a different technological base, can result in a discontinuous or radical change and are perhaps the most familiar example. The electronic calculator replacing electro-mechanical calculators, transistors replacing vacuum tubes, jet engines replacing piston driven engines in aircraft, and diesel electric locomotives replacing steam locomotives for rail transport are among the examples of this type.

Dramatic change in process technology, structure and economics, can also create new businesses and undermine existing investments. For example, Pilkington's float process for making plate glass removed the need for laborious grinding and polishing in finishing plate glass and resulted in a highly automatic and integrated process with superior economics. Today, most flat glass production is accomplished through the licensed Pilkington process. Another example is the process for making ammonia using centrifugal compressors which was introduced by the Kellogg Company. This process not only quickly replaced the existing plants of many manufacturers, but also encouraged the entry of a number of new firms and encouraged the production of ammonia in new locations. [7]

Direct regulation of products and processes may result in higher barriers to entry and more entrenched market positions for existing products. It may also result in greater conservatism in design and focus on improvement of existing technology. But regulatory impacts may also produce revolutionary changes, at least from the viewpoint of the productive unit. For example, restriction of chlorinated hydrocarbons for use as dielectrics in transformers has resulted in the entry of new competitors in this market with products such as silicones and phthalate esters.

Drastic change in the cost of inputs may also result in rapid shifts in technology. Of course, the most familiar example is the recent increase in oil prices which has made past investments predicated on declining prices unattractive. But shifts in the availability of other materials, for example, the loss of natural rubber supplies during World War II, have resulted in major new businesses in the past and may well also in the future.

The data plotted in Figure 2 show an example of one such discontinuous or radical change. Major product and process innovations by the Ford Motor Company are plotted over the period from 1900-1940. [8] The period 1900-1909 saw Ford introduce seven different models of automobile with cumulative production volume slightly exceeding 40,000 units. In 1908, the

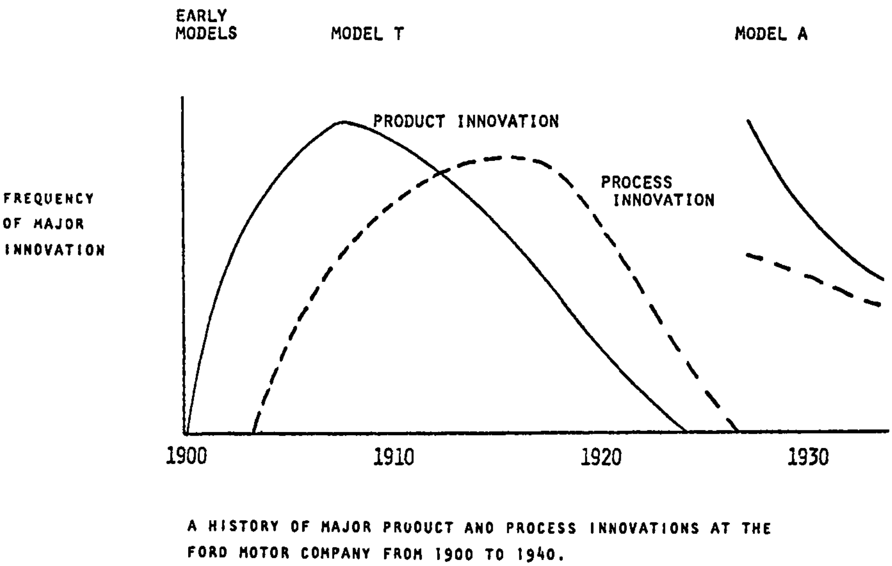


Figure 2. An example of discontinous change in products at the Ford Motor Company (data taken from 8*)*

Model T emerged and a year later became the dominant design in the company's product line. The shift away from product innovation and the rising importance of major process changes at this point can be clearly seen. The Model T was produced for nineteen years with cumulative production volume rising during the period to exceed ten million units. The consequent reduction in both product and process innovation over this period of rising product standardization, and an implicit shift toward more incremental cost reducing types of change, can be seen in the center of the Figure. Then, the introduction of a new technology and functional technological competition resulted in a period of crisis and discontinuity in the auto industry, especially for Ford. The advent of ductile steel sheet allowed the deep drawing of body parts. This, among other factors, enabled Dodge and General Motors to introduce the enclosed automobile, providing higher performance at a higher price. Ford soon found its market share and profit margins dropping as a result of the invasion of its markets. Falling volume produced heavy penalties because of the large fixed investment made earlier by Ford in its efforts to achieve productivity through plant expansion and vertical integration. Ford's attempts to improve its existing product to meet the new competition further eroded its profitability. [9] The well known result was that Ford shut down its operations during 1927 throwing 60,000 persons out of work, discarding much of its capital equipment at a cost to the company of over 200 million dollars in investment in current dollars. The Figure clearly shows another result which was an immediate jump in major product change to nearly the maximum level that had been reached just prior to 1909. Process innovation can also be seen to have accelerated, though there is a greater degree of carry-over in production process technology than was true in the product technology.

In examining case studies and sources of historical evidence on the process of innovation, one is struck by the fact that the Model T example cited above is more the general rule than a unique case. Periods of rapid change do often appear to be followed by periods of consolidation, adjustment through incremental change, and productivity advances as suggested above. More remarkable is the prevalence of periods of crisis or "reversals" toward more innovative behavior in each of the areas studied. Fairly complete evidence are available on more than thirty such discontinuities and fragmentary evidence and suggestions of that many more. In addition to those already mentioned above, some of the more striking cases are the replacement of manual typewriters by electric typewriters, synthetic fibers displacing natural fibers, celluloid roll film replacing gelatin plates in photography, natural ice being replaced first by manufactured ice and later by mechanical refrigeration, tufted carpeting for woven carpeting, the basic oxygen furnace for steel making replacing the open hearth system, gas lamps replaced first by carbon filament incandescent lights, later by tungsten filaments and still later by fluorescent lighting.

A General Pattern of Response to Technological Invasion.

Established firms often respond to an invasion of their product line by new technology with redoubled creative effort and investment in what they know well. The new technology may be viewed as expensive and relatively crude at first, leading to the belief that it will find only limited application. Crude as it is, the new technology may have great performance advantages in certain submarkets and gains ground by competing in them first, and use of the new technology expands by means of its capture of a series of submarkets. [10] As the market expands it may also have much greater potential for improvement and cost reduction than does the existing technology. This quickly reduces the effectiveness of price cutting by established units as a defense. The new technology often opens new applications. In many cases, sales of an established technology actually increase while substitution is occurring, but the new technology captures most of the expansion of the market. Certain submarkets may be free from competition from the new technology for a long period of time. During a period of technological invasion the defensive efforts of established firms may cause the old technology to reach much higher levels of performance and sophistication than those previously attained, but this usually ultimately proves to be a futile response resulting in loss of market share and exit from the business.

Usually a radical innovation originates outside the recognized set of competing units in an industry. Small new ventures, or larger firms entering a new business, introduce a disproportionate share of the innovations which create major threats and conversely opportunities. There are many reasons why new entrants as opposed to firms with an existing stake in a business should be expected to be major innovators. The rewards may be greater to the entering firm which views the innovation as opening a new market rather than as a substitute for an existing product. The established firm may view rewards to be obtained from improvement of the existing technology as more attractive, because given the high volume of production of existing lines, return on investment in improvements can be high, rapidly realized, and relatively certain. By entering the new technology, an existing firm may substitute for its own products, thus reducing the benefits to be gained. In markets with relatively stable demand an innovation may even lower total revenues. Established firms are faced with choosing among massive investment in new equipment which will result in stable or declining sales, modifications of current products which can be built with existing equipment, price cutting or exit from

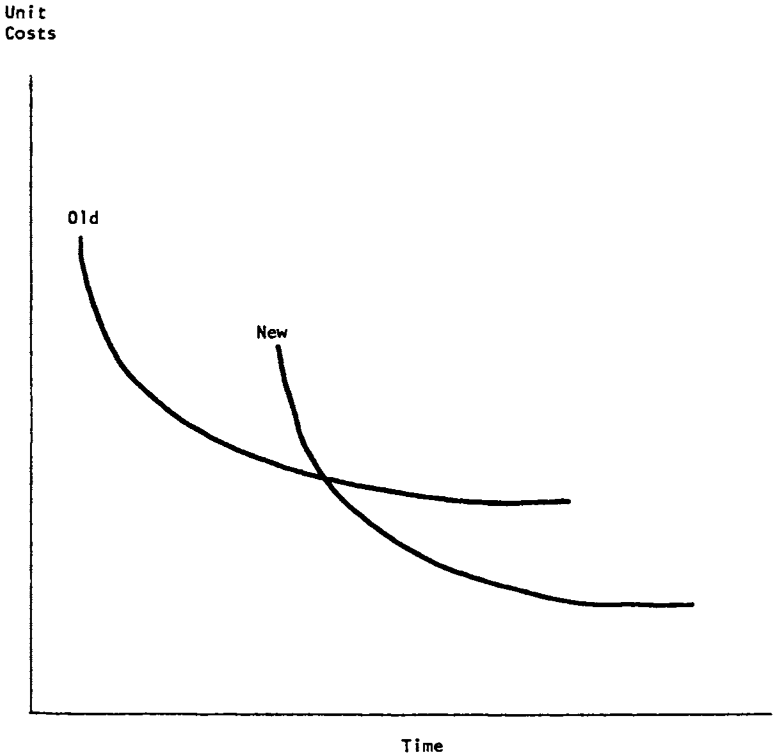
In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

business. But the new firm without an existing stake sees the innovative product as a means for market penetration and rapid expansion.

Established firms are ordinarily highly sophisticated and capable in technical terms. In almost every instance of an invasion studied, existing firms had considered and tried the new technology earlier themselves, or at the same time that invading firms were developing it and rejected it for a number of reasons. While economic arguments may reinforce perceptions and organizational influences, the latter must be governing in most cases. The established business may be growing moderately or strongly. Peoples' careers in the organization have been built on a subtle understanding and long contribution to the development of the established business. Ways to improve the old may be clearly seen while the potentials in the new are much more difficult to comprehend either by the established firms or invading firms. The returns to the old will be quick and sure and spread over a large production volume, while the early gains in the new technology will be slow in coming and difficult. Most importantly, the established firm will tend to view the new technology simply as a substitute for the old, and it is objectively a poor substitute at first. Its real potential to broaden the base of the technology and market may well be hidden at first and may develop in completely surprising and unexpected ways as users experiment with it in various applications and combinations.

The viewpoints of established and invading productive units are contrasted in Figure 3. The established technology follows the upper and left most curve, and at a particular time noted on the abscissa we can see that it has reached a low and gradually declining level of unit cost and a relatively high level of quality or performance. At the same time, the entering new technology shown by the right most curve can be seen to have relatively high unit cost, low quality and performance. It is in this situation that an established firm might emphasize the major difference in cost and quality between the new and the old technology, while the entering firm might emphasize the unique performance properties, and the very rapid rate of improvement in its technology, of the new technology regardless of cost and price. As can be seen from Figure 3 this situation may quickly change as the new technology captures successive market segments and as production volume expands, and it may dominate the old technology on the basis of cost as well as perfomance. After the new technology bypasses the old, there may be a sharp break in the old technology from the extrapolation of the path it had been following as many creative improvements in both product and process are explored.

At this point, the situation in the business has dramatically changed. Firms which were not competitors a few years before will be major actors in the business and may even dominate



THE COST OF AN INVADING PRODUCT, OR OF A FAMILIAR PRODUCT PRODUCED WITH A NEW PRODUCTION PROCESS, MAY AT FIRST BE WELL ABOVE THOSE OF AN ESTABLISHED PRODUCT OR PROCESS. AT THE SAME TIME, COSTS OF THE NEW MAY FALL MUCH MORE SHARPLY THAN FOR THE ESTABLISHED TECHNOLOGY AS EARLY GAINS ARE MADE.

Figure 3. Unit costs of an established and an invading product over time

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

it. Firms which were strong earlier may be markedly weaker and may exit from the business. The technological base, raw materials, labor skills and support functions necessary in the business may be markedly different.

The emphasis in competition will shift to product performance and away from cost and quality while, at the same time, prices may drop with extraordinary rapidity, and many new options and performance dimensions may be available to users. The total market may expand as a direct consequence of the invading innovation. This postpones the inevitable abrupt decline of the established technology and lends false strength to arguments against withdrawal from the old and rapid investment in the new on the part of established actors in the business. In the following sections each of these ideas is examined in the light of specific cases and examples.

The Traditional Technology Improves Dramatically When Threatened

Rather than beginning to atrophy when challenged by new technology, the traditional technology often goes through a rapid creative surge and a period of renewed vigor and investment. Following the introduction by Eastman Kodak of celluloid roll film, the Scoville Corporation attempted to penetrate the same amateur market with small lightweight plate cameras and developing and printing outfits for amateurs. Perhaps the most creative response to the invasion of the photographic market by multiple exposure systems was the development of a magazine camera in which a pack of rigid plates each moved in turn into the focal plane as the previously exposed plate was folded into the bottom of the camera. [11] The makers of steam locomotives for the railroads introduced two remarkable innovations in response to the invasion of their traditional markets by the new diesel electric technology. [12] Both were based on steam turbines, one of which was mechanically coupled to the driving wheels of the locomotive, the other of which was coupled to the driving wheels through an electric generator and electric motor. Five of the turbine-mechanical engines were actually built and three of the turbine-electric, which were sent around the United States on tour prior to their introduction in commercial use. All were quietly scrapped a few years later. The makers of natural fibers such as wool and cotton labored mightily under competitive stress from synthetic fibers to make their product more easily used in manufacturers' applications. Their innovations included ways of grading the fibers to assure uniform staple lengths in each batch and ways of coating the fibers to make them more workable and less likely to break when formed into yarn. [13]

Echoes of todays concerns are often found when examining responses of older technologies to earlier crises. When confronted with competition from home electric refrigerators, the makers of iceboxes and ice for home refrigeration responded in remarkably contemporary ways. Iceboxes were introduced with far better insulation and ventilation allowing a given amount of ice to last as much as three times longer than it did in prior models. Cost of use to the homeowner was reduced in other ways as well, including automatic systems for removing melt water from the icebox, systems for easily cutting cubes from the larger cake of ice, and prescoring of the hundred pound blocks delivered door to door to assure the homeowner of a fair and accurate delivery of ice. The iceman's unshaven appearance was improved, and he was given a uniform and a canvas bag in which to carry the ice to the kitchen, preventing puddles on the floor and improving the company's image for reliable and efficient service. [14] These measures effectively lowered the life cycle cost of ownership and use of the icebox to the consumer and allowed the industry to retain a respectable share of the market for a much longer period than might have been expected. [15]

Sometimes the creative response of the old technology may be so vigorous as to drive back or nearly overturn the new technology. Aluminum engine blocks, which provided better handling characteristics and fuel economy for automobiles, appeared to be certain to capture a major part of the market prior to the introduction of thin-walled cast iron engine blocks in response. Thin-wall casting technology, introduced by the Ford Motor Company, allowed a greater transfer of production equipment and machining and maintenance skills to the new use and soon prevailed over the aluminum alternative. [16] Prior to the introduction of the carbon filament electric lamp by Edison, gas illumination was accomplished by using an open flame like a candle flame. The disappearance of their business to the newer competitor stimulated the innovation of the gas mantle, which consisted of a set of glowing ceramic filaments, excited by the flame, to produce more pleasing illumination from gas with five times greater efficiency. The resulting sharp jump in the appeal of gas made it a much stronger competitor for a time.

The give and take between electric and gas illumination also illustrates how, often, the seeds of the new technology or creative response were sown in a much earlier period, but not recognized until a crisis caused the need to search broadly for alternatives and solutions. A button of calcium oxide, heated by a gas flame, had been used to provide the bright light needed for theater illumination as early as 1820. Our phrase, "to be in the limelight", originates from this technology which foreshadowed the idea of the gas mantle. Similarly, Edison used various metals as experimental filaments in his lamps, including tungsten, and various gases to serve as envelopes for filaments, all suggestive of technologies which were later brought to perfection to replace the original carbon lamp. [17]

Arnold Cooper and Dan Schendel have studied the strategic responses of established firms in six industries to functional technological competition. No threatened firm adopted a strategy of early withdrawal from the old technology in order to concentrate on the new. Moreover, all but one of the twenty-two companies continued to make heavy commitments to the improvement of the old technology.

Most of the firms followed a strategy of dividing their resources, so as to participate in a major way in both the old and new technologies. Baldwin Locomotive developed both advanced turbine-powered electric locomotives and diesel-electric locomotives. CBS and Raytheon developed new lines of vacuum tubes and also made major investments in research and development and production facilities for transistors. This dual strategy was not usually successful, particularly in relation to building a strong competitive position in the new technology. There were no apparent actions taken by the traditional firms to create or strengthen the barriers to adoption and diffusion of the innovations.

Firms that pioneered the new technology generally did not enter the old technology. The new technology often evolved rapidly. Transistors, nuclear power plants and jet engines all confronted participants with a succession of decisions about commitments to evolving technologies. Early leaders, such as Raytheon in transistors and Curtiss-Wright in jet engines, lost their competitive positions as the technology changed.

Over the long run most of the traditional firms that tried to participate in the new technology were not successful. Of the fifteen firms making major commitments, only two, Parker in ball-point pens and United Aircraft in jet engines, enjoyed long-term success as independent firms participating in the new technology. [18]

The New Technology is Crude, Expensive and Unreliable

The old technology is almost always less expensive, more reliable, and better in performance than the new technology when it is introduced, but it may have unique performance advantages that make it desirable in some few applications. For example, the fluorescent light was extremely costly at first, but because of its cool light and long periods between replacement of the lamps, the production of the Sylvania and General Electric Companies could scarcely keep up with burgeoning initial industrial demand. [19] The early transistors were extremely limited in frequency response and had poor temperature stability, but their extreme ruggedness, light weight and low power requirements made them highly desirable for certain missile guidance and miniature applications. The early diesel locomotives for rail use were cumbersome and underpowered but had advantages which made them attractive for special applications, such as yard work and switching. Early electric typewriters were expensive, and the manufacturers of manual typewriters generally thought of them as limited in application.

Celluloid photographic film gave poor quality images which were often blurred by the discharge of static electricity in the film. Under heavy competitive pressure from larger established companies in gelatin plate technology, George Eastman decided to emphasize the unique advantages of his system which resulted in the now famous roll film and camera for amateur use. Eastman sold the camera loaded with 100 exposures for ten dollars. Once these were taken by the user, the entire camera containing the film was mailed back to Kodak for processing and the resulting prints were returned with a freshly loaded camera to the owner for an additional fee of five dollars. His innovations made photography simple, inexpensive and portable and thus opened a much broader potential market than that held by the professional dry plate systems then available. [20]

The cases above amply illustrate that the new technology may have great potential for improvement however crude it may seem at first. Each of the technologies just cited quickly changed as they became the focus of technical investigation. In every case, they advanced much more rapidly than the older technology and quickly overtook it and dominated it. Each of these new technologies also established new firms or new entrants in their respective businesses and led to bankruptcy or much weaker positions for several of the strong existing competitors, a point to which we will return in a later section.

The New Technology Enters a Special Market Niche

Use of the new technology first expands through the capture of some market segments where its unique performance advantages are critical and where less emphasis may be placed on the disadvantages just discussed. Mechanical means for making ice were first used in locations in the South far removed from ocean shipping where less expensive naturally frozen ice shipped in from the North was unavailable. As mechanical icemaking technology improved, it became increasingly competitive with natural ice harvested from rivers and ponds and moved successively northward until the last commercial operation using harvested ice closed its doors in Massachusetts in 1949. [21] Edison's carbon filament incandescent lamps were first used on shipboard where their great safety and convenience made them especially attractive. Rotating machinery was also readily available to drive the generators. The user innovator in this case, Henry Villard, later became a major investor and president of the Edison Company, later the General Electric Company. [22] Contemporary examples would include the solar generation of electricity, which while unattractive for general use, has found applications in remote pumping and communications stations where the cost of generating electricity by other means locally or transmitting it over long distances would be more prohibitive.

The special expansion or vacant market niches required for invasion are often provided by the performance demands of the federal government or of large manufacturers. That is, a large customer may act as an "external champion" for the radical invading innovation through investment or initial purchases. Examples which quickly come to mind are the transistor, and later the integrated circuit, and jet aircraft engines and computers, all of which received significant stimulation from the demands of the Department of Defense. In each case, new firms were formed to meet needs for high performance products. Changes in the market can be created in other ways as well. For example, lighter weight automobiles and the use of new materials and electronics in autos may be the result of federally mandated emission and fuel economy standards.

On the commercial side, the demand for new processes by which to produce large volumes of plate glass was initially the result of the development of enclosed automobiles and the consequent demands of Ford for volumes of plate glass. The Ford Motor Company developed the mechanical elements of a process for continuous casting of glass. Lack of experience in operating the glass melting tank caused problems which Pilkington, an established glass manufacturer in the U.K., helped to solve. [23] (The relationship of this development, if any, to the later float glass process is not clear.)

The desire of the calculator industry to provide features such as printing led to the development of the first microprocessor chip according to Richard Petritz. He notes that the same Japanese calculator company, Busicom, which worked with Intel on the business calculator program that had led to the first microprocessor, had earlier worked with Mostek on the four function calculator. [24] Clearly user needs and sponsorship play an important role in stimulating radical, that is capital destructive, innovations.

Technological Innovation Leads to Changes in Market Structure

In an earlier article, Bill Abernathy and I contended that major new products would tend to be introduced either by their users, by small new enterprises entering a business or by larger firms diversifying into new markets based on their technological strengths. [25] The present analysis strongly reinforces this idea. George Eastman started his business as a hobby, and he was one of the early amateur photographers. Because he was not committed to the ideas and materials used by professional photographers, he experimented widely with other possibilities for making film. [26] Rayon was first developed and extruded by a manufacturer of electric incandescent lamps, the Swan Lamp Company, which needed to produce more uniform and reliable carbon filaments. [27] One of the first systems for manufacturing ice was developed by a docotr for medical uses in his hospital. [28] Eric von Hippel's recent work gives other examples and reasons why users might be expected to play this role. [29]

Major corporations can also create radical changes in unexpected arenas by building on their technological skills. For example, the advent of the diesel electric locomotive was the result of a conscious decision of General Motors to carry its business beyond its traditional lines. General Motors heavily backed a number of projects to diversify around the theme of durable goods connected with motors. Within these boundaries the diesel venture, in 1930, appeared as an opportunity to be pursued. [30] The electric typewriter resulted from a similar urge on the part of IBM to diversify beyond its traditional lines. Tufted carpeting also came from an outside group of firms, those which were making bedspreads, based on the adaptation of their production equipment and the use of synthetic fibers for carpet making. This innovation occurred at a time when the market for woven carpet was stagnating and the traditional firms in the industry were suffering from declining volume, rising prices and lower profit margins. The new entrants revolutionized the market for carpeting by providing a low cost utility material that could be used widely, and this provided a rapid market expansion and dominance by the new firms. [31]

It is intriguing to note that even in the few examples cited above, the new small enterprises appear to enter first in essentially vacant market niches or expansion markets where in the initial steps in their growth they do not meet frontal competition from established participants in a line of business. On the other hand, one might speculate that substitution markets are the forte of existing enterprises exploiting their technological skills in a new way. What are the characteristics of a corporation that husbands a major innovation and thrust into a new market area? Rosenbloom suggests that General Motor's new decentralized structure of largely autonomous operating divisions and the freedom this provided to evaluate new areas for corporate ventures and for development by the technical staff and the research laboratory under Kettering, may have been critical incubating conditions for its venture into diesel engines and locomotives. [32]

The payoffs for established firms in a line of business may be quite different from those for new entrants, either new enterprises or new ventures of existing corporations. The traditional firms may see the new technology as essentially capital destructive. Using purely short term economic criteria, they may reasonably choose a sequence of incremental innovations to improve the old technology over withdrawal and investment in the new until the point at which they go bankrupt. Indeed, it is difficult to clearly see the threat from the new technology at first, as mentioned above, especially when it is providing a market expansion or entering a special purpose market segment. Amateur roll film did not immediately compete with the much higher quality dry plates being used by professional photographers, yet Eastman Kodak's market share climbed relentlessly, and its product improved until the once dominant Anthony and Scoville Companies were forced to merge into the Ansco Corporation and occupy a minor part of the photographic market. [33] Nor did mechanical processes for making ice immediately appear to afford the threat of a host of new entrants to the increasingly concentrated natural ice harvesting industry. But entry occurred first where economics were most favorable, that is, where natural ice was least available and transportation costs were greatest. Next, breweries and meat packers converted to mechanical ice making because, at the time, nearly half of their land and capital were tied up in massive icehouses for storing ice from one winter to the next. This process continued inexorably until natural ice was last replaced in the market segment which was most favorable to it, the part of the United States with the longest and coldest winters. [34]

It is fascinating to speculate whether the outcomes we observe in the past might have been entirely different with different timing. For example, had steam turbine electric engines been introduced in the market a few years earlier, would we still have railroad transportation based on coal and steam? Or, with the current concern over energy availability and prices, and regulatory demands for industrial conversion to coal, might we again see railroad transportation based on a more sophisticated and highly developed form of one of these earlier failure attempts? What is clear from the cases is that the established firms reacted too late to save their business, and that waiting until a threat is obvious is clearly a dangerous strategy.

In some product lines, the last few firms in the established technology can be highly successful and profitable and even highly innovative. There will probably always be a demand for fine mechanical watches, and perhaps the few firms that survive the present shakeout in the industry will be highly profitable and stable companies. And the few firms which remain manufacturing vacuum tubes, probably supply a highly specialized and profitable market for high performance designs, research and other specialized applications.

What Does this Mean for Your Firm?

An accepted analysis for the determination of new product strategy and selection criteria in larger firms is often to project the desired growth of total sales on the one hand, and the declining value of sales of existing products on the other, resulting in a growing gap over future years which must be filled by sales of new products not presently marketed by the firm. This analysis is fine to a point, but it often results in the recommendation that the firm must have one or two products which will reach 100 million dollars sales in five years, or perhaps four or five new products that will each reach 40 or 50 million dollars sales within the next five years, and this is the point where the analysis breaks down. Worse, the firm may specify that the new products must be produced in ways that are similar to the production processes for its existing products and must be marketed through similar channels of distribution in similar markets. Products which ultimately become the commercially important high volume core of the business of large firms, typically start off with rather limited high performance sales prospects. The ultimate use of the product is almost never the one which is first envisioned, nor often is it even imagined at the beginning. It is surprising how often even the strongest and most rapidly growing element of a firm's existing business would fail the stringent tests posed by such a gap analysis for new product innovations. The message here is that new things must start small but may grow in unexpected, often startling ways.

The new line of business should start by stressing performance at a high price in a specialized market niche, whether it is being introduced by a new enterprise or an existing firm invading a new market. New enterprises may price their products too low in competition with existing alternatives, ignoring the extra values provided by their special performance characteristics. This may lead to a rapid expansion of demand and a corresponding attempt by the firm to expand its production by rapidly adding to personnel, in-process-inventory, and so on. The consequence is a serious problem with cash flow and often the need to sell control of the firm to raise capital in the face of great success in the marketplace. Higher initial prices allow a greater degree of trial and error at small volumes, of modification and adaptation of the initial product designs, and of beginning development of the production process, before the need to expand volume rapidly occurs.

How might a firm recognize a small high performance market niche which has the potential to expand broadly. One answer is to work with several highly demanding users. This may involve taking the firm into a market which it would not otherwise enter and which might appear to be inconsequential.

Another approach is to explore the implications of a new unrelated technology which might provide the same function as the firm's core product line. This requires a special concern for the legitimacy of the new effort which might be provided by internal technological and business champions. [35] In the extreme, this alternative might require that resources for development be withdrawn from the current technology and given to the new, unless the expenditure of resources for the vigorous and competitive development of the older technology is also desired.

The importance of this is that the complexity of managing and introducing the new product is as great as successfully managing a larger and ongoing business, and the organizational and competitive demands of the new business might be quite different from that of the old as well. Because the new business generally requires an initially much lower level of investment, number of people and so on, if combined with an ongoing business, it may well receive a proportionately smaller part of management's attention. In either case, a different type of organization is required for the smaller and newer line of business.

Notes

1. Firms vary greatly in size, diversity of product lines, resources, and in their attempts to create different kinds of innovations. To deal with this diversity, the convention of looking at what might be termed a productive unit or simple firm--that is, a part of an organization which produces a related group of products, and its associated production technology--will be adopted. In the case of a diversified or multidivisional company, this would be one of its divisions, often geographically and usually managerially separate from other parts of the organization. These units often exhibit consistent patterns of innovation, with some stressing new products and product performance, others stressing major advances in production technology, and yet others constantly improving product quality, costs, and productivity. While these patterns are not completely exclusive, it will be shown later that the way in which innovation occurs, the forces which stimulate innovation, and the types of policies which influence it, will vary directly with these different sorts of innovations and emphases.

2. By analogy this might be extended to the case of services (although indeed there is very little information available on service innovations) whether they be major new services offered to the public or to industry, completely different ways of providing a service, or improvements in service quality and cost.

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RECEIVED November 13, 1979.

The Economics of Innovation

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The purpose of this paper is to summarize very briefly some results that my students and I have obtained in some econometric studies financed by the National Science Foundation. These studies pertain to the social rates of return from investments in new technology. By a social rate of return, economists mean the rate of return to society as a whole. Although it has long been recognized by economists that estimates of such rates of return are of crucial importance in formulating any rational policy toward civilian technology, no estimates of this sort have been made for industrial innovations. To help fill this gap, we constructed a model which indicates how such estimates can be made for many, but by no means all, innovations. This model includes the pricing behavior of the innovator, the effects of the innovation on displaced products, and the costs of uncommercialized R and D and of R and D outside the innovating organization, as well as a large number of other factors.

In an econometric study described in detail in a recent book (1), we obtained very detailed data concerning 17 innovations from the producers and users of the new technologies, and applied this model to obtain an estimate of the social rate of return in each case. Practically all of these innovations were of average or routine importance, not major breakthroughs. (For one thing, we wanted to avoid biasing the sample toward innovations that probably had relatively high rates of return.) Although the sample cannot be regarded as randomly chosen, there is no obvious indication that it is biased toward relatively profitable innovations (socially or privately) or relatively unprofitable ones. In large part, it contains undramatic, run-of-the-mill improvements in products and processes, like a new type of thread or an improved machine tool. As many studies indicate (2), this is the type of work that accounts for most industrial research and development.

The findings are quite striking. The median social rate of return from these 17 innovations was about 56 percent, which indicates that the investments in these new technologies paid off

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handsomely from society's point of view. To check this result, we used the same model to estimate, for one of the nation's largest firms, a lower bound on the social rate of return from its investment in new process technology in 1960-1972. This result too was about 50 percent. Of course, our sample, although large relative to what was previously available, is too small to support definitive conclusions, but the results certainly suggest that, even taking into account the riskiness of innovative activity, the rate of return from investments in new technology has tended to be high.

To extend this sample and to replicate our analysis, the National Science Foundation commissioned two follow-on studies, one by Robert R. Nathan Associates and one by Foster Associates. Nathan, based on its sample of 20 innovations, found the median social rate of return to be 70 percent and the median private rate of return to be 36 percent. Foster, based on its sample of 20 innovations, found the median social rate of return to be 99 percent and the private rate of return to be 24 percent. Thus, their results, like ours, indicate that the median social rate of return tends to be very high, and much higher than the private rate of return. (The private rate of return is, of course, the rate of return to the firm that introduced the innovation.)

One reason why economists are interested in estimates of this sort is that they provide clues as to whether we as a nation are under-investing or over-investing in civilian technology. If the marginal social rate of return from investments in civilian technology is greater than the marginal social rate of return from other uses of the relevant resources, this is evidence of an under-investment in civilian technology. Unfortunately, our results pertain to the average, not the marginal social rate of return from investments in civilian technology. William Fellner and Zvi Griliches have argued that it is legitimate--or at least not too rash--to make the jump from average to marginal rates of return. Indeed, in Griliches's view, there is no reason to believe that the marginal rate of return differs much from the average rate of return. If this is the case, our results certainly suggest that there may be an under-investment in civilian technology in the United States, since the average rate of return seems very high.

Our findings concerning rates of return are quite consistent with other econometric studies that have relied on more indirect methods and have used more highly aggregated data. In a previous study based on statistical production functions (3), I found that the marginal rate of return from R and D in the chemical and petroleum industries was 30-40 percent. Minasian obtained similar results. In a more recent study, Terleckyj has estimated about a 30 percent rate of return from an industry's R and D (in manufacturing), based only on the effects of an industry's R and D on its own productivity. In addition, his findings suggest a very substantial effect of an industry's R and D on productivity growth in other industries, resulting in a social rate of return greatly exceeding the 30 percent figure. Without exception, econometric studies based on production functions point in the same direction as our studies described above. Although these and other investigations (including our own) have noteworthy limitations, it is remarkable that the results, which rely on quite different methods and data, are so similar (4).

To see why there may be some under-investment in civilian technology, one must recognize that private rates of return may not equal social rates of return. As is evident from our 17 case studies, as well as the detailed investigation of the R and D activities of the major firm during 1960-1972, firms often cannot appropriate all of the social benefits from an innovation. A good example is a new type of thread that we studied. Although the social rate of return was over 300 percent, the private rate of return was only 27 percent, partly because other firms began imitating the new thread within six months after the innovator introduced it.

Our findings provide the first glimpse of the differences between private and social rates of return from investments in new technology. In general, social rates of return seem to exceed private rates of return, although this is not always the case. Specifically, the median social rate of return is about double the median private rate of return in our sample, and the social rate of return from the major firm's investment in new process technology in 1960-1972 seemed to be at least double the private rate of return. When we look at specific innovations, the difference between the social and private rate of return seems to be related to the economic importance of the innovation (measured by absolute annual benefits) and to the costs of imitating the innovation. These results are quite consistent with hypotheses put forth by economic theorists (1).

Socially worthwhile innovations--that is, projects where the social rate of return is high enough to warrant going ahead with the project--will not be carried out if the perceived private rate of return is so low that the potential innovator rejects the project (5). An important question facing policy makers is: how frequently does this situation arise, and in what areas is it most prevalent? If this situation is common, it suggests the desirability of direct or indirect government support for such projects. If it is much more common in some types of industries and for some types of innovations than for others, then this support should be focused on such industries and such types of innovations. Economists have long recognized that this question lies at the heart of any discussion of public policy toward civilian technology, but until now there has been no direct evidence concerning it.

Our results cannot indicate a great deal about the frequency with which such situations arise, because our data pertain to innovations that were carried out. (The difficulty, if not impossibility, of obtaining such data for innovations that were not carried out should be obvious.) But a limited amount of evidence can perhaps be derived on this score from the data concerning the 17 innovations. For 9 of these innovations, we could obtain data concerning the approximate private rate of return expected from the innovation by the innovator when it began the project. In 5 of the 9 cases, this expected private rate of return was less than 15 percent (before taxes), which indicates that these 5 projects were quite marginal from the point of view of the firm. (Indeed, the executives of the firms confirmed that they were marginal.) Yet the average social rate of return of these 5 innovations was over 100 percent.

Unless the social rate of return drops precipitously when the expected private rate of return falls from 10 or 12 percent to (say) 5 or 6 percent, this result seems to indicate that there may be many projects where the expected rate of return was a bit lower than for these 5 projects (with the result that they were not carried out), but where the social rate of return would have been quite high. Among the innovations for which we have data, there is no significant correlation between an innovation's expected private rate of return and its social rate of return. Thus, unless there is a sharp discontinuity in the slope of whatever relationship exists between the expected private rate of return and the social rate of return, no evidence exists to suggest a precipitous drop in the social rate of return when the expected private rate of return falls from 10 to 12 percent to 5 or 6 percent. These results, like those discussed above, may point toward some under-investment in civilian technology.

What sorts of public policy mechanisms might be adopted to help deal with whatever under-investment may exist in civilian technology? At least three kinds of mechanisms are suggested frequently--government grants and contracts to industry and universities for more such work, increased use of government laboratories for such purposes, and tax credits for private industry. Our results indicate some of the problems in each of these mechanisms. With regard to grants and contracts, as with any selective mechanism, one runs into the problem that benefits and costs of various kinds of R and D are very hard to forecast. Even major corporations have difficulties using various forms of cost-benefit analysis for R and D project selection, although they have a benefit concept that is much easier to estimate than most government agencies do. To illustrate how far off benefit estimates are, the chances were about 50-50 that a new product's (or new process's) estimated discounted profits would be more than double, or less than one-half, the actual discounted profits in one major firm we studied (6). Also, such estimates may be biased for parochial, selfish, or political reasons, the result being a distortion of social priorities, if the estimates are taken seriously.

Turning to the increased use of government laboratories to

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

promote civilian technology, our results suggest the problems in having R and D conducted by organizations that are not in close touch with the marketing and production of the product. It is very important that there be unimpeded flows of information and good coordination of R and D, on the one hand, and marketing and production, on the other. Otherwise, the R and D is likely to be misdirected, or even if it is not, it may be neglected or resisted by potential users. This is a difficult problem for various divisions of a firm, and it would seem to be made worse if the R and D is done in government laboratories. In the last decade, many governments have tended to convert government laboratories and to increase the amount of government-financed R and D done in industrial firms in order to bring R and D into closer contact with application and commercialization.

Turning to tax credits, it is evident that they would reward firms for doing R and D that they would have done anyway, that they would not help firms with no profits, and that they would encourage firms to define R and D as widely as possible. Some of these problems might be solved by a tax credit for increases in R and D, but many problems remain. For example, firms would still have an incentive to redefine R and D, and for firms that can appropriate little of the social returns from new technologies, R and D would still be unprofitable even if the tax credit existed.

At present, it is difficult, if not impossible, to specify what combination of these (and other) mechanisms would be most effective in compensating for whatever under-investment there is in civilian technology. But it seems likely that any such civilian technology program should be neither large-scale nor organized on a crash basis, that it should not focus on helping sick industries (merely because they are sick), that it should not get the government involved in the latter stages of development work, that a proper coupling should be maintained between technology and the market, and that the advantages of pluralism and decentralized decision making should be recognized. Given the current uncertainties (which, as we have repeatedly stressed, are great), it would seem wise to proceed with considerable caution, and to build into any program the capacity and necessity to resolve many of the key uncertainties before too big a commitment is made.

Finally, it is important to recognize that our nation's technology policies cannot be separated from its economic policies. Measures which encourage economic growth, saving and investment, and price stability are likely to enhance our technological position. And measures which reduce unwarranted regulatory burdens are likely to do the same. Just as many of our current technological problems can be traced to sources outside science and engineering, so these problems may be resolved in considerable part by improvements in the general economic climate in the United States. Indeed, improvements in our general economic climate may have more impact on the state of U.S. technology than many of the specific measures that have been proposed to stimulate technological change.

Acknowledgements

The studies cited in this paper were supported by a grant from the National Science Foundation. Of course, the Foundation is not responsible for the opinions expressed here. This paper is based largely on material taken from reference 1.

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RECEIVED November 13, 1979.

8

Technological Progress and the Investment Climate

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A few years back, many of us grew concerned about the decline in Federal support for R&D that existed for nearly a decade between 1968 and 1976. And we resolved to try to turn this around.

Our methods, in the light of the techniques of contemporary protest movements, may seem strangely antiquated. We didn't march, we didn't scale fences or lie down before any gates, and so far as I know none of us got arrested. We just made speeches, held interviews, testified in Washington. But we were, nevertheless, apparently effective. The U.S. is ticketing well over $50 billion for its R&D efforts this year. And in the past two or three years, R&D spending has been pretty much holding its own -- even with double-digit inflation.

But it soon became obvious that mere increases in Federal spending for R&D alone were not the total solution for the problems of lagging innovation and productivity in the U.S.

The translation of R&D into innovative new products and services is an extremely complex and inherently risky operation. To find answers to why the pace of innovation might be lagging in the U.S., it was necessary to examine the question of why companies innovate anyway, and what specific actions, or lack of action, might stimulate or impede the process.

It was in this perspective, that the Committee for Economic Development, about a year ago, initiated a study of Technology Policy in the U.S. Several task groups, comprised of CED trustees and their advisors, were established to study concurrently the areas of tax policy, patent policy, international technology transfer, regulation, and Federal support of R&D.

The Subcommittee itself was comprised of 30 chief executive officers of leading corporations and university presidents. I served as Chairman of the Subcommittee on Technology Policy.

Professor Ed Mills, of the Princeton Economics Department, served as project director. On May 16 our chief conclusions and recommendations were presented and approved by CED's Research & Policy Committee.

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Our general conclusion was that the environment needed to encourage adequate longer-term investment has deteriorated seriously over the past several years. I won't reiterate all the factors which have contributed to this because you have heard them so many times -- but, taken singly, each one has had its own independent negative impact, and, taken together, they constitute a more serious deterrent than would be implied by the sum of their parts. The overriding concern is the present lack of business confidence in the ability and will of government to frame and implement policies which constructively support the solution to our common problems.

Historically, and over the long-term, spending on physical capital and on R&D are closely linked, and respond to the same set of economic forces. Plant and equipment spending is also closely related to profitability and cash flow.

These factors, in conjunction with concerns about inflation and lagging productivity, in the experience of the 30 chief executive officers, led to the conclusion that policies to reverse the decline in technological innovation cannot be directed at research and development alone, but must address the larger problem of declining business investment.

Technological progress requires an investment climate in which there is a feeling of confidence and reasonable predictability of the long-range future.

For both large and small businesses, technological innovation today is truly a high-stakes game. When the risk/reward ratio changes in ways that reduce the odds on making a gain which requires long-term investments in the creation and application of advanced technology, the responsible business executive is forced to pull back, change strategies, and shift to shorter-term goals. And that is exactly what has happened. Technology managers tell us they are placing much more emphasis on evolutionary fast-payback improvements, regulatory compliance, etc., than on longer-term revolutionary opportunities. This implies, in our view, a need to concentrate first on our economic and regulatory environment.

A system that stacks the odds in favor of refining and acquiring existing businesses, can hardly be called an innovative one -- and certainly this is not the way to create new jobs!

Our proposed strategy is to:

- Begin by improving the environment for new productive facilities. If we can raise the level of investment in plant and equipment, we will increase immediately the rate of diffusion of new technology into the economy and improve the rate of productivity growth.

- Our first priority approach to accomplish this objective is to reduce existing tax disincentives to productive investment, and to reduce non-cost-effective regulatory constraints and uncertainties.

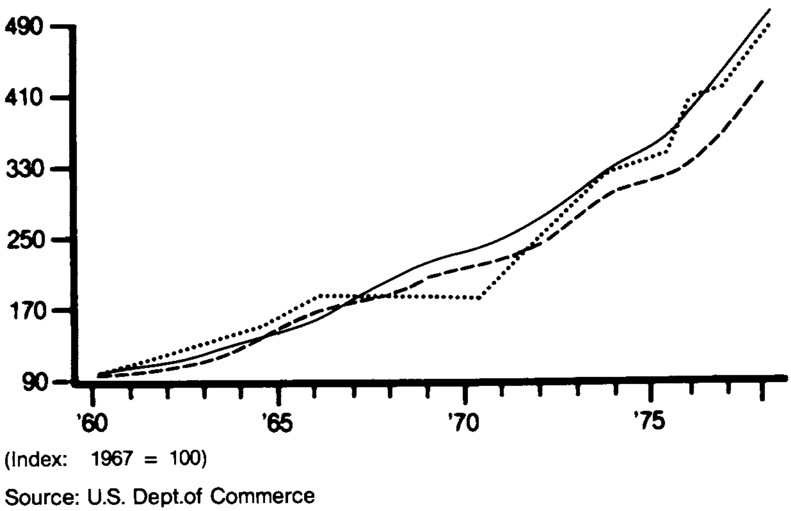


Figure 1. Industry investment and cash flow. Research and development (——); plant and equipment (– – –); cash flow (· · ·).

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

This would provide the structural changes necessary for a lasting improvement in productivity and, thereby, on the control of inflation. In conjunction with the improved economic performance and increased demand for advanced technology that would result from a higher level of investment, the removal of these deterrents would help create a climate in which investments in all phases of technological innovation would be increased as a natural result of the entrepreneurial process.

- We also recommend policy changes affecting patents, and direct Federal support of R&D, which we believe will complement these high priority initiatives.

Our rate of productivity growth has been much slower relative to our major international competitors. Recent productivity improvements have been unable to offset nominal wage increases by a wide margin. The result is rapidly rising labor costs which contribute to existing inflationary pressures.

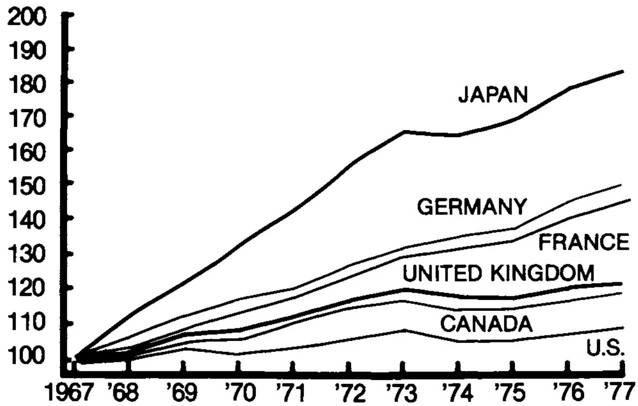
Investment in new plants and equipment -- necessary to embody the results of successful research and development efforts -- has been extremely discouraging. The U.S. now lags behind other major industrial countries in capital investment as a proportion of gross domestic product.

This decline has a redoubled impact since investment in capital equipment not only improves productivity and stimulates employment opportunities, but also encourages investment in research and development. Our leading competitors have increased their efforts in R&D much more than we have. While our R&D expenditures are much larger than any other nation's, a very large portion of the U.S. effort is directed toward defense and other objectives.

The Committee finds the risk/reward relationship for long-term, high-risk investments currently out of balance. Disincentives have been introduced in terms of increased risk and reduced potential rewards. Increased risk has resulted from the expansion and sometimes injudicious administration of government regulatory activities, and uncertain energy and economic policies. Reduced potential rewards have resulted from current tax policies in combination with the inability to control inflation. The result is investment funds are being channeled away from the more innovative longer-term opportunities toward consumption-oriented and hedging types of investments.

We believe that unless there is speedy correction and elimination of these deterrents, the nation will find it increasingly difficult to achieve its economic goals and probably impossible to achieve its social objectives.

On the basis of the Committee's analysis of the causes of the decline in technological innovation in the U.S., we recommend the following changes:



(Index: 1960 = 100)

Source: Bureau of Labor Statistics

Figure 2. Change in GDP per employee

	% Output 1960-76
U.S.	17.2
U.K.	13.4
France*	19.1
Canada	19.7
Germany*	19.6
Japan	28.6

* For total economy

Source: Bureau of Labor Statistics

Figure 3. Capital investment

I. Changes in Tax Policy:

The primary role of tax policy in stimulating investment is illustrated by the apparent response of venture capital to last year's reduction in the capital gains tax. The availability of new venture capital is particularly crucial to the formation of new, high-technology businesses.

During the first quarter of 1978, the amount of venture capital raised by independent venture capital companies was zero.

By the second quarter, when it became apparent that enough votes had been accumulated to push the Steiger Amendment through Congress, the picture began to change. And by the end of 1978, 13 management groups had been formed, and $215 million in new venture capital had been raised.

An important result of inflation is that the effective corporate tax rate is considerably higher than the reported rate because of such things as phantom inventory profits. The book value of inventories reflects a capital gain which is not a real gain. As a result, taxable profits are higher than actual profits. More important for the rate of industrial innovation is the impact of allowed capital recovery rates in our tax system. Depreciation of existing plant and equipment is based on historical costs, which in an inflationary period, are much lower than replacement costs. This means that real cash flow is effectively held down while real costs of new plant and equipment are going up.

The Committee believes that an improved capital recovery allowance should be enacted immediately to stimulate investment in new plant and equipment.

We support current legislative proposals to separate the capital recovery period from the traditional concept of permitting depreciation over the useful life of the asset. In order to increase investment in new plant and equipment, it is necessary to permit a write-off more in keeping with replacement costs.

Our analysis of the impact of tax policies on technological innovation also leads us to conclude that consideration would be given to special measures to encourage investment in research and development. The complexity and sophistication of modern research facilities and equipment are increasing much more rapidly than is recognized by the present tax system. To help maintain an efficient and effective industrial R&D resource, we recommend the depreciation provisions of the Tax Code be amended to allow "Flexible depreciation" of all such fixed assets.

Under such a system, the taxpayer would have the option of depreciating these assets fully in the first year of their life, or to adopt any other time period desired, while at the same time retaining the benefits of the allowable investment tax credit.

II. Changes in Regulatory Policy:

Restoring the relative attractiveness of investment in technological innovation also will require changes in the current regulatory climate.

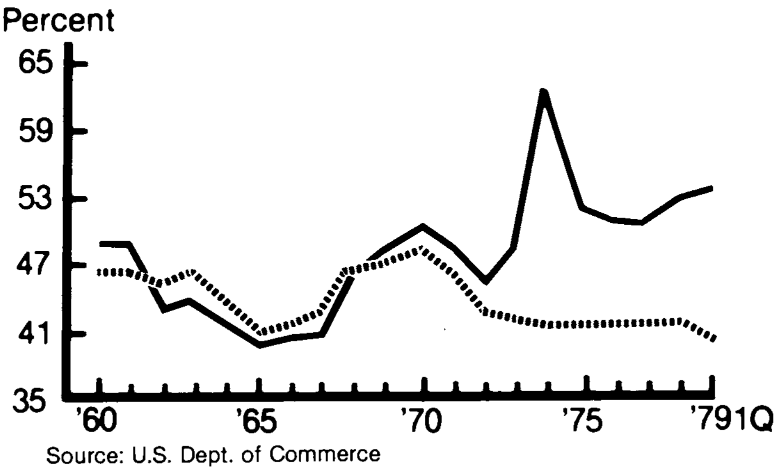


Figure 4. Impact of inflation on corporate tax. Effective rate (——); reported rate (----).

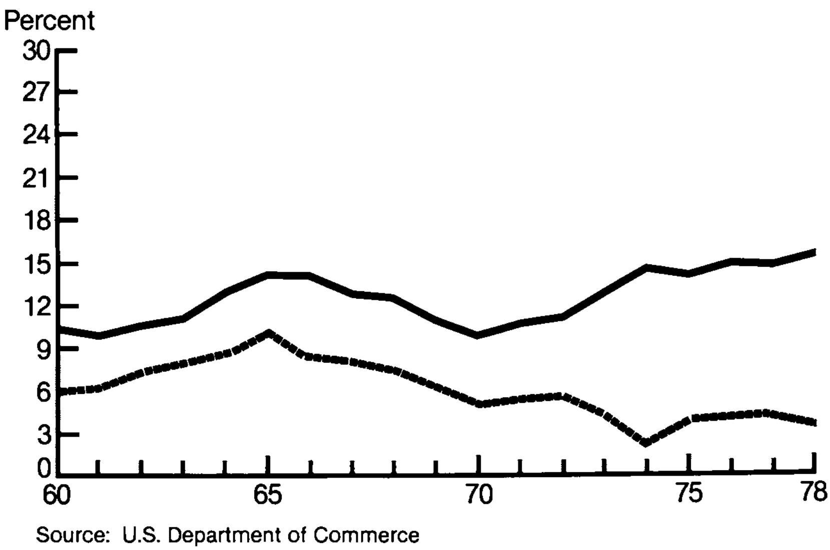


Figure 5. Return on capital investment. Original cost (——); replacement cost (----).

While recognizing that some government regulation is necessary, our Committee found that in many cases compliance costs are not in keeping with apparent lost benefits, reducing the resources available for technological innovation. "Zero risk" goals, requirements for "best available technology," and the frequent changes in production standards sometimes required, has all led to compliance cost escalation. The accompanying uncertainty about the acceptability of advanced technology applications has further thrown out of balance the risk/reward ratio for innovative investments.

In carrying out regulatory policies there is frequently excessive use of detailed rules and specifications. We believe realistic standards should be set, but that businesses seeking the most cost-effective method of production should be allowed the freedom to meet these standards in their own way.

CED's recent policy statement, Redefining Government's Role in the Market System, contains an extensive analysis of regulatory policies and the need to assess their impact on the economy.

On the basis of this analysis, the Committee places a high priority on the need to consider the impact of regulation on technological innovation as a means for achieving our economic objectives. We, therefore, support the efforts of the Administration and Congress to achieve regulatory reform, as an important step towards these goals.

We especially encourage the development of guidelines for determining whether or not new or existing regulations are needed, and a process for periodically reviewing both the effectiveness and economic impact of social as well as economic regulations.

III. Changes in the U.S. Patent System:

The U.S. patent system has served us long and well as a stimulus to industrial innovation. The protection provided by patents encourages the investment of funds not only in research and development, but also in facilities to commercialize the R&D output.

However, we would propose a number of changes in the system to increase its effectiveness and strengthen its role in the innovation process.

One key area of needed improvement is the resolution of disputes over issued patents. The time and cost currently required to resolve contested situations seriously detract from the effective functioning of the system.

Three changes are needed: First, arbitration should be endorsed by statute as an acceptable way of settling patent controversies.

Second, a single court of appeals for patent cases should be established to provide nationwide uniformity in the patent law.

And third, a statutory reexamination procedure should be instituted to enable the Patent and Trademark Office to strike obviously invalid patents from the rolls.

A second major area of needed improvement lies in the timing of the patent grant and thereby its reliability in business planning. Here two changes are recommended:

1. To protect innovation adequately in fields subject to government regulation, a procedure should be established providing for an appropriate adjustment in the patent term when commercialization is held up due to regulatory delay.

2. To prevent extended controversies and long delays in the issuance of patents when two or more inventors are claiming the same improvement, the nation should change to a first-to-file system, whereby the first inventor to file his patent application would receive the patent. (A personal right of use would be preserved for anyone filing later who, in fact, invented first and took steps leading to commercialization).

With this system, the ownership of patents would be determined promptly, and the public would benefit from early publication of the patent disclosure.

These and other changes recommended in the full report would improve the functioning of the patent system and strengthen its supporting role in U.S. innovation, and are an important complement to the policy changes in other areas which we believe should be implemented with highest priority.

IV. Federal Support of R&D:

The very large program of federally supported R&D is seen as extremely important to industrial innovation.

The Committee supports moves towards increased public support for basic research, but recommends that Federal involvement in the selection and management of technology development aimed at commercial application should be undertaken only under extremely limited circumstances. Specific criteria for such decision-making are suggested in the full report.

V. Summary and Conclusion:

The CED Subcommittee on Technology Policy concludes that an improved rate of technological change in industry is essential to achieving national economic and social objectives. But while technological innovation can contribute broadly to future economic strength, business confidence in the future of the economy is a necessary condition for an adequate level of private investment in longer-term, high-risk ventures which lead to significant innovations.

High and uncertain rates of inflation have become one of the most severe constraints on the nation's future economic growth. One of the underlying causes of inflation is our low rate of productivity improvement. Productivity can be significantly increased through the application of advanced technology in our industry processes -- microprocessor and computer technology is a case in point. In our view, and supported by the studies of such noted economists as Edward Denison, stimulation of a higher rate of investment in the productive base of our economy will create more rapid technological advances and at the same time have a greater leverage on productivity and inflation control than many of our present policies.

We recommend that this be accomplished by taking steps, beginning immediately, to raise the level of investment in plant and equipment. This, in turn, would increase the rate of diffusion of new technology into industrial processes, impact favorably on our productivity, and reduce inflation.

And we recommend the reduction and elimination of unessential regulatory constraints and uncertainties on productive investments. In conjunction with the improved economic performance that would result from faster growth, this would create the essential climate in which investment in all phases of technological innovation would be increased as a natural response to the entrepreneurial process.

And, finally, although it does not come within the purview of the CED study, a personal observation:

There are those who maintain that the growth era is over for the U.S. Those who hold these views, whether in glee or in grief, cite the profound changes in American life introduced by the counterculture movement in the '60s. David Riesman, the Harvard sociologist, declares that "the counterculture has triumped" and feels that the movement has "seriously damaged" American intellectural and cultural life, and national productivity.

I believe the problems of declining productivity are structural not cultural -- and are rooted in the specifics we have discussed here. One basis for this is the revival in venture capital we have seen following the reduction last year in capital gains tax rates. To be sure, these are very few straws in the wind, but they do indicate that the economy still responds to incentives and is not in the clutches of some inexorable process.

I am also convinced that given the alternatives, the great majority of Americans would opt for growth over non-growth and recession. These alternatives were clearly laid out recently by the Joint Economic Committee, which warned that a continuation of the present rate of decline in U.S. productivity into the 1980s could mean that by 1988, a gallon of gas would cost $5.80, a loaf of bread $2.06, and an average house $151,200. They pointed out that such a slow-down in productivity, "the economic linchpin," would result in special hardships for all disadvantaged minorities.

The restoration of that confidence which would contribute to economic vigor will not occur simply because we are exhorted to become more confident, but only through specific steps to remove the disincentives that prevent the U.S. economy from performing as it should. Once the steps are made plain, and the alternatives are made clear, I am convinced we will once more be well on the way in America not only to a restoration of our confidence, but also to an augmentation of our long-term economic gains and social progress.

RECEIVED April 29, 1980.

9

Personal Observations on the DPR Process

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For the uninitiated, DPR is shorthand for the Domestic Policy Review on Industrial Innovation. The DPR was officially started in May of 1978 at the direction of the President. It was an interagency effort, chaired by the Secretary of Commerce, who delegated the day-to-day management to the Assistant Secretary for Science and Technology, Dr. Jordan Baruch. The goal of the DPR was to develop recommendations for the President concerning policies and programs the Federal Government could implement which would positively influence the rate and direction of industrial innovation in the United States. A program plan for the DPR was prepared over the summer, and activities began in September.

From the very beginning, one of the implicit goals of the DPR process was to raise the consciousness level of the Federal Government, of private industry itself, and of the general public at large, as to the nature and importance of industrial innovation for the nation. To some extent, we have achieved that goal. "Innovation" is now a word that is more commonly used around the country and there are more innovation meetings these days than I could ever go to. Innovation is more and more a word that firms want to be identified with - it is a good image - and hopefully some of that image will become reality. I haven't done a random sample survey, but my own observations of Madison Avenue TV commercials convince me of this. Federal officials are now also more cognizant of the need for innovation, because increasingly innovation can be related to departmental or agency missions. Not only is Business Week discussing innovation; Newsweek has also done a cover story on it.

What elements of the DPR process helped in this effort? Well, first of all, before the process really started, all Federal departments or agencies involved - some 28 of them - were asked to conduct an internal review of all policies or programs which directly or indirectly affected innovation. The quality of these reviews varied, but for the most part they were thorough and thoughtful. Many individuals who became involved in their agency reviews stayed involved and turned out to be continually helpful and supportive throughout the DPR process. The documents themselves provided useful background information and some surprising cases of policies or programs that we had not known about.

Secondly, there was a very great input from the private sector into the process. As Dr. Baruch has pointed out from the beginning, industrial innovation occurs in private industry, at the level of the firm. Over 100 executives participated directly as members of the Advisory Subcommittee from Private Industry, and significant staff resources were volunteered as well. We made a deliberate attempt to involve not only the Vice Presidents or Directors of R&D, but also Chief Executive Officers, Chairmen and Presidents; Vice Presidents and Directors of manufacturing, environmental quality control, planning, accounting and finance, etc.; and attorneys, chief economists, and the like. We wanted viewpoints which represented all aspects of the innovation decision process - not just R&D - and we got them.

The timing of the private sector input was also planned. Their subcommittees met from September into December - publishing a first draft of their reports around December 15th. Government interagency task forces were organized in November-December, and did the bulk of their work from January through March, 1979. This timing provided an overlap which allowed the task forces to develop and maintain a significant awareness of the deliberations of the private industry subcommittees and who was on them. The meetings of all the advisory committees were open to the public, and many task force members attended at least some of them. More importantly, however, the timing sequence meant that each of the recommendations made by private industry received careful attention and analysis from the government. Each recommendation was reviewed for its perceived effect on innovation, its cost, and its political and institutional feasibility.

A special attempt was made to involve representatives of technology-based small business in the process. Although the industrial subcommittees were dominated numerically by big business, several representatives of the interests of small business were on each of them. In addition, several of these small business people formed their own committee and produced their own report setting forth the viewpoints and recommendations of small business regarding innovation.

One of the observations I made during several subcommittee discussions was a kind of restrained irritation on the part of several representatives from big business while the importance of small business to innovation was repeatedly and ardently being espoused. I'm sure you've heard some of the figures cited about the contribution of small business to employment as compared to big business, their contribution in the form of taxes, their contribution to economic growth, etc, - and I'm sure you are all aware of the difficulties which large, existing corporations have in developing major new product innovations, and how new ventures formed around an innovation like this are often more successful at it. Still, innovation occurs in both large and small firms, even if the questions of how much and of what kind are debatable, and there were perceived interests in common which drew the two sides together on most issues. If nothing else, there was a lot of learning that occurred within private industry as the unique problems of big and small business were brought out. The most interesting individuals to watch in this process were those who had succeeded in both worlds - those who started out with a small company and who had managed its growth and development into a large one. In the end, I believe that small business feels it had its fair day in court in the DPR process.

A second, again perhaps implicit, goal of the DPR process that was present from the beginning was that of lessening the adversary relationship between Government and business that has increasingly dominated our national economy and society. This adversary relationship is particularly noticeable when one looks at the situation in Japan and Germany - the two nations which are increasingly challenging us on our own grounds: technological competitiveness and industrial performance - and even in some of the newly industrializing nations such as Taiwan, South Korea, Singapore, Brazil, Mexico, etc. In these countries, the relationship between government and business is one of cooperation and, indeed, of mutual promotion and dependence. One need not be accused of "selling out" to suggest that our own adversarial relationship is not necessarily the best way to do things. There is fault enough - on both sides - to more than go around, of course.

Here again, I believe we at least partially achieved this goal in the DPR process and contributed to a lessening of this adversary relationship. There is no doubt that many industrial representatives came into the process with a "if government will only get off our backs..." attitude, and some of them were not convinced otherwise. It is also no surprise that many government people approached the DPR with extreme skepticism, if not distrust, of industry's motives, and some of these feelings remained. Years of feuding and fighting cannot be made up overnight.

But some attitudes did change. Private industry, I believe correctly, perceived that if they participated in the DPR as representatives of selfish, vested interests instead of as business statesmen, the credibility of their position would suffer. The statesmanlike approach prevailed. I learned a lot as I listened to industrial spokesmen tell of instances where government had made positive contributions to innovation in their own firms, and how the lessons learned could apply to an appropriate role for the government in the future. I also listened with some irony to the sometimes vociferous philosophical debates among different industrial representatives regarding whether or not the government should be helping the ailing steel industry -- attitudes toward government depend to some extent on what industry you're in. Successful small businessmen had a different attitude toward government incentives directed toward start-up of new ventures than did those who had experienced failure. The "If I can make it on my own, you should be able to also" attitude was very strong.

Still, all in all, even over the most contentious issues -- most of them in the regulatory area -- there appeared to be a minimum of hostile confrontation between government and business and at least a willingness to explore differing views and opinions. We in the Department of Commerce felt a special responsibility in this area. Of all the Federal departments and agencies, we are most concerned with industrial development; but at the same time we are also part of government and committed to its goals of higher standards in the environment, in health and in safety.

A third goal of the DPR process was to be comprehensive in identifying the wide variety of Federal policies and programs which might positively impact on different aspects of industrial innovation. In structuring the DPR, therefore, advisory subcommittees and following task forces were formed according to policy areas which were recognized to have the most relevance to industrial innovation. In order to keep the process manageable, these were grouped under five headings: Economic and Trade Policy; Procurement and Direct Support of Research and Development; Patent and Information Policy; Environment, Health, and Safety Regulations; and Regulation of Industry Structure and Competition.

The five private industry advisory subcommittees formed in these policy areas were supposed to manage their own operations, however, and so the planned structure did not stay that way for long. The Regulatory subcommittee broke up into three groups concerning health, safety, and the environment; each group issued its own report, and the three were integrated into a first draft report. In Patents and Information, and in Procurement and Direct Support of R&D, the subcommittees split and each produced their own reports which stood on their own. So we ended up with seven reports from the private sector instead of five -- if you haven't seen them, they're available from NTIS. We had so many requests for them that we're out.

Structuring the DPR process in this way had certain implications and problems associated with it -- as any structure would. It was obvious that there was going to be some overlapping among policy area subcommittees, and there was. The DPR staff tried to coordinate these overlaps as much as possible, but our preference was to duplicate rather than let something fall

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

between the cracks. Although there was a specific subcommittee to address health, safety, and environmental regulations, all the subcommittees wanted to say something about this issue in their reports and most of them did. Many of the subcommittees also became involved in tax policy and tax incentives, although this again was to have been the responsibility of the Economic and Trade Policy Subcommittee. Despite our own efforts, some important innovation issues were not addressed in any great depth by the subcommittees -- e.g., the relation between innovation and trade, the special problems of disaggregated industries, etc.

The subcommittees were charged with developing recommendations -- specific recommendations for Federal policies/programs distinctly targeted toward industrial innovation. They again did their own thing. In the Economic and Trade report, for example, there are numerous specific and targeted recommendations. Their very first recommendation, however, labels all of them as "just so much tinkering at the margin," and goes on to address the general issue of capital availability for innovation. In the same report, there are numerous definitional problems recognized in targeting certain recommended incentives to, for example, technology-based small business. Their answer to this very tough implementation question was to simply say that the Department of Commerce or Congress should resolve it.

In the end, however, we got results -- some 150 specific recommendations from private industry on what the government should do about industrial innovation.

A fourth goal of the DPR process was to involve groups which did not produce innovation, but did have some stake or interest in the outcome. This was done by establishing two advisory subcommittees composed, respectively, of representatives from labor and from public interest groups. Labor, of course, has a stake in innovation, in both the short-term and long-term effects on employment and the work environment. Public interest groups have a more diffused stake in the innovation process, concerned with both the negative effects of the application of technology and the positive social benefits potentially available from innovation. To ignore either of these legitimate interests would have been counterproductive; therefore they were involved, and in the case of the public interest subcommittee, we provided them with support for their own staff.

These advisory subcommittees were asked both to respond to and comment on the private industry recommendations, and to develop and provide their own recommendations regarding Federal policies and programs related to industrial innovation. To the degree to which sharp differences of opinion emerged on some issues -- particularly between the public interest subcommittee and the industry subcommittee on regulations -- they were able to generally come to understand the different interests which had to be balanced in developing industrial innovation policy. Their two reports are also available from NTIS.

Another goal we had was to bring the most up-to-date knowledge available on industrial innovation to bear on the DPR process. To this end, a series of state-of-the-art papers were prepared by the MIT Center for Policy Alternatives under the direction of Herb Holloman -- soon to be published in book form -- and distributed to the advisory subcommittees and the government task forces. Another set of state-of-the-art policy papers was prepared by NSF and similarly distributed.

An advisory subcommittee of prominant academics in the innovation field was also formed, chaired by Professor Brian Quinn of Dartmouth College. This subcommittee acted as advisors really to Dr. Baruch and ourselves on the DPR staff. They also reviewed the reports put out by the private sector subcommittees and made constructive comments regarding their recommendations.

The last aspect of the DPR process that I'm going to talk about this afternoon was the series of seven public meetings or seminars, held in the Department of Commerce Auditorium this past January. Many of you no doubt attended some of them. These meetings were chaired by Dr. Baruch and included, as part of the formal panel, four to five members from the particular private sector subcommittee whose report was being discussed, government executives from agencies or departments most directly concerned, and one or more members from the Labor, Public Interest, and Academic subcommittees. The public audiences ranged from 50 to 150, I would guess. Snowstorms in the midwest sometimes intervened in this process, but telecommunications technology overcame some of the difficulty. The purpose of these meetings was two-fold: first of all to provide a forum for interaction between the diverse interests participating in the DPR process; and secondly to involve the public, the press, the professional societies -- all who were interested in innovation but were not officially involved in the DPR itself.

The meetings were not all sweetness and light. There was disagreement over controversial issues and criticism. The most controversial area was -- again -- in health, safety, and environmental regulations. For those of you who were not there, here are some personal impressions from one who was listening and watching in the audience: of Don Frey, Chief Executive Officer of Bell and Howell, snowbound in Chicago, speaking to the audience from his office by telephone hookup, and complaining about the lack of technology to do something with mountains of snow even when removal equipment has the situation under control; of Dr. Baruch, making the ultimate sacrifice and putting out his cigar at the request of the public interest representative, Clair Nader; of George Lockwood's recitation of the Federal, State, and Local regulatory problems faced by a small businessman in a new and unique innovation area; of the debate between Donald Kennedy, then Commissioner of FDA, and Cornelius Pettings, Executive Vice President of Eli Lilly, over the interpretation and relevance of data related to innovation in the drug industry; of the question from Labor of how one can place a value on the loss of an arm to the worker who cannot play catch with his son on Sunday afternoon, and Dr. Baruch's response that, from the government's viewpoint, in allocating its limited resources among various missions, government does place value on such things; of Clair Nader's defense of regulations, criticism of industry's past performance in failing to provide high enough standards of health, safety, and environmental protection, and challenge to industry to develop technology to solve these problems rather than expend resources on fighting regulation; of spirited and provocative questions and remarks from the audience; and so on. It was, to say the least, an interesting time. The fact that it was carried off successfully was due in part to the competence and consideration shown by the participants, and in part to the skills of Dr. Baruch in moderating diverse opinions and keeping the focus on innovation.

From this point on, the DPR process went into executive session -- into the Executive Branch process. Interagency task forces operated in each of the seven policy areas, developing recommendations which were submitted to the DPR Steering Committee.

This personal view of the formative and background studies and work which supported the DPR should aid in understanding the significant cooperative effort on the part of the concerned public and private sectors which went into this endeavor.

RECEIVED November 13, 1979.

Research and Innovation: Joint Economic Committee Special Study on Economic Change

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The Research and Innovation Area Study (RIAS) is a study being conducted for the Joint Economic Committee of the U.S. Congress, which is currently chaired by Senator Lloyd Bentsen of Texas. We have been working on RIAS for about two years now and are in the process of completing the first phase. The entire study is scheduled for completion in mid-1980. The objectives and procedures of the study, the contents of the final report, and some of its implications are described in this paper.

Special Study of Economic Change

RIAS is part of a larger study called the Special Study of Economic Change (SSEC). The SSEC was approved by the Congress in July 1977. At that time, the chairman of the Joint Economic Committee was Rep. Richard Bolling of Missouri. The Special Study was conceived as a broad examination of the thesis that economic, social, political, international, and technical conditions have changed and are continuing to change markedly, such that conventional economic theory and tools may no longer be equal to making sound policy for the future in the economic area. A special temporary staff was hired to conduct the Special Study and a time frame of about three years was set. The end product was to be information and analysis necessary for consideration of legislation by a number of the legislative standing committees of the Congress. The Joint Economic Committee itself is a non-legislative committee and so may not introduce legislation, but in the past it has been quite influential through its study activities. In fact, the J.E.C. is in a unique position to contribute to congressional understanding of central economic problems that require a long-term perspective and a broad outlook.

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The Special Study was to consist of three phases:

Analysis and Assessment;
Integration of Findings; and
Consideration of Policy Alternatives.

The first of these phases, analysis and assessment, is just now being completed. The integration phase is to occur between now and the end of 1979, and the policy consideration phase, which will involve the Members of the Joint Economic Committee, will take place in the first six months of 1980.

The Special Study consists of nine Area Studies, of which RIAS is one. The other Area Studies are:

Human Resources and Demographics;
Materials and Energy;
"Stagflation" (persistent inflation with unemployment);
Federal Sector Finances;
State and Local Finances;
Pension Systems;
Government Impact (largely regulation); and
The International Environment.

The Special Study was headed by Dr. Charles S. Sheldon II as Research Director and by Dr. Robert Wallace as Senior Economist until the end of 1978. Dr. Louis Krauthoff assumed the position of director of the Special Study in 1979.

For each of the nine Area Studies, recognized experts were named as Area Directors. In addition, a member of the regular staff of the Joint Economic Committee and one from the Congressional Research Service were appointed to assist each Area Director. For the Research and Innovation Area Study, which I will describe in more detail later, Walter Hahn, Senior Specialist at the CRS is Area Director. Richard Kaufman, General Counsel of the Joint Economic Committee is the JEC representative, and I am the CRS staff representative.

Each of the Area Directors approached his task in a different manner. Some held hearings, some commissioned series of papers, and one Area Director is writing the whole thing himself in the form of a book. A series of volumes for each Area Study is scheduled to be published by the Committee by the end of 1979. Meanwhile, the integration of the findings from the Area Studies is being started by the staff of the Special Study.

The Research and Innovation Area Study

Now let me describe in more detail the Research and Innovation Area Study. We regard it as a low-profile congressional counterpart to the Domestic Policy Review of Industrial Innovation which was conducted concurrently in the executive branch. We have also regarded it as an opportunity to facilitate the inclusion of scientific and technological factors in the consideration of possible economic policy changes.

We viewed our role as providing a contextual and informational base for the succeeding phases of the Special Study, relating to the role of research and development (R&D) and industrial innovation in the economy. We view the innovation process as going beyond R&D to include the distribution and use of new technology in both the public and private sectors. We wanted to look at R&D and innovation both as sources of economic change and as they are affected by the economy. We wanted to take a future-oriented look at these relationships, focusing on the period stretching from five to 30 years from now. If any "model" guided our thoughts, it was a "systems"-type model, stressing the interconnected parts of the innovation process and innovation as a part of a larger system of economic, political, and social factors.

Our approach was not to hold hearings, nor to undertake major new analyses, but rather, to review existing research and to build, to the extent possible, on the many ongoing, related activities, such as the presidential Domestic Policy Review and the Committee for Economic Development's study. We prepared a variety of review and synthesis papers and assembled selected key studies from the past. We commissioned a few analytical pieces to fill in gaps in knowledge and held a meeting in December 1978 on the subject of research, innovation, and economic change. Our report attempts to present what is known about the role of innovation in the economy, past trends and the present state of the "innovation system", and the outlook and options for the future.

Contents of the Report

The report is organized along these same lines: a "what is known" section; a present state of affairs section, and an outlook section.

The first paper in the "what is known" section is THE PROCESS OF TECHNOLOGICAL INNOVATION IN INDUSTRY: A STATE-OF-KNOWLEDGE REVIEW FOR CONGRESS. The thesis of this review is that, although knowlege remains limited, recent research has resulted in more information about the process of industrial innovation than most policymakers realize. The objective of the paper is to summarize and translate these research findings into a form useful to congressional staff and Members.

In addition to the research literature, there has been a substantial number of policy studies in the last two decades. A paper entitled TWO DECADES OF RESEARCH ON INNOVATION:

SELECTED STUDIES OF CURRENT RELEVANCE provides a selection of the executive summaries (or equivalent) from 42 prior studies. The 205 major recommendations from these studies have been pulled out and categorized in terms of taxes, R&D support, patents, etc. An attempt has been made to array them in such a way as to show who the action parties would be if they were to be implemented.

The third piece under "what is known" is entitled THE EXECUTIVE BRANCH DOMESTIC POLICY REVIEW STUDIES ON INDUSTRIAL INNOVATION: A SUMMARY AND PRELIMINARY EVALUATION. The major purpose of this collection of reprinted materials is to make available in condensed form to the Members of Congress and the SSEC, the key input documents to the Administration's Domestic Policy Review. (Any evaluation will be preliminary and restricted to materials publicly available at the time.)

In parallel with the foregoing efforts, the Committee for Economic Development has conducted an in-depth policy analysis entitled, REVITALIZING TECHNOLOGICAL PROGRESS IN THE UNITED STATES. The CED summary chapter, completed in August 1979 and to be published in October 1979, is to be reprinted with their permission in our report, where it will be directly available to Members of Congress.

The final paper in the "known" category presents an overview of what is known about THE RELATIONSHIP OF FEDERAL SUPPORT OF BASIC RESEARCH IN UNIVERSITIES TO INDUSTRIAL INNOVATION AND PRODUCTIVITY. It reviews three kinds of evidence which bear upon this issue: the conceptual relationship between science and technology, the nature of university-industry relations, and economic studies of the contribution of research and development to economic growth and productivity.

Since the literature is often somewhat behind the times with respect to research and policy issues, a second section of the report attempts to bring up to date our knowledge of innovation, the economy, and policy initiatives. One paper in this section is RESEARCH, INNOVATION, AND ECONOMIC CHANGE, which is a summary and analysis of a workshop by the same name that we sponsored in December 1978. The workshop helped provide up-dated information on the relationship of R&D, innovation, and the economy, and it provided a dialogue, which is sometimes more revealing than conventional written presentations. Among the major issues discussed were the innovation process, technology transfer, the linkages between innovation and economic growth and productivity, and the Government's role.

To assure an up-to-date and comprehensive review of the status of legislative action in this area, the report also contains the latest CRS "Issue Brief," entitled INDUSTRIAL INNOVATION. It records all relevant bills and other legislative actions, along with statements on the issues involved, and includes appropriate supporting and background materials.

A paper entitled TECHNICAL ADVANCE AND ECONOMIC GROWTH: PRESENT PROBLEMS AND POLICY ISSUES analyzes the causes of some of the aspects of present economic malaise such as inflation, unemployment, and declining productivity growth. (Included by permission of the author, Richard Nelson, and the New York Academy of Sciences.) It concludes that the decline in economic productivity growth cannot be ascribed to the deceleration of R&D expenditures. On the other hand, the decline in R&D has been largely due to the deceleration in growth of economic output. However, slow and conservative technical advance can make it more difficult to get out of the current economic rut, while faster and more innovative technical advance may make it easier to get out. The author does not promote government stimulus of basic technology as the most important instrument in resolving today's macroeconomic problems, but argues that such policies can be important parts of an effective policy package.

Another paper in this section is SCIENCE INDICATORS: IMPROVEMENTS NEEDED IN DESIGN, CONSTRUCTION, AND INTERPRETATION. This is an evaluation of measures currently used to assess the status of U.S. science and technology, with particular attention to the needs of policymakers. Several areas are identified where improvements in science indicators can be made, including the development of new indicators and new models of science and technology.

Another paper was commissioned on THE ROLE OF IMBEDDED TECHNOLOGY IN THE INDUSTRIAL INNOVATION PROCESS. This conceptual paper attempts to define the concept of "imbedded" technology, and to describe its nature and importance. Roughly defined, "imbedded" technology is that great bulk of incremental technological changes that occur in manufacturing and other industrial activities that do not directly result from organized R&D efforts. The author argues that imbedded technology is a necessary condition for successful innovation and that its role has not been recognized adequately by top management and public policymakers.

A paper entitled A QUANTITATIVE TECHNOLOGY INDEX TO AID IN FORMING NATIONAL TECHNOLOGY POLICY attempts to go beyond the widely used but vague terms, "high" and "low" technology, to provide an extended and more replicable method of categorizing technology for policymaking purposes. The index proposed is composed of multiple scales in three descriptive areas: the technological product per se, the process of its manufacture, and the nature and extent of the distribution system.

The final paper in the second section is entitled THE ROLE OF SMALL SCALE TECHNOLOGY IN INNOVATION. This paper deals with an innovation issue which is just emerging on the American domestic scene, although it has been an issue in the developing nations for some time--that is, innovation for small-scale, decentralized, low energy, low pollution, and possibly more labor-intensive technologies and processes.

A paper entitled A SCIENCE AND TECHNOLOGY OUTLOOK identifies those factors internal and external to science and technology that need to be understood by policymakers to integrate science and technology policy effectively into the overall techno-economic policies of the Government. It also identifies major world problem areas to which science and technology will be called upon to respond in the years ahead, such as food, population, energy, and the environment. And it identifies emerging technological developments. Covering a period starting about five years in the future, this outlook goes out three decades, with the emphasis on the 15 year middle zone. The outlook sketches three scenarios of alternative futures: an extrapolative scenario, a catastrophic scenario, and a "changing values" scenario.

Concluding Observations

I would now like to make some concluding observations, based on our experience in conducting this project. These are not firm conclusions based on definitive evidence nor in-depth analysis, because that was not the nature of our project. Nor are they recommendations because our project did not result in policy recommendations (although it does include about 400 recommendations made in other studies). Rather, these observations are the result of my taking a step back from the immediate issues and looking at them in the context of the process of public policymaking.

It frequently has been noted that many studies of innovation and innovation policy have been done in the past. We identified 42 major studies and about 400 public policy recommendations to stimulate innovation. It seems reasonable to ask why so many studies have been done and so little action taken. I have come up with six factors that I think are holding back action in the innovation policy area. These are not offered with the presumption that Government should or should not do something about innovation, but from the perspective of the analyst attempting to explain why so little action has been taken to date. I think, however, that these points can be useful to those who take a more advocatory position, although some of the problems may be relatively intractable. Before I list the six factors, I would note that they appear to fall into two categories: limitations on data and analysis, and constraints on our ability to act politically.

The six factors are:

1) Lack of consensus on what the "innovation problem" is and how serious it is.

2) Lack of consensus on the importance of R&D and innovation in our current economic problems and their utility in ameliorating those problems.

3) Lack of consensus on whether or how much current Government policies inhibit innovation.
4) Lack of consensus on what the effects of policy changes would be on innovation and what other effects would be.
5) Lack of consensus on what the Government should do, if anything, and lack of confidence that Government can intervene effectively.
6) Antagonism between Government, public interest groups, and private industry.

Closing

In closing, then, I would summarize some of the most important results of the RIAS study in the following way, noting that they tend to be predispositions that we brought to the project with us and that survived the exercise, albeit, in somewhat altered form:

1) Innovation needs to be viewed "holistically", that is, as the sum of its interrelated parts and as a subsystem interacting with the economic, political, and social factors in its environment;
2) There does not seem to be any "easy fix" to perceived innovation problems;
3) Proponents of Government intervention in innovation will have to work on developing a consensus and a strategic, coordinated approach, if they hope to be effective;
4) These types of policy issues are among the most difficult for our political system to deal with; and
5) The Joint Economic Committee's Special Study on Economic Change may be a first step toward integrating technology policy with macro-economic policies at the Federal level.

RECEIVED November 13, 1979.

11

The Role of the Individual in Innovation

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There are possibilities for debate as to whether technological innovation is declining in the United States, and if so at what rate. But I believe no doubt can be sustained, at least amongst us industrial chemists and chemical engineers that the economic welfare of this country is critically dependent on technological innovation. By extension, since social and political well being are built on economic foundations, our health and strength as a nation and our influence in the community of nations are solidly based on our abilities to innovate and compete technologically in the open and restricted markets of the world at large.

The Inner Temple -- The Self

Since we all know the distinction between invention and innovation I do not need to stress it, but only to mention it because of its consequences. Innovatión is distinguished from invention by the necessity that an innovation has to succeed commercially to deserve the title, whilst an invention does not require such success to be allowed as an invention. From this distinction it follows that whilst an invention can be perfected through the activities of a single person, it is almost a logical as well as a factual necessity that a technological innovation is a process in which many individuals participate. A novel process, product or service has to be conceived and realized. Next, it is often tested at a pilot scale with the cooperation of other scientists, engineers, technologists and technicians. It is then reworked and produced on a semi- or full-commercial scale when many other designers, managers, cost accountants and other specialists are directly and indirectly involved. The final stage of successful marketing brings in other specialists in marketing, selling, financing, contract-writing and a horde of other activities. Here we observe two further facts. The first is an important asym-

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metry. While failure is assured if either competence or the will to succeed is lacking at any one stage, success demands both competence and the will to succeed at every stage. Hence, in technological innovations, failure is an orphan while success has many fathers. The second observation reinforces the consequences of the first: the cost of the first step in innovation, the conception and first realization of the idea into a concrete prototype, may well be of the order of only one percent of the total cost of successfully marketing it as an innovation, a reminder of Edison's prescription: 1% inspiration and 99% perspiration.

These two facts of commercial life tend to diminish the primary significance and the essential role of the individual innovator when the complex process of innovation is superficially examined by the unwary. In my judgment, underestimating the value of the individual who conceived and brought forth the innovation would be a grave error and a serious hazard to our future welfare as a nation or as single businesses.

I visualize the process of innovation as a series of concentric circles expanding outwards in our milieu or culture. When a perception of a problem and an idea to solve it strike the would be innovator, a disturbance is set up within him like the disturbance created by a stone striking the surface of a pond. An impulse is generated driven by his psychic and intellectual energies and resisted by his phobias and his misconceptions about the world. A wave of activity is initiated, expanding outwards as successes provide positive feedbacks to amplify his drives, and setbacks keep them within bounds. Thus, during this initial stage, and until the innovator has something to demonstrate the promise of his ideas to an outside sponsor, most if not all struggles are confined within the inner circle of the self.

When the innovator has a concrete demonstration of his solution to the problem, his activities spill over into the outer and larger circle of the sponsor, be that the corporation of his employer, a group of family and friends who are willing to risk an investment into the innovation, or a venture-capital organization buying rights of ownership of parts of the innovation. Once this step is taken the innovator is subjected to a new set of drives and brakes, the principal characteristic of which is their externality to the innovator. Rewards and punishments do not arise from within the self as they have done when the innovator was struggling within the innermost circle. They arise from without and are perceived as impositions. However, they are still direct and the innovator still has a feeling of being more or less in charge of his own fate. Once again, successes at the pilot scale, and as semi-commercial or full-scale production problems are solved, the innovator's activities transcend the outer barriers of the second circle and spill into the outermost, indefinitely expanding circle of the market place.

Here the drives and checks, the rewards and punishments not only emanate from external sources, as those in the second circle did, but have a new distinguishing characteristic. Mostly they affect the innovator indirectly. Laws which govern his new product, process or service have been made without his direct participation and are likely to change without his consultation -- unlike his contract with his sponsor. The preferences of potential customers are not only beyond his direct influence, but most times beyond his knowledge until after the event, -- again, unlike the ideas and preferences of his sponsor which are accessible to the innovator and even amenable to change by persuasion or power-play which the innovator may wish to excercise.

If the picture I have sketched of the innovator and the innovation process has a touch of realism in general, not necessarily in every detail, certain conclusions follow:

1) The role of the individual innovator is the heart and center of the entire innovation process. Like a Greek deity, the innovator occupies the sanctum sanctorum, the third and innermost room of the temple in the creative ritual of innovation.

2) We who constitute the outer two circles in the innovation process, as employers or as citizens respectively, can more easily be the cause of failure than become the motive power for success in technological innovation. This is due to the asymmetry which decrees failure for the innovation if a single major link in the chain of events fails but demands continuous cooperative effort and success at all major points of interaction before the innovation enterprise may succeed.

3) Since our personal responsibility for failure of innovation in our corporations may become crucial, sometimes inadvertently because we have misunderstood the needs of the innovator, or passively by our withholding vitally needed support at a critical juncture, it is our responsibility to understand the essential characteristics of the innovator. Only by understanding these essential qualities may we have a reasonable chance of attracting, holding and nurturing innovators, and hopefully innovations, in our corporations; or help guide our society to encourage rather than hinder innovation in the development of our social mores and values and the enactment of our laws and regulations.

Not by Bread Alone

What, then, are the essential characteristics of the innovator? To pretend that I can fully answer this question is the height of arrogance. Every human, no matter how "ordinary" we care to think he or she is, is one of the most complex entities in God's universe. The innovator is one of those entities in every respect, with genetic and cultural programs and encrustations, but with a personality further complicated by extraordinary drives and peculiar depths and insights in particular areas of the intellect. Indeed, there may not even be a general answer to the question: "What are the essential characteristics of the innovator?" Each innovative personality may be unique, with the mold that shaped it broken, so that no two innovators may be found to share a common characteristic. Innovators may well belong to Bertrand Russell's paradoxical class of unclassifiable entities.

My aim in addressing this crucial question is much more modest. I wish to show three aspects of this problem:

1) In answering this question, there are false leads which we should avoid, as they may take us to wrong conclusions. I shall illustrate one such false lead which appears to be particularly inviting to follow to false conclusions.

2) There are, at least, two important qualities of the innovator which appear to be so universal among innovators -- at least I have not come across an exception to it in my studies of historical and living innovators -- they demand our special attention.

3) Bearing these two qualities in mind, one may begin to hope for correct attitudes and actions in thinking of incentives and barriers for technological innovation at the level of the individual innovator.

I said earlier that it was necessary to mention the distinction between invention and innovation. An invention is a technological activity culminating in a legal instrument, the patent. Thus its criteria for success are strictly legal and the unit of measurements in assessing its value to the innovator is the area it claims for the sole, monopolistic, use of the inventor. A technological innovation is, again, a technological activity but it culminates with commercial activity in the market place. Its criteria for success are strictly economic and the unit of measurement in assessing its value to the innovator is the dollar or its equivalent in other monies. Thus, it would appear that an essential and distinguishing feature of the innovator is a desire to make money. I believe this is a false lead.

First, I should explain that I believe an innovator is as interested in accumulating wealth as any other human. Some innovators have indeed amassed wealth on a very large scale for themselves and for their partners or sponsors. Recent innovators like Henry Ford, Chester Carlson and Edwin Land come to mind. My point is not that technological innovators are disinterested in making money but that this trait is not an all-consuming or controlling drive in <u>all</u> innovators. To prove this point, I really need to give a single unequivocal example. I shall give two. I believe you can think of many others.

My two examples are the archetypes of innovation in chemistry and in engineering technology respectively, Sir William Henry Perkins, Sr., one of the founders of industrial chemistry and Thomas Alva Edison, the inventor and developer of the industrial research laboratory, -- in both cases, one should add "among many other inventions and innovations."

Perkins, in a search for synthesizing quinine, oxidized aniline with potassium bichromate and thereby, at the age of 18, discovered the first synthetic aniline dye: aniline purple or mauve. With money from his father and brother and, at first, using kitchen utensils but later in a small works near Harrow, England, the young innovator inaugurated the artificial dye industry. Further work brought forth more dyes based on alizarine. But by the age of 36, Perkins abandoned his manufacturing and commercial activities to resume pure research, discovering the Perkins reaction for making unsaturated acids and later devoting his life to the study of the Faraday rotation of plane polarized light in matter by a magnetic field. Thus, whilst building a fortune was one of the results of his innovations, I am persuaded to think that money was not a controlling drive in his life. This conclusion is reinforced, I think, though indirectly, by the fact that all three sons of his grew up to be scientists of stature -- not leaders of industry or commerce. Thus, W. H. Perkins, Jr. became, according to the Senior Perkins' biographer, J. G. Crowther (1), "the leading organic chemist in England," and in the pages of the Encyclopedia Britannica, "one of the foremost synthetic organic chemists of the time." His second son, A. G. Perkins became a professor of tinctorial chemistry at Leeds University and his third son, "a well-known electrochemist." These facts, I believe, speak to a persistence of scientific and technological drives in Perkins to dominate his life and renders his profits as results of rather than causes for technological innovations.

What of our other arch-type for innovators, Edison? It was reported of him that he told an intimate: "Well, I'm not a scientist. I'm an inventor. Faraday was a scientist. He did not work for money. Said he hadn't time to do so. But I do. I measure everything I do by the size of the silver dollar. If it don't come up to that standard then I know it's no good." (2) This criterion does indeed distinguish the inventor/innovator from the discoverer/scientist typified by Edison and Faraday, each a giant in his class. But, was the dollar the motivating force in Edison's endeavor, or just a scale against which he measured his success? We have his own words in a letter to Henry Villard who was planning a gigantic and monopolistic merger of the Edison General Electric with Thompson-Houston and thus cornering the whole market for electric lighting: "If you make the coalition, my usefulness as an inventor is gone. My services wouldn't be worth a penny. I can only invent under powerful incentives. No competition means no invention. It's the same with the men I have around me. It's not money they want but a chance for their ambition to grow." The emphasis was Edison's. Villard continued on his course for a merger and as Edison's biographer states, "The restless Edison now panted for fresh pastures, for new subjects to which he could apply his unique inventive talents in his own way, ..."

I emphasize these points because they lead us to the following conclusion: While adequate and fair monetary rewards are as necessary to attract, hold and encourage innovators as they are for other desirable personnel in a corporation, they are not sufficient, particularly when the truly great innovators are sought. If there are motivations which are both necessary and sufficient, what are they? Let us follow the innovator and find out.

Problem -- A State of Discomfort

The first step in innovation is when the innovator perceives a problem which he sets out to solve. What is a "problem?" Bertrand Russell is quoted by D. W. Mac Kinnon (3) describing the first step in creativity as "a problem, a puzzle involving discomfort." I shall then borrow Russell's concept and define the type of problem which puzzles an innovator as "a state of discomfort." Now, the most peculiar aspect of this type of a problem is that generally, it is a state of discomfort which only the innovator feels. The millions of people surrounding him in his culture, generally feel no such discomfort. This statement may sound of doubtful validity for, again generally speaking, after the innovator has solved his problem and removed the cause of his discomfort, it is difficult to conceive that the world had not felt the same discomfort. The thought may arise that all, or most people, indeed felt the same discomfort and were simply waiting for the genius to arrive and remove it. I think it is important to understand that the truth is the opposite and that indeed most people not only do not see the problem but actively oppose the meddling innovator who is trying to change the order of things. To emphasize this point, for it is very important to my thesis, let me give two examples.

The invention of the wheel is one of the earliest of recorded technology. It appears in very ancient Summer carvings and in the oldest Egyptian monuments -- our two oldest civilizations. Indeed we take the invention of the wheel to be such a prime innovation for a technological civilization that we deride false innovators as trying to reinvent it. Quite clearly, the need for the wheel was perceived at the very beginning of what I may term "Homo Technicus" and thus the problem of its absence, the state of discomfort, would appear to be universal. Yet we know of several advanced technical civilizations which florished in pre-Columbian Americas without the benefit of the wheel. Put simply, of the very many genuises and innovators who helped to build up those civilizations, none felt the state of discomfort at the lack of the wheel sufficiently to do anything useful about it. If even the absence of the wheel is not a cause of a universal state of discomfort, I am persuaded that no other lack would cause it.

Another example may be taken from the Roman Empire. By the first century A.D. -- say when Pompeii was buried in the ashes of Vesuvius in 79 A.D. -- the Romans had all the knowledge which was needed to inaugurate the industrial revolution, or at least the explosive technological brilliance of the Renaissance. Not only did they know the principles of the lever, the winch, the gear train and other mechanisms, but also they had considerable knowledge of energy transformation by hydraulic systems and, of course, of Hero's demonstration of steam power to move things. Yet, they were content to use human muscle power to fulfill their needs, simply because they had a superabundance of slaves. They did not even use animal power, which might have led to mechanical prime movers. I have heard a professor of history at a public lecture at Birmingham University, England attribute the fall of the Roman Empire, in a significant measure, to this absence of feeling for the need to use mechanisms -- except as toys to amuse the Emperor -- when there were no more countries to conquer, no more fresh supplies of slaves to carry the burden of day-to-day running of a sophisticated empire. This lack of sensitivity to a state of discomfort by some genius innovator kept Europe in a steady state for a thousand years before innovators came forth with hydraulic hammers and mills, complicated systems of gears and cams, pumps and other technological equipment and, of course, the supreme catalyst of a movable type for printing.

I hope it is clear that the state of discomfort with the status quo felt by the innovator is mostly not felt by others at the time. Thus, a distinguishing feature of the technological innovator emerges. An innovator has an exceptionally low threshold for a state of discomfort with the order of things. I believe this insight is of crucial importance in the role of the individual innovator in the innovation process.

One Percent + Ninety Nine Percent

Before I discuss the conclusion to which this premise leads me, let me discuss an equally important second characteristic of the innovator. This other characteristic is related to the "Eureka" experience, the "sudden flash of genius" reported of innovators, inventors and other creative people. You remember that Archimedes was in his bath when suddenly, as if with a blinding flash of insight, he saw the solution to his problem of the golden crown. We are told that Isaac Newton was in his garden and, observing an apple fall, suddenly saw the universal law of gravitation in all its majesty.

But let us go to an innovator to tell us of his "Eureka experience." His experience is worthy of our attention, since James Watt is one of the most creative innovators in history.

Fifty years after the event, he described what took place so vividly that it still has a ring of actuality about it. He was originally trained and practiced as an instrument maker, particularly of surveying instruments. But in 1764, he was asked to repair -- note, only to repair -- an already existing Newcomen engine. This he did, and to most other engineers, no problems would have arisen. But to young Watt, there was a problem -- a "state of discomfort." For we find him a year later, in 1765, as follows:

"It was on the Green of Glasgow -- I had gone to take a walk on a fine Sabbath afternoon, I had entered the Green by the gate at the foot of Charlotte St. -- had passed the old washing house. I was thinking upon the engine at the time and had gone as far as the Herd's house when the idea came into my mind, that as steam was an elastic body it would rush into a vacuum, and if a communication was made between the cylinder and an exhausted vessel, it would rush into it, and might there be condensed without cooling the cylinder. I then saw that I must get quit of the condensed steam and injected water, if I used a jet as in Newcomen's engine. Two ways of doing this occurred to me. First the water might be run off by a descending pipe, if an offlet could be got at the depth of 35 or 36 ft., and any air might be extracted by a small pump; the second was to make the pump large enough to extract both water and air. I had not walked further than the Golfhouse when the whole thing was arranged in my mind."

Thus we find the actual activity is not connected with the problem -- a walk on a fine Sabbath afternoon. But, and this is the crucial point, James Watt was "thinking upon the engine at the time." So, one must surmise, was Archimedes thinking upon the king's crown at the time when he was about to take a bath. And so, one must intuitively generalize, were many other creative scientists and engineers thinking upon their pet problems when they were to all outside observers performing everyday functions of living, working, or recreating their physical energies. This, I believe, is the second distinguishing mark of the creative engineer and scientist; others, less creative, are not so "absent-mined" for they do not make a habit of thinking upon the problem so continuously and so persistently.

In my view, what is characteristic in all these myths and factual revelations of the creative person is his persistence, his mental stamina which enables him to wrestle with his problem now consciously and now subconsciously, at times by voluntary application entailing great effort and then, when lesser men would fall exhausted, to continue the struggle at a deeper level of consciousness and never to give up until the "flash" strikes, and even then to go on until "the whole thing was arranged" in Watt's mind. Whether it is Edison working for many years on perfecting his inventions of the electric lamp and central generation and supply system or William Henry Perkins working "during the Easter vacation of 1856, in my rough laboratory at home" and discovering the synthesis of aniline dyes when he was a mere youth of 18, forming a family company, building a chemical plant, and actually marketing the dye in December 1857 when he was not more than 19 -- the same thread of single-minded endurance and stamina runs throughout the many-colored tapestry of great innovations. These innovators seem to fasten onto problems literally for dear life; they are simply incapable of stopping thinking upon the problem.

This faculty is not a common one. The average person is fatigued far more quickly. It is rare for people, not known for creativity, to deal with a single problem to its ultimate solution if such an effort extends beyond minutes, hours or, at most, days -- at least not if they are left to follow their natural, voluntary ways.

Thus, we find the innovator possessed of two extraordinary qualities: 1) The innovator is possessed of an extraordinarily low threshold to a state of discomfort with some aspect of the order of things, the status quo. 2) He compliments this sensitivity with an extraordinarily high level of mental stamina, enabling him to persist until he removes the state of discomfort, -- again, the 99% perspiration of which Edison spoke.

I know of no other quality which is as universal to all innovators as these two. In my study of innovators, admittedly not exhaustively, I have found no major innovator lacking either of these qualities.

Conclusions -- Scratching Where it Itches and ROI

What lesson do we learn from this? I posed the question earlier that if monetary rewards were necessary but not sufficient to attract, hold and encourage our innovators, what other incentives were? I do not think I can give all the incentives (and per coutra the barriers) but it seems the following two are essential:

1) I believe it was Sommerset Maugham who defined "happiness" as "scratching where it itches." It seems to me this dictum applies to the innovator. If he shows signs of discomfort, of distress, with the status quo of a process, a product or a service, allow him to scratch where it itches. Do not try to beguile him to solve your problems; allow him to solve his. If you have an organization problem, do not solve it by taking him away from his problem; solve it with someone else -- but don't forget to reward your innovator fairly. If there is a fire to be put out in the mill, factory or workshop, be sure to bring it to the innovator's attention. But allow him freedom of choice. He may smother it for you and create another innovation or he may beg to be excused. In the latter situation, let him attend to his own state of discomfort. Let him scratch where it itches, but not where you want him to scratch. He will not experience happiness, even if you paid him well, to do your bidding. If he is not happy with you, you can not blame him if he leaves for greener pastures where he may find a scratching post more to his liking.

2) Innovations need a peculiar type of persistence, both conscious and unconscious -- a type which is peculiarly, probably uniquely possessed by innovators. We must allow the innovators to exercise this rare gift. Probably, the most subtle danger, the most insurmountable barrier to this exercise of this persistence, is the use of a certain particularly powerful eco-

nomic diagnostic tool at too early a stage. I refer to the concept of "return on investment," the R.O.I. R.O.I. in the hands of a skillful manager, or the treasury department can be as effective as a scalpel in the hands of a skillful surgeon separating morbid and dead tissues from healthy and vital organs. When applied to the creative efforts of an innovator at too early a stage, it is a knife to the heart. Since I think of the innovator as a human with the divine urge to create, I have often had, as a research director, an odd thought about the Great Creator Himself. I would think that if the Great Innovator on that first day, when He "divided the light from the darkness," had applied the criterion of R.O.I. to His innovation, I doubt that He would have persisted to the sixth day and made man and woman in His own image. For, even now fourteen to fifteen thousand million years later, there is serious questioning that He has had any returns on His investments in us.

Summary

In brief, if a problem needing an innovative solution is defined as "a state of discomfort in the innovator," we find innovators are possessed of two primary and rare characteristics when compared to the rest of the population: First, they appear to have a very low threshold for such discomfort. Secondly, they possess extraordinary stamina to stay with the problem until it is solved and they revert to a comparative state of comfort -- until the next time they meet a "problem" which is no problem to anyone else.

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RECEIVED November 13, 1979.

12

The Effect of Serendipity and Specialization on Invention

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You are trying to find a way to make the world beat a path to your door, but nothing seems to work. Then you discover that one of the worthless mousetraps you have built actually is the best potato masher ever devised.

This is serendipity, the happy faculty of stumbling across something valuable accidentally. Serendipity has always played a major part in the development of new and useful things - like floating soap, a nonstick coating for cookware, better brakes for jetliners, the vulcanization process for rubber, a widely used artificial sweetener and a rat poison that harms no other creature.

Many giant firms, however, don't like to talk about luck's role in their research and development efforts. After all, how does it look for a researcher to stumble blindly onto a better gadget after he and a host of other highly trained and well-paid scientists have expended months of work and a pile of money on a major, organized effort - without success? A spokesman for one big midwestern consumer products firm says he is eager to tell about a new device developed accidentally, but then a vice president squelches him. Bad for the corporate image, he is told.

Other firms are more outspoken. "We spend a great deal of time planning our work, and I think this is very important," says a vice president for research and development at General Electric Co. "But you can't really plan many research discoveries. Frequently unexpected things happen that are the most valuable and useful results of the research."

Into The Frying Pan

And sometimes things happen that have nothing to do with the line of research. In 1938, for example, chemist Roy Plunkett was trying to make an improved refrigerant for Du Pont Co. He filled several cylinders with various mixtures of gases and stored them in dry ice. One morning he found that the gases in one cylinder had formed a white waxy solid that didn't dissolve in conventional solvents or react to extreme temperatures. Thus the discovery

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of Teflon*.

A few months before Mr. Plunkett stumbled on Teflon*, a graduate student in chemistry named Michael Sveda was puffing on a cigaret in a lab at the University of Illinois, where he was puttering with various compounds in a search to find a fever-reducing drug. Ordinarily a pipe smoker, he absentmindedly chewed his way through his cigaret, leaving bits of tobacco on his lips and tongue. He brushed them off with a finger - and suddenly noticed an overpowering sweet taste. "I knew right away that I had something important," Mr. Sveda recalls. He tasted everything on his lab bench (some of the compounds were quite toxic, he later realized) to find the substance that had put the sweet taste on his fingers. That was the birth of sodium cyclamate.

A Scouring Pad Makes Good

A new technology, fiber metallurgy, owes a great deal to the frustration of Appy Juras. In 1935, Mr. Juras was a technical salesman for a plastics company that was trying to lick a certain problem. The firm wanted to use a tough new epoxy resin plastic for such shapes as auto dashboards, but the plastic mix didn't harden evenly when cast. At a workshop in his Detroit home, Mr. Juras was trying to find a way to conduct heat quickly out of the plastic mix so it would cool evenly.

He wasn't getting anywhere. Finally, in a what-the-hell mood, he chucked a steel wool scouring pad into the syrupy mass. Within a few hours, Mr. Juras realized he had the answer: the steel wool had adsorbed the heat quickly and conducted it out of the mix, allowing the plastic to harden evenly. And the steel fibers imbedded throughout it imparted an extra toughness to the substance.

Mr. Juras followed up on his discovery. He soon found ways to tailor metal fibers so that when they were combined with other substances, stronger, better-wearing products could be made. In 1965, he formed his own firm to produce the fibers, and he worked with auto makers and other firms on specific applications.

He helped Bendix Corp. develop a jet airliner brake with a lining containing metal fibers: it gave big military and commercial jets 400 safe stops instead of 40 to a set of brake linings. He also developed a cloth used on some autos.

Many inventions exist only because of fluffs in the lab or on the production line. In 1839, Charles Goodyear accidentally dropped a glob of rubber and sulphur on a stove, running an experiment aimed at trying to make rubber more versatile. But the rubber cooked into a substance that wasn't brittle at low temperatures and din't soften at higher temperatures, the main drawbacks at the time to the wider use of rubber. Goodyear named the accidental process vulcanization, and a huge new industry was

*Trademark of E. I. DuPont

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

launched.

In 1926, physician-turned-chemist, Joseph C. Patrick, was trying to make a cheaper antifreeze for autos. He didn't make it, but one sticky, smelly mess he produced hardened into one of the first useful varieties of synthetic rubber. A businessman talked Dr. Patrick into exploiting the discovery, and Thiokol Chemical Corp. was formed as a result.

It Floats!

Ivory* soap was a mistake, too. The first batch made in 1898 when a Procter & Gamble Co. workman went to lunch without remembering to turn off a blending machine. The resulting batch of soap had tiny air bubbles beaten into it: when it reached the market, the enthusiastic requests for "more of that floating soap" convinced P&G to keep making it. Dynamite, puffed wheat and puffed rice cereals, and LSD are traceable to mistakes.

Serendipity doesn't always bring fame and fortune to the inventor. Charles Goodyear, who failed to patent his vulcanization process, died $200,000 in debt. Also, Lady Luck does little for those who don't recognize a break when they see one. As Louis Pasteur put it: "In the fields of observation, chance favors only minds that are prepared."

Consider physicist John Tyndall, who in 1895 idly but accurately noted the antibacterial action of a certain bluish-green mold. Almost 50 years later, Scottish bacteriologist Alexander Fleming made precisely the same observation when he left a bacteria culture uncovered and found it contaminated by the same mold. The difference was that Mr. Fleming knew he had discovered something important and followed through. The result: Penicillin.

Some firms take special pains to insure that the fruits of serendipity aren't overlooked. Monsanto Co., for example, sends every compound it develops to all its various specialist divisions, on the off chance it may have a use its developers haven't thought of. Sometimes it does: the company's Agricultural Chemicals Division, for example, found Vegadex®, a herbicide for vegetable crops, upon examination of a rubber-processing chemical.

My discovery of Vegadex® can be partly attributed to serendipity. At this point it should be mentioned that Vegadex® is a preemergent herbicide for controlling weeds in edible crops, such as celery, lettuce, asparagus, etc. Once we had Vegadex®, we were able to parlay luck into a carefully designed research program. With the aid of P. C. Hamm, a correlation of herbicidal activity versus structure furnished us a model for the future synthesis of

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similar chemicals. This correlation of herbicidal activity versus structure coupled with the replacement of sulphur with an oxygen atom, hydrogen with a chlorine atom, and diethylamino with diisopropylamino moiety of the Vegadex® molecule, led to the discovery of Avadex®, a preemergent wild oat eradicant. The further replacement of another hydrogen atom with a chlorine atom led to the discovery of Avadex BW®. Both Avadex® and Avadex BW® are presently being used as a preemergent herbicide in crops such as normal oats, barley, wheat, sugar beets and flax.

The use of either Avadex® or Avadex BW® at a rate of 1-1/2 lbs per acre, completely eradicates fields contaminated with wild oats and without being toxic to such crops as barley, wheat, oats, sugar beets and flax.

In conclusion, granted that Lady Luck played a part in the discovery of Vegadex®, the discovery of Avadex® and Avadex BW® was a direct result of a well organized synthesis program coupled with an excellent team effort between the chemist, the agronomist, management, and the patent attorney.

No one denies that the kind of luck that brings such things to light will continue to play a big part in the story of invention. But there are those who believe that in the corporate sphere at least, serendipitous invention will become somewhat rarer as the complexity and specialization of technology increases. One who thinks so is Robert J. Bouthilet, President of Foster D. Snell, Inc. He sees a growing "generalist gap" that leaves companies exposed to the danger of missing many a serendipitous opportunity.

"There are fewer generalists who can translate observations in one field into another," he says. "We have too many specialists, too many precisionists. Their tool, the computer, is too logical to make the casual observations necessary to serendipity." Mr. Bouthilet recommends that industry scramble up to its scientists a bit more, allowing them more time to work outside narrow specialties and apply their know-how to different problems.

In closing, I have never invented anything, for God is the creator and inventor of all things. He is the beginning and the end. Finally, I want to thank God for supplying me with many fruitful ideas.

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The Individual in Research Innovation: Eleven Hypotheses About Innovators

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There are a number of conceptions, stereotypes, legends and notions that commonly come to mind even within the scientific community when the innovative person is described. We have sought to test and validate or invalidate some of the more common of these conceptions with this study.

Eleven hypotheses were generated from commonly held notions about innovators and innovation. Fortunately, we had the opportunity to use an industrial laboratory and an academic organization (containing two laboratories) as our testing ground.

For this study, we defined innovation as a discrete jump in theory, method, or product. The concept of discontinuity is the important essential in the definition. It should be noted that the definition only refers to measurable outcomes, e.g., theory, method, or product. The definition does not deal with ideas or abstractions that do not enter fields of knowledge in a testable manner.

By the use of peer nomination in the three different laboratories, we established samples of innovative, productive and non-productive scnentists. Having peer nomination coverage for individuals from each group yielded a validity of convergent placement. The sample represented sixteen different disciplines, thirty-three different U. S. universities, and twelve foreign universities. This was a very diversely trained group of people. Utilizing this sample of scientists, we investigated these eleven testable hypotheses or notions about innovators in the form of questions using interviews and questionnaires.

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0-8412-0561-2/80/47-129-147$5.00/0

1. Do innovative individuals possess a unique quality that enables them to innovate?

There is a large body of literature dealing with this question, and it seems everyone has been looking for the Holy Grail in picking innovators. Unfortunately, there is no one unique quality that differentiates innovators from non-innovators.

Conclusion: In research, the ability to innovate is a complex product of inherited attributes, social origins, parental support, training, chance factors and work environmental factors.

2. What about inheritable attributes such as intelligence. Are they more intelligent than their peers?

At first thought, one might think that the innovators must be smarter than the non-innovators. However, there is obviously a problem correlating intelligence with innovation. They are not the same thing.

Conclusion: Intelligence (a high degree of it) is needed to carry out innovative work in science and engineering, but it is only a necessary, but not sufficient condition. We could not distinguish the innovative from the non-innovative individuals by intellectual prowess.

At least intellect does not differentiate innovators from non-innovators. That does not say that you do not need a degree of intelligence to be an innovator. But it does say that it is obviously not the only condition necessary to be an innovator. There is something else missing. So we move onto another question which is probably the most common assumption, namely, innovators are crazy.

3. Innovators have to be weird or otherwise they could not innovate. A previous paper in this book drew the conclusion that innovators must to step outside of their culture; if they did not, they could not innovate. Is this true?

The problem with discussing normality is -- What are the dimensions of normality? Are we considering them socially different? Are they deviant or psychologically are they strange. Are we talking about them physically or do they have some kind of disability. We categorize those dimensions of normality and examined them as differentiators of innovators and non-innovators. Using deviant behaviors or characteristics, we could not find any difference between the groups. The innovators had a lower divorce rate, closer family ties, and all of the normal social attributes. There was no deviation, and we could not differentiate the groups.

Conclusion: Innovative individuals are "normal" in those attributes usually used to define normality. The use of deviant characteristics or behaviors would not allow one to discriminate innovative from non-innovative researchers.

4. One commonly held argument which is very strongly articulated by the scientists is that they are more independent than their peers, and that is why they come up with these new developments. Again, this presents a problem. What does this mean--independence? Does it mean that they are socially independent, that they are financially so independent they can go off and do what they want? Does it mean that somehow intellectually they are independent?

Conclusion: Innovative individuals are intellectually independent of their parents at early ages. This allows for individual testing of the environment. The resulting experience leads to an independence of thought.

Notice that the conclusion states--"intellectually independent" --not emotionally. The innovative individual still had supportive parents. They could go back to the parents when they needed to be patted on the head. However, if their father said, "You never touch a wire to that little outlet over there, you might get hurt" the innovative individual will wait until the father leaves and think, "I wonder if that's true?" and proceed to stick the wire in the outlet. The interesting thing about this behavior was that the innovative individual is constantly experimenting without knowing it. This is very different from other children that are told not to put wires into an outlet so that they will not be hurt. These children never do and never suffer the consequences, and they never gain the joys. This makes a big difference in the motivation of the innovator. The innovators regales us with stories that are absolutely hysterical. Some of the stories were not so humerous because the innovator was hurt. On the other hand, an unpleasant experience did not stop them; it even excited them more about solving some problems. This becomes very important as a source of motivation for the innovator.

5. Did the innovators have skills at young ages or later in life that other people did not possess? What gave them some of this intellectual independence?

   We looked for all types of skills--mathematical, reading, observations and even athletic prowess. We found that there was one that differentiated; the rest of the skills did not. That particular skill may be one of the most important intellectually, because it may be a corollary of some other intellectual aspects of the innovator. This skill was reported also by Roe in 1952 in her study of eminent scientists which stated that innovative individuals could read at much earlier ages than their non-innovative counterparts, and they were avid readers as children.

Conclusion: Reading as a skill is manifested early in the life of innovative scientists. This "avid" reading may be an early indication of their unending curiosity.

6. A commonly stated difference between innovators and non-innovators is that the innovators are great risk-takers and are much more willing to take a risk.

   We examined various inventions and tracked these inventions back to who was responsible for them. This included how it was done and what was done.

Conclusion: Innovative individuals, when compared to productive researchers of equal technical background, are no more highly risk-taking. Given the preparation, work, intelligence and persistence of innovators, most of what may be perceived as risks by others, are fairly sure "bets" for innovators.

When working on a new concept, an innovator becomes so certain that it is such a sure bet that he does not understand why others think it is a risk. Additionally, an innovator considers every failure that he has had as just more information. That is very different than the person who sees every potential failure as a risk. Therefore, we can not conclude that innovators are more risk-taking because they do not think that they are, although from an outside perspective they are. Innovators see this as simply a process of obtaining more information. You could say that innovators are greater risk-takers if you take it from your perspective.

7. Another notion attributed to innovators is that they are more adaptive or flexible than their more rigid counterparts in science.

   The problem with flexibility is the same as with normality or with risk-taking, that is, "How do you define flexibility?" Do we define it in terms of trying all the alternatives or willing to explore avenues. What does it mean to be flexible?

   To the innovator, flexibility means an openness to information exchange. They are very flexible and will listen to almost anything. This is probably why serendipity occurs. An innovator thinks, "Hum, I don't know. Let's try it."

In that sense, they are more flexible. There is a very important difference. They can generate more alternatives and that is why they are more flexible. If an individual and you are working on a problem and you only have one solution, what do you do? You keep getting a larger hammer. That's all you do. But what does an innovator do? He tries another alternative.

It doesn't bother them to have four experiments simultaneously being conducted on the same problem. Whereas, for the non-innovator that's almost too much to handle in terms of their rigidity. They would have a nervous breakdown if all four were ongoing. Suppose they all worked?

Conclusion: What may appear to be flexibility in the innovator may be the result of the innovator's ability to generate more than one alternative coupled with his maturity in tolerating ambiguity to gain a tested solution.

8. Are innovators better trained than their non-innovating counterparts? Did they study under better people? Did they go to better schools? Did they have better equipment?

Because surprisingly enough, given the Federal Government's and the state governments' intervention in education, we might think that this question would have been asked. We couldn't find one piece of literature on it; we could not differentiate innovators by where they went to school, who they studied with, or the equipment that they used.

The innovators emerged from even some of the poorer environments for science. The training did not seem to differentiate them from non-innovators. Training did, by the way, differentiate productive from non-productive scientists. Training has a lot to do with better normal science, not innovation.

Conclusion: The skills (e.g., verbal, mathematics) necessary to gain a formal degree in science and engineering need early development in the home environment. But training at the college level did not differentiate innovative from non-innovative researchers.

9. A commonly held sociological axiom is that innovation may not flourish unless the culture or the belief system allows it.

We investigated this but in a different way. We investigated this notion by again looking at the three groups of scientists and determining if the belief systems that they grew up under, mainly religious, would differentiate them in terms of innovation. It turns out it does.

Do value or beliefs differentiate innovators? It turns out that it does. If the belief system incorporates the universe as unknowable or as a child one is told not to ask certain questions, this becomes one's belief. Why would you become a scientist? This is fatalistic in the sense that this system considers that there is nothing we can do about nature anyway. Therefore, one would normally go off and do something else. Secondly, there is a suspicion of science which certain religious beliefs do hold. Of course, if the center of the belief is on the after life, why would you be concerned with now? If one is very busy getting ready to die, you're not going to concern yourself with improving the current state of affairs. Belief systems do have a lot to do with innovation. We can not necessarily generalize that to the question of the effect of culture. But certainly for the individuals we examined, it did.

Conclusion: Certain belief systems, namely, those incorporating the universe as unknowable, suspicion of science, tradition of authoritarianism, and the focus of thought on the afterlife lower the probability of an individual becoming an innovative scientist or engineer.

10. A related notion to the freedom of belief is the freedom of the scientist. What about freedom? Does the innovator have to have a free environment to innovate? Or, as some authors believe, anybody can innovate if you give them freedom to innovate.

There was a notion extremely prevalent in the sixties that complete freedom in the laboratories would lead to greater innovation. Companies moved their R&D laboratories out into the woods. The results were disappointing. Companies are now moving their laboratories back closer to the factories. Why would that increase innovation? The innovators were not persisting in their work, they were persisting in thinking. But the two have to go together. That is one conclusion all the innovators told us. Edison was right. There is no substitute for work. They are constantly working. When we went to visit innovators, some were in their lab fixing equipment. When asked if they had technicians, they said, "yes, but if I use the technicians, how am I going to get ideas?" Therefore, the innovators themselves were in the laboratory working.

We examined freedom for the innovator. It is a fairly complicated answer. There is ample evidence that in very restrictive environments you obtain innovation. Most people do not want to hear that but it is absolutely true. One may have to be in by eight and can not leave until five; one may be forced to take their lunch hour from twelve to one; one may be held accountable every month, you write reports--all kinds of restrictions. However, this is not to argue that, given more freedom, you would not obtain more innovation. But it does say that some of the arguments about freedom really are fitting American dogma more than they are fitting the data. It is a nice idea but I am not so sure that this native concept of freedom led to more innovation. They were absolutely slaves to the problem on which they were working. Freedom is defined as the ability to just leave and walk away from work. Innovators can not walk away from it. They are thinking about the problem constantly. They are very confined individuals in the intellectual sense.

Conclusion: There is evidence that innovation can occur in a "free" or in a restrictive environment. This is not to say that any individual may be more innovative in a "free" environment than in a "non-free" situation. But it does indicate that the assumption that freedom is necessary for innovation is a gross oversimplification fitting American dogma.

This has been an oversimplified supposition about freedom which is just not true. There is tremendous discipline going into research. Discipline and freedom to explore alternatives are not incompatible, but nonaccountability and no discipline do not lead to scientific innovation.

Our specific findings suggest that giving the innovative individual authority and responsibility over his own research may enhance innovation.

A comment should be made on accountability and the innovator.

Innovators prefer to be held accountable because they are successful and have innovative successes. They want these innovations recognized.

11. Do innovators, when compared to non-innovators, have unclear boundaries between work and non-work. In other words, do innovative researchers incorporate work as the fabric of their life more than a non-innovator?

Conclusion: Innovative individuals have no distinct boundaries between work and nonwork. They love research. They center their lives on the meaning of their work.

These eleven hypotheses and the resulting conclusions from our interviews are a start to more realistically describing and explaining the innovator.

RECEIVED November 19, 1979.

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The Individual in Industrial Research and Innovation

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Innovation has always been, and continues to be, a controversial and contemporary topic to which it is difficult to bring anything startlingly new. But it is a curious fact that innovations -- historically like reovlutions -- are usually in progress before they are recognized. Perhaps the greatest value of a symposium like this one is to provide some recognitive insights on the "detection, symptoms and treatment" of innovation in its various stages. Innovation does take many forms and modes. Considered as the ouput of an induvudual, or a team of individuals, it can be addressed in numerous ways. Let us them consider the "case study" of the induvidual in industrial research/innovation from several viewpoints, and conclude with some observations about current economic and political climates which most certainly have an effect on the individuals who innovate.

Innovators -- like artists, musicians, and authors, come in all shapes and sizes. But they do seem to sahre some common attributes:

1. innate curiousity, self discipline,
2. incurable optimism,
3. the ability to adapt concepts known in a particular field across disciplinary boundaries into "virgin territories,"
4. the ability to recognize and correlate newly observed phenomena into working hypotheses -- however imperfect at first, and last, but not least,
5. the willingness to take risks in a scientific or technological sense in departing from -- or even opposing -- traditional concepts.

These characteristics may be exhibited in an extroverted way, or they may be part of a much more conservative personality. But they will be there all the same. So the first consideration in dealing with the innovative process in industry is to recognize

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and select the individuals who display these characteristics. Sometimes they are latent - but more often not, if we look carefully.

The environment in which the innovator lives and works is - in my opinion - of exactly equal importance to his/her intellectual make-up, though second in order in the innovative scheme. As we know, this subject has been examined in countless dimensions. But we should recount some of the axioms. The innovator typically will not function very efficiently in a highly supervised atmosphere. Broadly scoped objectives are much to be preferred to tightly drawn ones, though exceptions prove this rule. But we should not make the mistake of assigning the innovator to a problem or project where innovation is not needed.

The organizational structure in which the innovator works also is a key part of the environment. Apart from the obvious cliche' about not mixing clashing personalities, in my experience, innovative individuals in industrial surroundings can work well either alone or in a team with other innovators. The most important guideline here, I think, is to gauge the size and scope of the project correctly in relation to the amount of innovative talent applied. In areas such as new process exploration or development, the "critical mass" may be as high as half a dozen truly innovative scientists/engineers. Such a cadre obviously will require careful but not obtrusive coordination and management. I say management, rather than leadership, because the leadership - at least the technical leadership - will be supplied by the innovators.

Some opinions to the contrary, it seems to me that management by objective is the ideal way to focus and manage such a team. In fact, management by objective may be the best way to manage the lone innovator, too - since it gives him/her the maximum delegation of technical and professional freedom to attack an industrial type of problem with a clear understanding of what is desired as the end result of his/her efforts.

The innovator must be supported to the maximum extent possible by staff and facilities. By this, I don't mean that he/she needs six assistants when one or two are enough, and the latest model electron microscope is usually not required when the model purchased five years ago has been updated with necessary auxilary equipment. But it is certainly counterproductive to understaff the innovator's work and unconsciously force him/her to apply his/her talent to devising supportive measures that are more readily supplied by an (or another) assistant. Supportive equipment, since it often involves significant capital outlay, is another matter; but I suggest that it is prudent to provide the best equipment the company can afford to provide maximum information and shortest possible response time in supportive functions like analytical or instrument service. After all, time is nearly always the most vital commodity in any research or development project - earlier completion means a plant on stream sooner or a process/product improvement installed and advanced cash flow.

A little more on organizational handling of innovators. They are typically very bright and mentally acute, and will likely have a first priority interest in technical aspects of their projects. But never make the mistake of thinking them uninterested in the larger economic and business picture of their project and organization. Keeping them informed and allowing them to question or participate in these areas is very important.

How to keep the innovators innovating? Aside from the territory we've covered, there are two or three additional important points. Some of them may go the management ladder, others the scientific pathway, but in either case, especially the latter, the industrial innovator must be encouraged - and given every reasonable opportunity to stay in touch with new happenings in his field. Technological obsolescence of personnel is the bane of all scientists, but especially of the industrial scientists and innovators.

The innovators, as a class, are more self-propelled when it comes to keeping abreast of the literature and their field, but give them help at every opportunity. Literature search assistance, professional society participation and meeting attendance, encouragement - even requirements - that a certain portion of the work week be spent with the literature or in the library is essential. Really innovative people don't need too much reminding.

But even this is becoming greatly insufficient. More opportunity to keep in active touch with the academic community is essential for the innovator to keep in fighting trim. More university-industry interaction - BOTH WAYS - are, in my opinion, the best way to fight technological obsolescence and keep innovators innovating. We are simply going to have to find ways - and it will be difficult - to handle the proprietary information hurdles which often block many in-depth academic-industrial research collaborations because of the academic innovator's need to publish papers. The industrial sabbatical for university scientists and the academic sabbatical for industrial scientists are powerful tools for keeping the innovator productive - even enhancing his/her productivity. Their use of the sabbatical must be increased on both sides. Industry cannot afford the current rate of scientific and technological obsolescence we are experiencing. The professional society and the library and journals are all doing their parts - but there is no substitute for a year, or even six months in the academic, governmental, or industry counterpart to the scientist/engineer/innovator home base.

The problem of publishing and maintaining professional stature for the industrial innovator is very real in comparison to their academic counterparts. It is also a fact of life that proprietary industrial technology must be protected in order to earn a profit and pay stockholders a dividend. We have seen a lot of progress in recent years with industrial organizations recognizing the value of publishing to attract business and enhance their commercial image. Both the innovator and the company benefit. But there is another aspect to the whole situation: the prestige - or lack of it - of a patent as a scientific publication. What can be done to truly enhance the prestige of the patent as a publication? This is a real frontier.

The recognition from publications is some reward for innovators - especially if the innovation is commercialized. But, finally, we must consider the dollar. There are very different plans among the industrial firms for financially rewarding the inventor/innovator. Commonly there is a set reward - sometimes pretty significant - for patent applications and issuance and most of the progressive chemical companies also have an additional award or bonus system by which the innovator can be further rewarded for economically significant and successful work - cases I know of. But are we doing enough? In many organizations, the only way to real financial reward is via the management ladder.

In closing, let's prognosticate briefly on the outlook for industrial innovation. Recently, much has been written and said about slowdown in innovation, and an innovation gap between the U. S. and the European countries and Japan. Not so! We should distinguish between the ability to innovate and the decision to innovate. Ability rests in the innovator, the decision in management - or sometimes beyond - to government policy limitations.

Without question, research and innovation directed at new and better processes and products has been slowed by OSHA regulations, premanufacturing notices, EPA regulatory constraints, etc. Development costs are spiralling, and much of the innovative talent that formerly went to new process/product areas has refocused on solving regulatory and environmental problems - in many cases - laudably and appropriately. The industrial innovator will find many challenges in these endeavors - though probably less patentable and less glamorous results. In the end we must hope that a cost/benefit philosophy will prevail in government and industry alike - but that goal perhaps requires the most innovation of all.

RECEIVED November 13, 1979.

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The Individual in Government Research and Innovation

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In this paper I will discuss the role of the researcher in Government, the climate in Government today and as it was years ago, and a little bit about the system of exploiting patents belonging to the Government.

All of the ideas that I express in this paper are strictly my own and do not necessarily represent the thoughts or policies of the management of the National Bureau of Standards or any other Government agency.

I think our large organizations are getting too large; I think they are too rational; and I think they are managed by the wrong people. When you have a multinational corporation which buys a set of my patents and when you talk to the director of one of the divisions that is supposed to develop my record player and he tells you he doesn't know anything about record players, when you realize that his superiors know even less than he does, and that they own 400 companies, you begin to wonder what is going to happen to our technology. The answer, of course, is quite obvious.

In an interesting article entitled "On the Statistics of Individual Variations of Productivity in Research Laboratories" about why some inventors invent a lot and some people do a lot of other creative things W. Shockley — the Nobel Prize winner for the transistor (Proceedings of the IRE, for March 1957), analyzes why it is that some inventors do a great deal and some do very little. Most of us do nothing. He discusses the relation between quality and quantity of output of creative people, and he comes to some nonobvious conclusions. It is probably the best article ever written on the subject, and it backs some of the things that are discussed in this book.

The United States Government performs a great amount of research and supports a great amount of research. It is rather interesting that in all the major wars our Government found it necessary to bypass the regular Army and Navy procedures and developed civilian laboratories to do what the Army and Navy laboratories presumably should have been doing. It is a truism that people who fight wars (that is, the professional people who fight wars — soldiers and officers) fight each war like the last war; and it usually turns out that it is not the way to fight the next war. You have to draw into the Government the best scientists, the best brains to create the new weapons and the new technologies. This was done in the Civil War; it was done in World War I; it was done, of course, in World War II, and I hope there will be enough time to do it for World War III.

In World War I, radio was very young. There was no Radio Corporation of America. So, the Government pulled together all the people and corporations who had patents and made a kind of conglomerate out of it. During that war a great deal more radio technology was developed. After the war, there was a question of what to do with this new organization that had so many new ideas and had done so much development, and out of this was born the Radio Corporation of America. It is rather interesting that for many years David Sarnoff was its president. David Sarnoff was a radio man; he was the radio operator who heard the SOS from the Titanic and organized the rescue crew that rescued all the boats there were to rescue. He also supported Zworykin, for example, for some twenty years before they developed electronic TV. They did it because David Sarnoff liked the idea. Today's management does not do this; it has to have a pay-off and the pay-off has to be rather quick. No sensible master of business administration would ever support a man like Zworykin for twenty years because he happens to like him.

This love of radio was also true of McDonald of Zenith. Zenith was one of our contractors during World War II. McDonald built radios. If a radio did not please him personally, it was not made by Zenith. This type of management is changing, and it is changing in the Government also.

During World War II, when I did a great deal of work on weaponry the atmosphere was as follows: You were asked to do a job, more or less indirectly. Someone would say, "Jack, we need a parachute release for a guided missile to save it after a test," or, "We want to inject a hypodermic needle into the behind of a pilot bailing out at 30,000 feet because he's going to lose oxygen; about 2,000 feet above ground, please inject the Adrenalin needle into his backside." I found to my amazement that this was not an easy problem because if he bails out over a high mountain you can not use barometric pressure; barometers are not reliable enough because one does not always know the weather ahead of time. Therefore you would like to do this by radio, proximity fuse. I found that brave pilots, who had no hesitation going over enemy lines, did not like to fly with a hypodermic needle facing their backsides. This was the kind of problem that was thrown at you, and you could do it anyway you pleased. The only question was, "How soon can you have it done?" There was no accounting of money; there was no project writing in advance; we did not do any "entity studies"; we did not worry about anything except how to do it and do it quickly. You worked simultaneously on big and little projects, and nobody cared about the distribution of time. Of course, the work was very efficient because there was no accounting. I never knew who paid the bills; I never had an "estimate" or a "proposal"; there was simply no paper work. Occasionally at the end of a project, we would write a report, but that would be only on the technical aspects. Now, of course, we do a great deal of accounting, which I will discuss shortly.

The organization was very simple. I was a P-1 when I started working at the Bureau of Standards. This was the lowest grade of professionals. I calibrated meters, plotted my own curves, and filled out the calibration papers. There was no one under me; no assistants. Altogether, there were four people in the organizational ladder, between the President and myself. I was a worker; there was the section chief, a Mr. Stutz; the division chief, Hugh Dryden; the Director of the Bureau of Standards, Dr. Briggs; the Secretary of Commerce; and there was the President of the United States. Many years later I tried to count the people in such a chain and I became lost. Not only is there a line of authority that goes for some 10 to 15 people or so but there are so many branches which have effects and power over one's work that you cannot trace them all. I will discuss some of the consequences of this.

During the war, people like Bill McLean, myself, and others who worked on weaponry, worked on many things. We also worked on projects on which we were not supposed to work but we got away with it perfectly legitimately. There is a Rabinow Law #13, I think, that says that everything you do illegally, you do efficiently. This, of course, is perfectly obvious. For one thing, you do not write at all because writing on an illegal project is suicide. For another thing, you work with whatever equipment you already have on hand, and, of course, you do everything on your lunch hour, which started at 8:00 in the morning and finished at 5:00 in the evening. Another thing, when it doesn't work well and because it is illegal, you drop it very quickly and kill the project. When it is legal, you carry it on to doomsday, hoping somebody else will carry it on so that when it finally fails you won't be blamed. If an illegal project does succeed, you will be a hero, but if it fails you would like no one to know about it, so you bury it quickly. Illegal projects are very, very efficient from many points of view. We were allowed to do much of this.[1]

For example, I was permitted to develop a new hand grenade — not really permitted. I used money from proximity fuses and developed a new hand grenade because our then current hand grenades were terrible weapons. I don't mean terrible for the enemy; it was terrible for us. If you should happen to drop it, it exploded in three seconds, give or take two seconds. This incidentally, technically is a very important point. When you throw a grenade, you can tell pretty well when it is going to hit the other side and you like to delay this as much as possible so that the enemy can't throw it back at you. He could throw it back at you. So, what you would like to know is exactly when it is going to explode; hold it in you hand for a little time and then throw it just before it is ready to explode. Unfortunately, with the three seconds plus or minus two, it may explode in your face and kill you and your friends. I began to work on a new grenade and succeeded in making one that had several advantages. When I finished, the Colonel who was in charge of our work said, "Jack, where did you get the $100,000 you spent on it?" I said, "I stole it from Proximity Fuses." He said, "You shouldn't have done it." I said, "Well, do you want me to stop the work?" He said, "No, continue." I said, "Colonel, would you have given me the money if I had asked for it earlier?" He said, "No," and I said, "That's why I didn't ask you." You see, we understood each other.

Of course, this is what you do in any good laboratory and we did quite a bit of this. As a matter of fact, the sidewinder missile (which was developed by Bill McLean, who was my boss during the Second World War, and who later went to China Lake) was done more or less illegally. It is hard to justify to anyone why an air-to-air missile should be built by a Naval research laboratory. However, Bill McLean thought he could make a cheap missile — an inexpensive missile that would cost its weight in silver. At that time, missiles cost their weight roughly in gold. So, he developed this device because he was the technical director, and that is another interesting story. I had asked him, "Why do you want to be technical director when you like technical things and you don't like to manage?" He said, "Because I know the SOB who will get the job if I don't take it. So, I'd rather take the job." I hope he forgives me for quoting him correctly. Anyway, because he was the technical director, he could take five percent of their budget and spend it on anything he liked, and he chose to build the air-to-air missile. It became a big thing. Eventually, industry took it over and the price went back up roughly to its weight in gold, which is not surprising.

I was in industry about half my lifetime and half in Government. The end of World War II meant, first of all, that defense work was to continue and the government workers were better off than ever. We had more money, more freedom and still very little organization. We really had a great time except for McCarthyism that fired some of our good people and for some other changes of atmosphere, but by and large until about the late 1950's the government workers really had a grand time. We had lots of money for R&D because the Government was on a research kick. In industry, also, everybody thought that you must do research whether you knew what the hell you were doing or not because it was the "growth" thing to do. Wall Street gave money to anybody who wanted to start a new R&D business; things were wonderful. And there was a religious belief that research was good for itself; no one questioned it. The Government had developed atomic energy, computers, radar, and so on.

There are arguments as to who invented the first computer. I don't really care, you never can go back far enough in any art to really know who did anything, but the big computer business was started by Eckert and Mauchly, who built the ENIAC for the Aberdeen Proving Grounds. Then they built the UNIVAC I for Census, which we in the Bureau of Standards helped to buy. The way it operated was that we write the specs because Census did not know how to write the electronic specs. We didn't know either how to write a spec for a computer, but we had "chutzpa"—translated, it means "gall." We wrote the specs. Then, as the computer was being developed, we kept changing the specs. So, Eckert or Mauchly would tell us what they were doing and we would change the spec. When the computer was finally delivered to Census, the specs matched. This, of course, is the way you do things in research. You don't write a tight requirement because if you knew exactly what you were doing you would not need the R&D. In practice, you have a vague idea of what you would like to have because some guy "sold" you the idea, and then you write a spec based on what the inventor said. Then, if you are clever, you keep modifying the specs and the R&D work until they come out even, and that's the way all great weapons are developed. I don't believe for a moment that the customer knows exactly what he wants and then writes a spec. If he does this, he will get a hack job and it will not have much effect on society. Great things are done because the inventor starts when he recognizes a need, or he thinks he can create a need. He then convinces someone that this is a good thing to do. Then this someone writes a specification for something the inventor suggested. That is how you get new ideas into the field. The field experience modifies it and eventually people think that they really need it.

What happened then as the years went by and the Government was sponsoring a great deal of research was that industry discovered that research and development was big business. It was not during the war or before. There were some research laboratories, but very few. R&D was an adjunct to other businesses, and it was not supposed to be a money-making proposition; R&D was never intended to make money. Bell Laboratories was not supposed to be a profit center. Nowhere were there many professional R&D outfits. There were a few, very few like Battelle and a couple of special consulting firms but very, very little R&D for profit. Industry discovered, after the war, that R&D is a business, that there was a lot of money to be made. They began to insist that the Government curtail its own R&D operation and that more and more work should be done outhouse, and I use the word deliberately. Several things happened as a result of this. First of all, when the missile crisis developed, scientific salaries in industry went way up. Simon Ramo, for example, offered salaries that were much higher than the Government could pay because the Government couldn't easily change its salary structure. We are a very large organization and it takes a Congressional act to do anything important. So, the Government did a curious thing; it increased the number of grade levels. The administrative people began to invent titles; there was no more simple "section chief" or "division chief." They set up "centers," "offices," or "laboratories." They set up "associate directors" for everything; they set up "division chiefs" and "associate division chiefs," and so on. This proliferation meant that you could raise salaries by inventing new titles. As you know, this works perfectly well in industry too. You may call a man "vice president of nothing" and increase his salary by doing so. So, the Government suddenly became much more complicated. The thing that happens when you do this (instead of six levels you may have thirteen) is that paper work grows because now you have to inform people. Before, when I was a section chief I could go to the division chief, who was on step above me, and say, "Dr. Dryden, I need permission to do this or this," and he could give it to me because the only one he would have to ask, if he couldn't do it himself, was the director of the Bureau of Standards. But that sort of thing stops when you have sixteen layers. By the way, the more layers there are the less they know each other and the less familiar they are of the work that is being done. The social distance increases. It also means that if you have an even chance of convincing your boss that what you are doing is correct and if he has an even chance to convince his boss, and so on, and if you have six people to convince, you have one chance in sixty-four of winning. For a really new idea, that is pretty tough. Then, several other things happened. Industry wanted to have competitive bidding for R&D, which is nonsense. You don't really ever have competitive bidding for R&D. Imagine that you, a king, instead of giving a commission to Beethoven to write a symphony, you ask for competitive bids as to who is going to write the symphony. You don't do this. So, there was "competitive" bidding and because of this, proposal writing became a racket. Proposal writing is really a fine art; it doesn't accomplish anything because, by actual measurement, it was found that 95 percent of all government projects go to the organization that is expected to get the contract in the first place, before the proposal was requested. But, you ask for proposals because of some legal nonsense about competitive bidding. The proposal writing developed the "two-platoon" system. The two-platoon system works as follows: The best people in your company write the proposals; when you get the contract, you don't give it to that team because you can't waste their time to do the work. So, you give it to a second platoon, who doesn't do as well. I once told this to a large corporation mangement, and they said that they have a third platoon to explain to the Government later why it didn't work. In addition, if you can't write a proposal you have somebody else to write it for you because there are special proposal-writing consulting firms. There are also proposal engineers.

One of my friends was a proposal engineer; his job was to write proposals. He is a very brilliant inventor, so he wrote proposals. I asked him, "Larry, who does the work after the company gets the contract?" He said, "I haven't the vaguest idea."

The thing that is happening to the Govenment worker is (and the reason I tell you these stories is because it affects the Government worker very seriously), that he begins to lose his expertise. He begins to sit at a desk, read proposals, write requests, and read criticisms. It gets so bad that he finally can't read the proposals fast or well enough and he can't read the reports that come in, so he hires another consulting firm to do the evaluation of the proposal or the evaluation of the work that is being done. So, you have a case where the liars write to the blind and the blind get other liars to review the work of the first set of liars. I could give you case histories but then I would have to give names, and this is embarrassing. The Government worker, who was an expert when he was hired, sits at a desk, he spends all his time writing and reading papers, and he loses his expertise. At the present time, his half-life, in electronics, is probably no more than three or four years. I, for example, was a good radio engineer once; I knew how to use vacuum tubes. I could build you a transmitter or receiver if you just gave me the wire, a soldering iron and a couple of tubes. Then during the war I had to learn how to use small vacuum tubes and fire them from guns; that was relatively easy because I'm an electrical engineer but I was hired as a mechanical engineer by the Bureau of Standards and so I learned a little of each. I could solve problems of mechanics by making electic analogies. Then, microwaves were born and suddenly I was thrown for a loop. I was used to wires; suddenly I had wave guides, plumbing, square tubes that carried current in curious ways, magnetrons, cyclotrons. By the time I got so I could understand at least what was being said, transistors were born. Suddenly everything I knew was out. Instead of voltage, I had to get used to currents — sloppy currents — but I had to learn how transistors work. I remember going to the first lecture at Bell Laboratories, in 1946 I believe, and they had some transistor radios. I asked one of the research people, one of the three inventors, "How long do these little things last?" He said, "Mr. Rabinow, they last indefinitely; but if you don't overheat them, they'll last much longer."

Anyway, as the years went by, more and more engineers sit at desks. There has been a study made of how much of this is good for a laboratory. The study was made by Dr. Apstein, who studied many of the Government laboratories. I don't have the reports with me but he concluded that if you do all the work in-house, you become incompetent because you don't have enough outside influence. There was such a Government laboratory that developed torpedos and it made some serious errors because of this. If you do all the work outhouse, you become incompetent also. You have to do enough inhouse to keep your expertise so you can talk as an equal to the contactor. One of the things that was and is still liked by our contactors, when we work at the Bureau of Standards, is that the contractors respect us because if they didn't do what we wanted them to do, particularly during the war, we would do it ourselves and very often made the first models. So, we talked as equals and everything worked beautifully. Then you compare that with some Post Office operations, for example, for whom I worked as a contractor. I was in industry then. We developed the equipment that is used for sorting mail. When you had 150 people doing an R&D operation in a company that runs now at eighteen billion dollars a year and when they should have a laboratory of some 10,000 people of quality like those of the Bell Laboratories, you can expect serious problems. Their laboratory has only a handful of people; their own research is pitifully small. The result is that the Department gets "snowed" by outside contractors, not because the outside contractor is necessarily corrupt but because the outside contractor really doesn't know the business. By outside contractors, I mean some of the largest corporation in America. The Post Office got sold things that could not possibly work; they design zip codes which are wrong to start with and which have to be replaced; you warn them; and they don't believe you. Here you have a situation where nearly all the work is done on contract and this is horrible. You must do about half inhouse and the other half outside. On that outside effort, you probably will spend perhaps half on managing technology and half on managing money.

What has happened as a result of all this is that the accountants have taken over our operations in the Government and business, and the R&D workers are now checked very closely. This "accountability" was mentioned elsewhere. It is more important to have your accounting correct than to build a new hand grenade. The kind of stuff I got away with, you cannot get away with today. For example, when I was working at the Bureau of Standards, I invented a clutch using magnetic particles and iron plates — a simple device, but it was the kind of device that everybody could have done but didn't. I received a lot of publicity. Dr. Vannevar Bush called me one day and said, "How fast does it operate?" I said, "I don't exactly know, perhaps three milliseconds." He said, "Thank you." He called a couple more times. So I said, "Dr. Bush, if you will tell me what the problem is, maybe I can work on the problem." Well, the result of that was that I worked on a Microfilm reader that he had invented, but it had some problems in starting and stopping film very quickly. Why was I working on a Microfilm reader? Because my boss didn't care. I was building weapons, but if I felt like working on a Microfilm reader part time for Dr. Bush, it was all right. He paid me whatever we asked and we lied. We said it would only cost $5,000 because $5,000 didn't require paper work. I don't know what it cost, but $5,000 is the official number. Out of that work came the fact that I suddenly realized that if I could read dots on Microfilm I could read printed characters. So, in 1953 or 1954 I said to Dr. Astin, "Allen, I would like to build a reading machine." He said, "Why?" I said, "I think I know how to do it." He said, "Keep it low, quiet, go ahead." So, I built a reading machine that read the output of a portable typewriter. It is now at the Smithsonian on permanent exhibition. It's rather slow; it read one character every minute but it was rather exciting. You would put a platen of paper in front of it; it would look at the first character, scan it for a while, make up its mind what the best guess was, light up a light, and everybody would cheer. If it couldn't decide, it would light up "Tilt." The thing that is interesting is that many years later when I was making machines for the Bank of America that read 14,000 characters a second in six different styles of print (to give you and idea of what that means, it reads a full typewritten sheet in half a second), no one cheered. By then everything was "electronic" and what did you expect? The thing that was interesting about that first machine is that it was done on Government money; it had nothing to do with my project; it was permitted because it was something the boss permitted as long as it was not to occupy too much time and didn't cost too much. (It cost about $30,000). Years later when I was back at the Bureau in my second coming, I asked one of the chiefs (who is not there now) if I could build a reading machine for the blind. I now had a lot of expertise; I had spent millions of dollars developing reading machines, and there were three other expert people who had come back with me to the Bureau. We are probably as good as anybody in the world on this. We would have liked to build a reading machine for the blind which could read most printed texts; it would cost perhaps $100,000 to prove the point. My chief said, "Expertise is no excuse to do work at the Bureau of Standards now." If expertise is no excuse, what the hell is? The management has changed since, and I did get $40,000 if I wanted to do it but now the other reading machine people are too busy with too many other projects. Some have retired, and I only work part time so I really can't do it now.

In the good old days, the question of justification would not have arisen. If you wanted to do something interesting, you just did it because the boss was a technical man, the accountants were not yet in charge, and you could do whatever you liked within reason. The result is that now in the Government (and I do not only speak of the Bureau which is probably still the best laboratory in the Government) the overhead is counted very carefully, there's a great deal of effort on accounting before and after each project. You have to write papers before you start. You make contact with your boss as to what you will accomplish next year, next year he looks to see what was accomplished and a committee looks at both of you. So, the whole senior staff of the Government today is concerned with paper and much less time is spent in the laboratory. Unless you do laboratory work, unless you dirty your hands, you cannot be a physicist or an engineer. I don't care how bright you are regarding the paper work, you must know why friction exists between shafts and bearings; you must know why gyroscopes drift; you must know why missiles sometimes tumble or why hand grenades explode in the wrong places; there's no way of doing this by looking at paper.

I was once asked why do I make experiments, why don't I compute everything ahead of time, like in the case of a reading machine which cost a quarter of million bucks to make. I did some thinking and decided that I know why—I don't know enough. I don't know enough of the things that happen in real machinery to predict everything ahead of time. I know the general things that are going to happen but unless I build a model, I simply don't know enough. You must build models and that's how you learn to be an engineer. Now, the work is done by third or fourth echelons down, which is most unfortunate; that is, the best physicists and engineers are now managers. When you go through a large laboratory today, you look to see who is doing the work in the lab, and you find that it's a technician who doesn't know enough. In my opinion, this is tragic.

Now, I would like to speak briefly about what the Government does with its patents. It now owns some 28,000 patents which it developed or owns. What happens to them is a tragedy because the Government is under various pressures. Admiral Rickover thinks that we should make them free to everybody because if they're free to everybody, everybody will pick them up. This is pure nonsense. A free patent is nothing; it's a piece of paper. No one is going to spend the kind of money it takes to develop a magnetic particle clutch unless he has an exclusive license. If you don't give exclusive licenses, people simply don't develop. In Europe I owned the patents of the clutch. I sold the patents to Eaton. I made $26,000 after taxes, which was nice. The American patent belonged to the American Government. In Europe, the clutch was used in five automoblies, and it was used a great deal in other machinery. It is used in the United States only when there's nothing else that will do the job. In the reading machine case, the Government gave me the commercial rights because the development was done in a military laboratory and military labs have different policies. I did build my own business as a result and we did make a great many reading machines. So, it does make a difference as to whether you have or don't have exclusive rights or incentives to develop. There are bills in Congress now to change the Government policy; the Government should be able to give exclusive licenses on inventions where it makes sense. You hear this stuff from a prominent Senator who says that this is a "give-away," that the patents belong to the people. That's not the question. The question is, do they get used? Do they create jobs? Do they create employment? In this connection, I can tell you a very simple story. During the war, we confiscated all the patents belonging to the Germans, the Austrians, the Italians. These were industrial, high-grade patents obtained here by their companies. We confiscated 15,000 of them and the Government made them available free to everybody and they died. No one wanted to make a Leica Camera when anybody else could make a Leica Camera. Some people did, and in a year or so nobody made Leicas any more, because there was no point in making something that somebody else could always make cheaper. The German patents simply died and the Government now has great trouble with its 28,000. You hear these stories about it "belonging to the people," therefore make it "free to everybody." People ask what would happen if the Government would develop a cure for cancer. Should it be made exclusive? I have my own reward for it. I would say this: "If you want to reward someone for the cure of cancer, you can give them only one reward. Money is not enough. You give him a gold license plate that enables him to park his car any place in the world."

Note

1. By illegal, I do not mean, of course, that there was an actual law against doing it. I only mean that doing the work was not approved in advance by some higher level of management.

RECEIVED November 13, 1979.

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Innovation Within the Corporation

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The Industrial Research Institute affirms that there is an urgent need to improve the understanding and stewardship of technological innovation within the U.S. corporate environment. The innovation of technology that translates into new products and processes for world markets is of strategic importance to the economic well-being of the nation.

Although innovation is inevitably affected by forces outside direct control by the corporations concerned, it is nevertheless felt that industry should allot more of its time and effort to managing the elements of the innovative process that are under its control. In this connection, the I.R.I. believes that the following areas are of prime importance within the corporation:

I. Top Management's Attitude toward Innovation
II. Functional Coupling within the Corporation
III. The Effect of Organizational Structure
IV. The Management of Change in Corporations

I. Top Management's Attitude toward Innovation

The demands of society are constantly challenging the existence of any system or enterprise. The lessons of history are quite clear that in order to survive, every enterprise must respond to societal values and expectations. Key to the survival of a corporation is its capacity for self-renewal and sustained momentum, and the stimulation and channeling of this capacity is a principal responsibility of senior corporate management and particularly the chief executive officer. In the case of high-technology corporations, self-renewal is almost synonymous with innovation. The fostering of innovation, then, is not an option but a vital necessity for the top leadership of a technology-oriented enterprise.

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Business managements are finding increasingly that they must sacrifice profits to satisfy these needs of their employees.

(e) Increasing Female Representation. The impact of more women in our labor force will continue to cause great changes. Management and scientific ranks in the male-dominated technological industries are prime areas for female participation. The effect of women on the innovation activity in the corporations in such industries is likely to be quite significant. How to take maximum advantage of these new inputs for the process of innovation is still another challenge in the management of change.

No one can prophesy the precise scenario of the future, but we have highlighted some key problems and challenges in what is emerging as one of the most dynamic periods in America's socioeconomic history. The top priorities of American corporations must embrace actions aimed at maintaining our ability to innovate in an atmosphere of constant change.

* * * * * * *

In closing, the Industrial Research Institute joins others in making a strong appeal for a rededication to technology innovation within and by American corporations. In a world of increasing competitiveness and rapid, often drastic socioeconomic change, corporations must continue to identify emerging needs and innovative directions and deal with them proactively. Techniques for guiding a complex array of talents and functions through the often long process of technological innovation are based on, among other things: (1) a receptive attitude toward the champions of new technology and the requirements of various departments involved in the innovative process, and (2) an ability to keep these various elements in balance and make certain they continue to be functionally coupled with each other and with factors from the marketplace, Government, and society as a whole.

Finally, to be successful, innovation, particularly of the breakthrough type, requires longer-term financial support. Boards of directors, as the final arbiters of corporate strategy, must be willing to authorize this kind of support in the face of pressures to put the major part of a company's effort into projects geared to current or near-term returns.

RECEIVED November 13, 1979.

The Industrial Research Institute believes that corporate leaders recognize innovation to be one of their most important responsibilities. However, a host of internal and external factors affecting the life of corporations have tended to force attention away from an energetic pursuit of technological innovation and can vitiate top management's readiness to mobilize corporate-wide cooperation. Such factors include increasing Government regulation, a burdensome tax structure, the deepening problems of capital fund creation, and rising labor, materials and energy costs. All of these, and more, represent urgent problems that corporate leadership has been forced to cope with in terms of a logical ordering of priorities, and innovation may have lost ground in that prioritization.

The formal training of corporate leadership has perhaps played a hand in the ordering of the above priorities. There has been a natural need to deal first with those issues that lend themselves to more rapid solutions and promise to yield solid returns immediately or in the near term. This attitude has both called for and also been reinforced by courses in the business and management curricula of universities as well as special programs and seminars that stress traditional business skills. Only recently have executive training programs begun to systematically address the problems and techniques of managing change and technological innovation. There is a need to accelerate the development and dissemination of such training programs at the highest levels in U.S. industry.

In many cases heightened awareness of the critical importance of technological innovation may be needed to bring about a change in the way corporations and their governing boards assess the long and difficult process that results in successful innovation. Technological innovation should be accorded the same day-to-day attention and support as has traditionally been given to corporate funding, share of market, plant operations and the like. In short, corporate strategic plans must include more of the alternatives based on technological innovation and stress a dedication - or rededication - to the correct stewardship of that complex process.

Two concrete recommendations geared to improving this stewardship are:

- Top leadership must assume the responsibility for studying, understanding, and implementing the techniques of innovation, above all in the high-technology corporations.
- Management training curricula should pay more attention to courses designed to sharpen the skills of corporate leadership in the area of technological innovation.

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

II. Functional Coupling within the Corporation

The management of innovation requires a balanced attack on many centers of uncertainty, whether technical, economic or social. Innovation must be managed not as an agglomeration of individual segments but as a total system in which diverse functions and attitudes are correctly coupled. Some key elements in a system aimed at technology innovation are:

- The technology itself, including a feasible manufacturing approach.
- The vision of desirability in the marketplace.
- Appropriate financial management, including capital formation and the allocation of risk capital.

Barriers to innovation, especially in the corporate environment of very large organizations, often arise because of problems inherent in coupling many diverse requirements, outlooks and functions. Some examples of these problems as they relate to the three key functions are:

Function 1. Technology. Innovation encompassing high risk but high reward often results from major technical advances, e.g., the transistor, synthetic fibers, antibiotics, xerography, the digital computer, and instant photography. Problems arise in this type of innovation because of the seemingly excessive time it takes to couple the gathering of fundamental knowledge to a vision of the marketplace or acceptable financial rewards. Thus, high-risk innovation meets with various degrees of opposition in the modern corporate environment. Attention to short-term gains often gets in the way of developing a balanced portfolio of short-term and long-term overall corporate strategies. If high-risk, high-reward breakthroughs are to be achieved, there will have to be a more tolerant, patient attitude toward the process of technology innovation.

Function 2. Market Desirability. Many important innovations address latent market needs. Since they create markets, the market cannot be quantified in advance. The vision relating what can be done - the invention - to what is worth doing - i.e., what is potentially marketable - is perhaps the most important element in the process of innovation. Failure to establish this coupling is a distinct barrier to innovation.

Senior corporate management must provide guidance as to how comfortable they are with selected fields and business areas and declare what they are willing to allow the corporation to engage in. Although much has been said about the desirability

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

of champions who will push a development, it is equally necessary that a corporation have tough, practical leadership that can pull differing functions and attitudes together and move them forward toward clearly defined goals. This push-pull mechanism is an extremely powerful coupling force. Failure to create the environment where the technologist works together with the marketing visionary and where both interface with top management is certainly a formidable barrier to innovation.

Function 3. Financial Management. Failure to properly assess financial resources is cited as a major cause of failure for individual entrepreneurs and small businesses. In contrast, large corporations often overdo financial evaluation and analysis of the prospects of a new idea. Indeed, the new-idea champions in a corporation rightly complain of "paralysis by analysis" and feel that few innovative ideas can get through these corporate filters.

Rigid application of classical financial analysis is not well suited to the early stages of innovation, where it can sometimes create an insurmountable barrier. As opposed to the control-oriented mode more generally applicable to mature business operations, a financial attitude that is supportive over the longer term is what is needed to stimulate innovation.

A more subtle financial barrier is the practice of placing responsibility for innovation on the research department but keeping financial control in the hands of profit-center management. To hold one function responsible for long-term results while financially controlling it via a corporate unit answerable primarily for short-term gains is counterproductive. In terms of the attitudes of top management, such an approach can only be looked upon as a "mixed signal" from above. The question then becomes: Do those in top management really support innovation or are they abdicating this particular responsibility in favor of other selected higher priorities?

Nothing is more effective in pulling down barriers to innovation than a management committed to all-out corporate-wide functional cooperation for innovation. The converse can be devastating. Here are some recommendations for functional coupling aimed at enhancing innovation:

- Recognize that innovation is a complex series of events taking place within the corporation as a whole. Failure to couple any of the functions in this series can make the whole system fail. Consistency of support is required by the long-time horizons of technology innovation. On/off support discourages risk-taking or personal commitment at the technical innovative level.

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

- Realize that there is no such thing as relying on an isolated function to be solely responsible for creativity. The whole corporation must share this responsibility.
- Be aware that classical financial analysis rigidly applied to the early stages of the innovation process can seriously inhibit or even totally stifle the process. A sustained level of funding over long periods of time is a critical requirement.
- Encourage the co-existence of technology development champions and the kind of top management that is supportive yet forceful. These two elements create the push-pull action needed to move innovation forward.

III. The Effect of Organizational Structure

It is probably impossible to arrive at a consensus on the precise character of the perfect organizational structure for maximizing innovation. Each industry has its own specific characteristics, and these characteristics determine how best to create such a structure. However, certain principles are noted:

- Modern technological innovation within large corporations seems to demand a critical mass that contains a sufficient array of specific basic skills, both technical and non-technical. If the scope is too narrow in terms of resources, individuals perceive very limited horizons.
- Every interface crossed in the process of technological innovation necessitates a technology transfer, and hence problems of acceptance, ownership and control arise. Each interface can become a potential barrier to innovation unless managed and coordinated with great skill.
- A profitable operation usually has the resources available to provide for the future. An unprofitable one often does not and is forced to focus on only short-range needs.

IV. The Management of Change

Innovation is a fragile process; and when rapid or significant changes in the total environment take place, the process can suffer severely if not managed in an empathetic manner. The turbulent seventies are probably a harbinger of things to come, and we must get accustomed to managing innovation in periods of continuous change. Examples of changes in the total environment that will particularly influence innovation are:

(a) Perceptions of the People. For the solution of problems such as inflation, energy shortages, pollution, urban blight and strife, and racial tension, the population looks mainly to two institutions - the Government and big business. As business shoulders an ever-increasing portion of the responsibility for providing such solutions and allocates more of its resources to them, corporate management may find itself being forced toward more conservative, risk-free positions - and the innovation process will suffer.

(b) Government-Business Interaction. Increased Government regulation of business is causing disturbing changes in the general business environment. Business leaders are becoming reactive instead of proactive. The expectation that Government will add to the list of imposed and sometimes arbitrary rules and regulations is causing short-term tactics to take precedence over the longer range, more strategic postures. If our tradition of innovation is to survive, a better balance of long- and short-term considerations must be achieved.

(c) International Competition. Our national prosperity will be tied more strongly in the future to how well American corporations can compete internationally, either as multinational partners or entrepreneurs in world markets. This trend requires that appropriate risk-benefit analyses be continuously performed to decide on the current balance between satisfying desirable social goals and achieving the necessary economic competitiveness. If the funding of high social goals drains too much of our resources away from technological innovation, not only will our world position be penalized but eventually so will our ability to fund these desirable social programs also lessen.

(d) Changing Work Ethic. The traditional work ethic is undergoing significant change. Personal desires such as job satisfaction, freedom of dissent, and discretionary time are becoming essential items in the minds of the labor force.

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Organizing for Innovation

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All of a sudden in the last few years, the importance of innovation to the U. S. economy has dawned upon the government, industry, and the citizenry. There are concerted efforts to stimulate innovation on a broad scale by government, who, in the past few years has done so many things to inhibit it. It is inferred that by spending enough money and applying enough effort, innovation will occur. I do not agree with this philosophy and believe it to be almost self-defeating. When a lot of money and a lot of effort are involved, it automatically follows that there will be a lot of controls and red tape created, which will, of itself lead to conformity and stifle novel thinking.

In trying to expedite innovation, why not study the golden period of innovation and see what made it golden, and the circumstances that fostered it. We would discover, I think, that the great inventions and innovations of the industrial revolution were sparked by perceived wants of an increasing population, a decrease in the supply of cheap labor, particularly in agriculture, the spreading of population over a large area, and by the absence of large scale government intervention; in other words, the free enterprise process.

There were few huge multi-national corporations, few rules governing the conduct of business, and decision making was concentrated in owner-managers.

The "self made man" was the hero of the day, and the great American dream of pulling oneself up by the bootstraps with outstanding individual effort, vis a vis Horatio Alger, prevailed.

We obviously can't go back to those 'good old days,' nor would anyone want to, but perhaps there are some lessons that might be learned from history that have some application today.

The title of this paper is "Organizing for Innovation,"

0-8412-0561-2/80/47-129-181$5.00/0

is misleading because organization as such, and particularly over-organization may be innovation's deadliest enemy.

It is a recognized fact that innovation occurs more often and more effectively in companies of small to medium size. This is attributed to many things such as:

Shorter lines of communication.
More involvement of management.
Shorter approval paths.
Less antipathy toward risk taking.
More and faster recognition and reward for innovators.
Less conflict with existing businesses.
Stronger desire to grow.
Less formality - more flexibility.
More sense of urgency due to financial restraints.

If one accepts these statements, and we personally do, any organization of substantial size should attempt to create the kind of organization, somewhere in its structure, which emulates these small company characteristics.

We know also that large corporations organize beautifully to produce at low cost and in high volume, mass sell and distribute at high efficiency, handle financial matters with a high degree of automation, and make good profits. All of this requires structure, formality, adherence to strict rules of procedure, and fine tuning repetitive operations for minimum costs. This makes it difficult and relatively unattractive to change anything, once it is in place and working.

This type of operation is not compatible with the innovation encouraging small company philosophy, so if a large company wishes to combine the advantages of a small company in the field of innovation with the mass production and marketing advantages of a large corporation, they must be independent of one another on the organization chart; that is, line operating functions separate from experimental and development activities.

On a corporate level, a New Business Development, or a New Ventures Division can be created to accomplish the separation. To whom this division reports is not of primary significance, as long as its charter is clear, although ideally it should have organizational status equivalent to that of an operating division.

The charter of this group gives it the functions of searching for, evaluating, and developing new business ideas to a point where commercial sales, costs, capital requirements, and financial viability can be predicted with a degree of accuracy of 50% - 75%. This infers that the new product or business will have

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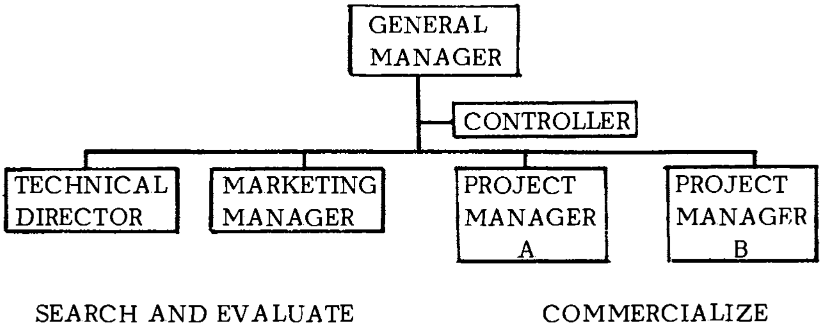
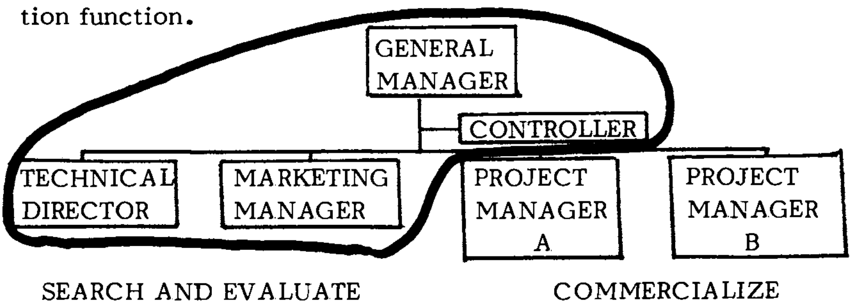
been manufactured at least in pilot quantity, sold to bona-fide customers, and generally proved in real life usage.

We believe that the general manager of this group should be a general manager in the true sense, with broad experience in all phases of business. Too often a scientist is chosen for this job, because in the first stages of development, technology predominates. In the later stages of development and commercialization however, marketing, manufacturing and finance play a major role, as does coordinating all these functions into a unified group. With this kind of leadership, the transition to a full commercial status is always easier, because many commercial problems have been anticipated and corrected prior to the transition.



For searching and evaluating, our general manager needs a technical director and a marketing manager, neither of whom should be beginners or novices. The technical director should have had broad exposure to multiple disciplines of science as well as engineering, and the marketing manager to the several phases of marketing - market research, field sales, advertising, sales promotion, etc..

These three, the marketing manager, technical director and general manager, together, make up the search and evaluation function.



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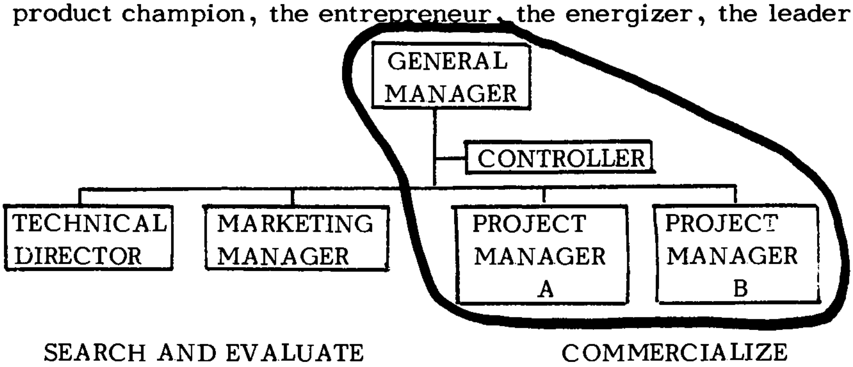
When search and evaluation are completed, the innovative project under consideration is either dropped or promoted to project status. This requires a project manager. The most critical personnel selection problem in a new business life is probably the selection of the first project manager. He is the product champion, the entrepreneur, the energizer, the leader.



It becomes his task and his responsibility to prove (or disprove) the facts that turned up in the evaluation step in the shortest possible time, and, if positive signs predominate, to get a profit-making product to market in minimum time, and for the greatest benefit to his employer over the long pull.

The project manager's incentive is to make his project go with the expectation of moving with it to full operating status and becoming the general manager of a new division. He will also have the respect and envy of his peers and the rest of the ego-building rewards that are so important. He will also have the self-satisfaction that comes with success in face of adversity.

Time does not permit going into the sources of corporate entrepreneurs, but suffice it to say that if the opportunity is there, an entrepreneur will find it.

One can see from these simple charts that the general manager is selected from the search and evaluate group, or perhaps even might be the former technical director or marketing manager.

Oftentimes the enthusiasm of individuals, generated in the 'search and evaluate' group, is sufficient to persuade them to step up and declare themselves candidates for participation in the project stage.

The 'climate for innovation' is given a lot of lip service, and responsibility for the maintenance of this climate laid on management's back. We can't argue with this too much, except to say that the innovator on a non-management level must also have some little understanding of the fact that industrial innovation's end purpose is to make a profit, so that he must tolerate some disappointments in management decisions, just as management must tolerate the 49 unsuccessful experiments that preceded the 50th and successful one.

Some say the 'enthusiastic support' of management is required. We would put it more mildly in the word 'tolerance.'

Included in the category of management tolerance is the recognition of the importance of 'bootlegging.' While there are no statistics to support the statement, my own personal experience would lead me to guess that a large portion of the successful innovations could be traced to bootlegging.

Bootlegging can be defined as beating the company on its own time. In terms of glory and the respect of one's peers this is second only to beating the competition.

While what we have said up to now was aimed at corporate level innovation-invention and development, the same philosophies apply to individual operating units. An operating profit center can handle new things on the same basis of separating day-to-day repetitive activities from the untried experimental ones and achieve good results. Usually the scope of activity will be limited to improvements and additions to existing product lines, as opposed to exploring fields in which the company has limited experience.

We have said nothing yet about financing innovative activity. We hear about plans for pouring millions if not billions into innovation with such goals as new sources of energy, new modes of mass transportation, etc.. What we really need is to put the knowledge we already possess to work. There are proven ways to process oil shale, convert coal to gas and liquid fuels, move large numbers of people at high speed from one place to another. The problem is they are not economic with $5 a barrel oil. We have seen this price multiply by 4 in the past few years with further increases a certainty.

A re-examination of existing technology and its adaptation to present problems is needed. What we need is innovative entrepreneurial activity - not more basic science.

This entrepreneurial talent needs elbow room, not more bureaucracy; it is unlikely that government can tolerate the flexibility required to bring new things to fruition. American industry in general has proved over the years that it can do this job. Certainly its efforts are not without fault, but if I look back over my own short life span and count the innovations that have brought things like radio, automobiles, television, air travel, electric refrigerators, and computers from the category of luxuries for the rich to that of commonplace everyday affordable items, I cannot help but be impressed. Why not make it possible to keep on doing things like these? Let's stop stopping things and start starting things.

Instead of rewarding the lazy and indigent conformers, why don't we reward the venturesome and ambitious a little more?

Dismounting now from the political soap box, industry is the only segment of our economy that can sponsor the kind of innovation that solves problems, makes profits, and pays taxes.

We think industry has let itself become enchanted with systems, controls, mathematical solutions and yes, computers, and has forgotten or at least neglected the realization that innovation is individual activity that departs from the norm, the formula, and the rules.

To encourage innovation, industry must now re-discover the fact that any innovation starts with a dream, and only people have dreams. It must accomodate to the individual in its organization planning, and allow some of those dreams to materialize.

We believe that new businesses have three basic stages: invention, entrepreneurship, managing. The lines of separation are hazy and overlap each other to varying degrees.

Up to now, we have touted the innovative dreamer entrepreneur type of person whose role is to dream of new things and reduce his dreams to reality. Sometimes, not too often, this same individual can father his dream from inception to a going business, and then perform the necessary functions to run the resulting business up to its full potential. This would be the ideal situation. The entrepreneurial types have difficulty adjusting to the routines of cost-reduction, financial analysis, distribution problems, labor negotiations, legal complications, and the like, and flounder or stall out before the business reaches its zenith. When this happens, a change in leadership becomes necessary for the good of all. This is a traumatic change for everyone, and there can be serious, if not fatal results unless this transition is handled delicately and with finesse.

To bring this discourse to a close, we stress again the need to treat innovation as a personal accomplishment, much as setting a new world record in the mile run, or painting a beautiful picture, or designing a grand building. It is not accomplished simply by the expenditure of large sums of money, or by masses of people,

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or by fiat.

We have a personal anathema for the appointment of committees of all kinds, and particularly those established for the purpose of finding, and developing new businesses. Committees normally function as fault-finding bodies and provide a forum for expressing opinions and demonstrating persuasive powers. Fresh new ideas have little chance of surviving this ordeal in their infancy. Only when the idea has reached a stage where it can be demonstrated, together with some market information, and rough profit estimates should it be exposed to a committee.

Organizing for innovation, the title of this paper, should more aptly be "Overcoming Organization for Innovation." We believe that any company can increase the frequency of innovation by its employees, as well as its quality by simply reducing the number of barriers that stand in its way. Simplicity and flexibility are two good characteristics to build into any organization charged with innovative responsibility.

Let's not get too enchanted with the wonders of machine-generated statistics, and keep reminding ourselves that an organization never had an idea, and that the individual human brain is still the only source of bold new thought.

RECEIVED November 15, 1979.

18

The Bureaucratization of American Science

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As a member of the Technology Assessment Board and the Health and Scientific Research Subcommittee, I have gained a new appreciation and a new insight into the problems of science and technology in our country. The national problems we face, the solutions of which could be assisted by advances in science and technology, are becoming almost secondary to the larger problem of managing resources for scientific research and technological development.

After the turn of the century, the reform movement came to prominence in the United States. The so-called "robber barons" of major industry were thought to have abused the free enterprise system, and the reform movement, personified in the Presidency of Woodrow Wilson, and to a lesser degree the administration of Theodore Roosevelt, succeeded in enacting a host of new laws designed to break up industrial cartels, regulate interstate and foreign commerce, establish working conditions for employees and rules for labor/management relations. Though insufficient at that time to have a wholly negative impact on science and technology, these reforms signalled the growing involvement of the federal government in determining the national interest and priorities. The government has expanded its authority to the point where little is left unregulated and business has little incentive to take risks on new and better products and processes.

Today, it is the policy of government to support research and development, primarily because overregulation and taxation has dried up so much of the capital in the private sector. The encouragement of science by the federal government has been institutionalized in such federally-sponsored agencies as the National Science Foundation, the National Aeronautics and Space Administration, the National Institutes of Health and the National Academy of Sciences. Through these agencies and others, the federal government presently funds about one-half of the estimated $52 billion total expenditure on R & D activities. Research and development is becoming too bureaucratic an enter-

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prise to yield the kind of progress that characterized the first and second industrial revolutions. The bureaucratization of science and technology can be traced to several factors.

Initially, Congress must debate the amount of the appropriation for each of the federal agencies engaged in R & D activity. Congress, of course, representing broad and diverse constituencies, argues not only over the total level of funding, but the proportion of funding from one program area to another. In the Congressional arena, hard sciences are pitted against the soft sciences, basic research against applied, and the priorities for research, reflected in the funding for each science discipline, are usually set in the end by political compromise.

After Congress has made its decision on funding, the federal agencies are then faced with the task of implementing the programs and distributing the available funds. While elaborate procedures for auditing grants to scientists and reviewing the proposals for federal assistance are necessary at these agencies, it should be no surprise that a great deal of paperwork and red tape is created. Our nation's scientists and technologists must now be not only in competition for limited federal funds, but devote long hours to the science of filling out government forms.

And, even in spite of these existing rules, Congress has learned that they have often been inadequate or loosely enforced, resulting in dishonesty, unfairness and misspent dollars in federal grants management. This is not a criticism of science, but a criticism of bureaucracy.

Almost without exception, when government takes over a function from the private sector, there is waste, fraud, and inherent discrimination. That the federal government has given itself the responsibility to support science and technology to this extent is the problem. Valuable capital for research and development is lost and priorities are set which do not really reflect the needs or capabilities of the American scientific enterprise. When fifty percent of all R & D funding is appropriated and awarded by government we will see declining results. We will begin lagging behind other western nations and Japan in the development of high technology. Already our growth rate in high technology endeavors is trailing Japan and West Germany.

It is imperative that the federal government diminish its role in R & D activity not directly related to national defense. The concepts of free enterprise apply to science and technology as much as to other aspects of the economy. When the government controls such a major portion of the R & D effort, it also controls the decisions, the priorities, and the people. In order for the United States to resume its position as the world leader in science and technology, government must allow private concerns to explore whatever areas of science they feel are appropriate and worthwhile. Each individual sponsor of research should be able to determine priorities in accord with future needs and consumer demand.

The profit motive ensures legitimate research in a reasonable time frame and with little waste. In spite of the negative connotation the word "profit" has picked up in recent years, the profit motive, in a competitive economy, still provides for consumers the best possible products at prices in line with the free market.

In addition to lessening the confusion over priorities by permitting the promoters of research to determine their own, it must be pointed out that in order for a new discovery to be useful to consumers and contribute to society, it must first be manufactured, distributed and serviced. This application of technology involves manpower training, equipment and materials procurement, plant sites, and other managerial costs. While it may often seem so, the government cannot yet coordinate the many various steps to complete the cycle after innovation. The private sector can take it through the production and delivery process, ensuring that the demand for a new product or improved service will be met in the shortest possible time and at less cost due to minimal waste and economies of scale for mass production. While the question of "de-bureaucratizing" the science efforts of nonprofit institutions such as universities and colleges is a most complex one, Congress should begin examining the situation carefully, hopefully to arrive at some alternative plans for assisting viable science and technology programs which lack the profit motive.

A key policy to adopt in an effort to overhaul our anemic science and technology status is the deregulation of those private entities having the desire and capacity to engage in R & D. Both large corporations and small business can provide strong impetus for innovation. Small and medium sized business accounted for nearly fifty percent of American innovation even though they received only three and one-half percent of the federal research grants.

The obvious example of how deregulation would inspire great benefits for our country is in the energy industries, in terms of price deregulation particularly. Another example is the steel industry which has the potential for contributing a great deal to the national R & D effort, but presently has to cope with some five thousand regulations imposed by twenty-seven different federal agencies. These regulations include everything from pricing restrictions, personnel guidelines, and interstate transportation restrictions to tax rules and materials specifications.

Relief from heavy and unreasonable regulation would in the first instance eliminate exorbitant paperwork costs to the company. The cost of meeting federal paperwork demands oftentimes reaches into the thousands of dollars for even small businesses depending on their field, and surely taps what could be millions from corporate research. Second, and most important, because federal regulations restrict other aspects of the innovative process, production, transportation and marketing, companies are unable to turn a profit high enough to justify the expense of research and development. We should compare the regulatory burden on industry in our country to that of other nations which do not harbor a bias against business and are on the upswing technologically. In Japan, for example, companies can write-off capital expenditures in three to five years, whereas in the United States the common time frame is ten years.

A wise teacher of economics once said that "the greater the risk, the greater the hope for profit." Today, American economic policies are providing little, and often no, hope for profit. Together with overregulation, inflation has eaten into productivity and opportunities for business expansion to the point where the United States has begun to stagnate technologically as well as economically. Consider these figures: The average of U.S. annual increases in productivity during the period from 1970 to 1977 lags significantly behind our major world competitors and trading partners, Japan, West Germany, France, Italy, Canada and even problem-laden Great Britain. While our overall productivity level remains high in comparison, these figures show a trend in the wrong direction. During the years from 1960 to 1977, government spending averaged over 20 percent of gross national product (GNP) while during the same period, private investment averaged only about 17 percent. Government spending in Japan was in the ten percent range and private investors accounted for about 33 percent of Japan's gross national product. In 1963, America was spending nearly three percent of GNP on research and development and Japan was only spending one and one-quarter percent. In 1976, however, the U.S. expenditure for R & D decreased to about two and one-quarter percent equal with West Germany which increased its average percentage from slightly more than one and one-half percent in 1963. Japan increased its average percentage to a full two percent. These statistics can also be related to the rates of inflation. West Germany's wholesale price index increased only 44 percent between 1970 and 1977, Japan's 68 percent, and the United States' 76 percent. In 1978, the national expenditure for R & D in the United States was $47 billion, but in constant dollars, only about $30 billion. This estimate uses 1967 as the base year and an assumed six percent inflation rate. Since, however, inflation is now hovering around 13 percent, this total is quite conservative and the negative effect of inflation on research is really much greater. Of the estimated $30 billion, only about $15 billion, in constant dollars, was spent by the private sector. The non-federal support of science represented only about one percent of America's GNP in 1978, and that proportion, which has been fairly consistent over the last five years, is not expected to rise in 1979. It is clear that the health of the American scientific and technological enterprise is a corollary effect of economic policy. It is further reason that the current governmental policy of excessive budget increases for federally-directed science programs, as if they were transfusions, is an incorrect treatment for our slow-down in science and technology. The federal diagnosis is faulty--our economy is not in recession because science has let us down, but rather R & D in the productive sector is suffering due to the economic disincentives and barriers.

Effective policies to control inflation, caused by huge deficits and high rates of taxation, must go hand in hand with any coherent and stable effort to revive American science and technology. A significant, across-the-board income tax reduction, as well as further consideration in capital gains taxation would provide incentive and working capital for risk-taking in the private sector.

The present tax rates make business expansion or research endeavor almost prohibitive. The rate of return is not great enough to take the risk--the greater the risk, the greater the hope for profit. Whereas business as a whole has lately been working only on subtle improvements to existing technologies, a tax cut would encourage a more concentrated, long-term commitment to R & D on radically new and, hopefully, innovative technologies.

Another policy hindering U.S. innovation in the comparative context is our willingness to export technology. I am especially concerned about those technologies which are critical to our national security and the transfers of that technology to nations whose motives are clearly dubious. I do not oppose exports of technology to our allies, but it should be a consideration, however, that the transfer of American technology abroad is filling in the gaps of foreign scientists and narrowing the U.S. lead in many fields. Scientists should carefully assess whether the benefits of international exchanges outweigh the losses. For other than controls on militarily sensitive technologies, the government cannot rightly or accurately evaluate the successes of these programs. Only those involved in the search for scientific information can make these judgements. I think it would be prudent to take stock of the advantages of this policy on a periodic basis.

Congress should also take the lead in a revival of the American dream. History is filled with examples of Americans striving versus all odds to accomplish seemingly unreachable goals. Our national character has always included the desire to do better, to "build a better light bulb". It seems as though this country as a whole has lost some of this enthusiasm for achievement. Today some people question whether advances in technology are worth other social costs, such as a clean environment. They question the importance of a new and improved brand of laundry detergent. They question the efficacy of space exploration in lieu of cancer research. These are apprehensions which ought to be discussed. They are valid concerns. The answer, however, lies in the ability of the private sector, led by consumer demand and preferences, to determine the priorities.

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ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

Betterment of our society should be at the heart of any government policy, including one focusing on technology and science. But society is comprised of individuals, and benefits to individual consumers is the inherent objective of a free enterprise economy. A scientific or technological advancement which increases the freedom of an individual to choose among many more options, or permits him more leisure time, is a worthwhile discovery which cannot be discounted. In addition to the new technology itself, the freedom to pursue our own goals and challenge our present knowledge is an intrinsic benefit of research and development in our country. Our grasp of science and technology put Americans on top in a very short time and we were second to none in terms of our accumulated accomplishments and our potential for future success. While this nation still maintains a considerable storehouse of technological knowledge and skill, our interest has waned and our progress toward meeting new needs and goals through science and technological means has diminished. Perhaps we as citizens began taking our continuous triumphs for granted, perhaps we relied too much on government to lead the effort for science and technology. A constitutional government, however, must reflect the will of the people. The government can devise its own policies only if it receives no clear mandate from the majority of citizens. More often it hears only one or more interest groups when it comes to science policy, since our science policy in the 1970's has reflected an overprotected attitude toward the environment as well as the bureaucrats themselves. Rather than be satisfied with the status quo, and in doing nothing allowing the United States' position in science and technology to slide further, we can take positive steps to provide government with its instructions to bolster science and technology in our country. The first step can be a renewed commitment on the part of all concerned citizens to bring back the drive and perseverence of our earlier history. In Jimmy Carter's own words, "why not the best?"

RECEIVED November 13, 1979.

19

Appropriate Role of Government in Innovation

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In this paper I shall discuss some of the factors that influence governments to effect technological change and innovation and suggest some policies and programs that might or could be adopted in the United States. All major industrialized countries are now concerned with innovation, the role of technology, and how technology affects industrial development. I would say that most countries have been ahead of the United States in their concern for industrial innovation and industrial technology with respect to economic development. The discussions we are now having in this country began in Europe and Japan several years ago and those nations have reached a state of sophistication and decision somewhat in advance of that of this country.

I wish to describe the circumstances with regard to industrial development and technology that the U. S. will face in the next decade. There are four circumstances which are important:

(1) Most major technological developments will take place outside of the United States in the future.

(2) The businesses that make relatively mature and commodity-like products will be threatened by the invasion of products of that same type from newly-industrialized nations of the world - Korea, Mexico, Brazil, Taiwan, Hong Kong, Singapore. Those countries will, in general, have lower factor costs than will American industry for relatively mature, slowly changing products. As a consequence, many U. S. firms will be threatened by invasion of products from abroad.

(3) The United States will find itself competing with other countries in which the technology is well supported and where there is a relatively sophisticated understanding of industrial development. Most particularly, the United States will be competing with Japan, West Germany, and to a lesser degree, with the other nations of the European Common Market.

(4) Factor costs of energy and some raw materials will rise throughout the world as shortages develop and as the OPEC cartel continues to raise prices.

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The recent rises in the last two years of oil prices are not the cause of our inflation, rather they are the result of inflation here. The price of oil is denominated in dollars and the decreasing value of the dollar will force and permit the cartel to raise its prices. Such inflation of prices has not occurred to any significant extent for the Japanese because the value of the yen has continued to rise with respect to that of the dollar. This rise in the value of the yen has almost compensated for the increase in oil prices denominated in dollars. The United States will, at the same time, be facing the same situation, to some degree, for which Sweden is the precursor. There have been and continue to be large transfers of funds from private to public hands, a large and growing concern for protectionism and security and for what the Swedes and the English now call a riskless society. One would expect the protectionism in the face of competition from abroad and in the face of a slowing economy with rising unemployment. One would expect the society to increasingly wish to protect, subsidize and otherwise act in a way to protect the general public welfare. On the other hand, such practices increase the transfer from private to public funds, put burdens on the increase in private savings and decrease generally the availability of capital while increasing the cost of capital. In addition the U. S., along with Great Britain and, to a lesser degree, France spend a very large fraction of our technical resources on defense and space. I do not believe that it is coincidental that the two fastest growing competitive countries are West Germany and Japan who spend almost none of their technical resources on the national needs for defense and space exploration.

With respect to the role of governments, there are two general overriding principles. The first principle was enunciated by Dr. Ed Mansfield who stated in his paper that all the evidence shows that the social benefit from technological change and innovation exceeds the private gain. In other words, people in industry and in firms investing in technology, industrial development, and innovation will always underinvest. They will underinvest from the point of view of the values that flow to the society generally as a consequence of the innovation activity. That does not mean that all projects will be underfunded. What it means is that the portfolio of projects will be such that many will not be funded that would bring positive benefits to the society generally even though not profitable for an individual firm. This general principle means that governments are driven to provide subsidy to reduce costs or increase the benefits. These policies encourage industry to invest in projects in which they otherwise would not. It was surprising to me the other day to hear at this Symposium that principle so clearly enunciated and two subsequent spokesmen for industry then demand that there be no activites of governments to subsidize and otherwise support the innovation process. These two points of view are contradictory. If social benefits or social returns exceed the private benefit, one must argue that there is an appropriate role for government to either decrease private costs or increase private gains. The second general principle is that the innovation process occurs throughout a product life cycle somewhat like that which James Utterback described in his paper in which the early stages of innovative activity take place by the entry of a large number of firms and institutions into the development of the product. Here the process is fluid and, as J. Selden states in his paper, the internal development takes place in organizations that are horizontal in structure. The innovative development takes place in imaginative ways using existing manufacturing facilities, the product is frequently adapted to the needs of customers and the original application of the product is usually not the one that succeeds. Additionally I would say that you know the name of the players in innovative organizations. Individuals contribute significantly to the fluid stage of innovative activities at the early incipient phases of the product life cycle. At the end of the product life cycle the product becomes mature and changes slowly with radical innovation not likely, product improvements occurring incrementally, and usually with a small number of manufacturers providing the product. The corporation at this stage is often characterized by large economies of scale, very large capital investments, and the style of the organization is bureaucratic, hierarchical and anonymous.

In a fluid organization, the organization that is entrepreneurial and risk-taking depends upon the imagination, courage, and daring of individuals -- individuals either in existing firms or in new firms. You know the names of the players. The Honda automobile was designed by Mr. Honda -- not be a design team that produced the X-body car. Dr. Land is responsible for Polaroid. The necessary organization situation with respect to innovative new products is fluid, horizontal, boldly venturesome, entrepreneurial and personal. The kind of organization that deals with improvement of the existing products of society is slowly changing. In between these extremes in the product cycle while the product matures, process innovation takes place. As the product has to meet competition from others who have entered the market, an improved production process becomes more important than the product. Therefore process innovation occurs dramatically after the initiation of the product to the market. In the chemical process industry, these two steps tend to take place simultaneously. On the other hand, in the assembly-parts business, first product innovation occurs rapidly and then declines, followed by the introduction of radical new processes. The product life cycle dominates not only the behavior of firms and whole industries but in a sense dominates the behavior of an industrial economy like the United States, Sweden, or West Germany.

The essential problem in Sweden today is that there has been little recent growth in its economy. It is one of the richest countries in the world. Only one of the top 40 Swedish companies was started after World War II. Sweden now has relatively mature commodity-like businesses where the threat from firms outside of Sweden having lower factor costs imperil the behavior of those Swedish firms and the economy of Sweden.

Government policy, therefore, has to be involved in three different kinds of activites which overlap. First and importantly, it must help create an environment in which risk-taking, entrepreneurial, personal kinds of new ventures will begin in existing firms or in new firms. That requires an economy not dominated by giant monopolies which cannot be entered by other firms who threaten the monopoly. It requires a patent or recovery system such that the innovative, adventuresome person can capture a significant part of the rewards of his own creativity. It requires a climate for risk-taking with the potential for huge rewards. Otherwise the risk is not worth the gain. Whether that be an existing firm or a new firm is irrelevant. Finally, and more importantly, it requires an atmosphere in which people are willing to save for the future.

Some people wonder how entrepreneurs can be recognized. Entrepreneurs are those people who have a negative discount rate. For the entrepreneurs all present costs are viewed as small and all future profits are infinite and that is their perspective of the world. The point I wish to make is that the atmosphere that encourages the beginning of the establishment of new products is quite different from the atmosphere and activites of governments to maintain and improve the position of the existing firms and the firms making relatively mature products. In this first phase of innovative activity there must be an environment that stimulates risk.

Secondly, from many seeds only a few flowers grow. As a consequence, the society must be willing to accept a substantial number of failures. Further those who fail should not be unduly punished but rather accommodated in ways that will revitalize their interest in creating new activity. Failure in some of the industrialized western countries can be as difficult as it is in closed societies as in the Soviet Union.

During the second stage of development of a product, process technology, manufacturing, automation, and quality control are all important. In that stage of the development of a product and those industries there usually is insufficient basic information about the technology of manufacturing and process. In this country, for example, as far as I know there is only one engineering school that offers a degree in manufacturing engineering. There is almost no research in American universities in process technology, quality control, materials specification and those matters that affect change in the manufacture of a new maturing product. Most of the developments during this second stage are not done by invaders from the outside, but rather from within the existing firm for acting as its own customer.

In the third stage of the product life cycle, incremental change, the diffusion of available knowledge, the transfer of know-how from one small or large firm to another, the nature of the accumulation of small product-cost reductions by process improvement developments are all an integral part. Here the role of government and society is to open the way for transfer of nonproprietary know-how.

Given the three stages and kinds of activities described above, we can now consider what governments actually do. Most countries are now beginning to provide startup capital for inventors and individual entrepreneurs to pursue new developments whether in existing or new firms. The program of the Delegatin Generale a la Recherche Scientifique et Technique (DGRST) in France provides on the order of fifty to sixty percent of the capital of the cash required for new product development. The National Swedish Board for Technical Development (STU) provides money to inventors and aspiring innovators to determine and prove the technical feasibility of their ideas. Japan, contrary to general opinion, has the most extensive programs of any country in the world to support new and innovative firms. The Japanese government offers no-interest loans to new firms requiring early prototype manufacturing equipment. Through their Ministry of International Trade and Industry (MITI) advice and counsel concerning taxes, investment policy, availability of cash for new, small and growing firms are dispensed. I am not suggesting that our government should undertake similar programs, but am simply describing what other countries are doing. Most major nations in the world are now beginning to see the advantages that this country had in the 1960s when government policies inadvertently encouraged startup and technical development of new products and processes. The inadvertent encouragement stemmed from the spillover from enormous expenditures in the National Aeronautical and Space Administration and the Department of Defense that aided startup of new venturesome firms during that period. Most countries provide support, direct or indirect, for product and process development within existing firms -- directly by subsidies and indirectly by substantial tax reductions or investment tax credits, the general argument being that firms do not take risks appropriate to social benefits.

In the third phase of development, that is during the period of incremental product change, all major countries provide existing firms with information on product design, new techniques environmental controls, etc. Also through industrial associations, extension services and through education, some countries are able to do more than others. In West Germany an industrial extension program based on local chambers of commerce has recently been established to advise existing firms concerning manufacturing and process development.

Such activites in this country are usually resisted by the proponents of R&D for a very simple reason: firms that support R&D are usually firms that do not need this information. But the 3 or 4 million other firms who manufacture parts, forgings, castings, and the like who do usually need that information cannot afford to obtain it independently. The Commerce Department makes an assessment every year or so of the productivity of firms in each of several industries. In general the productivity of the most productive firms in an industry is two or three times greater than the less productive firms in the same industry. The ratio of the productivity to the firms in the upper decile of productivity is usually two and a half to three times the productivity of the firms in the lower decile of productivity. The point is that if we simply worked as well as we know how, productivity in this country should increase on the order of 50 to 100 percent. Any of you who have been in relatively small firms that supply big companies of this country will recognize the practices that were well known ten, twenty or thirty years ago are not in practice in some of those firms today.

Most countries provide some kind of incentive for savings, whether removing certain taxes, as has been recently proposed by Representative Ullman in the House, or by direct subsidy. For example, in the case of the Japanese, I believe that the bonus system for workers that receive from one to two months supplemental pay per year at one time encourages savings. They cannot depend on it and therefore live at a certain level of income. The rate of saving in West Germany is two to three times greater than ours. Innovation and technological change, despite the state of technology and the economy, cannot occur without capital investment and capital investment is not possible without savings. If people consume only, productivity will suffer. No matter what we or other countries do to stimulate innovation, it will be to no avail if we do not save.

In conclusion I would like to present a summary of the thinking of the various countries regarding innovation. By far the most sophisticated country is Japan. The cooperative understanding between MITI and Japanese industry is deep; there is a good grasp of the nature of the product life cycle and a widespread acknowledgement of the importance of new small entrepreneurial firms. As you may know, the Japanese have decided on different policies for sunrise and sunset industries. The sunset industries are those that manufacture products at or near the end of their product life cycle or life. The sunrise industries are of high technological content, of higher value - industries for the future. They are making investments to move the sunset industries off the island and to bring the sunrise industries into being. No other country appreciates more the significance of the dynamism of industrial technology and growth than does Japan. Other nations tend to protect their mature industries by manipulation of tariffs and pricing policies.

Most of the reaction of other industrialized countries with the exception of Japan and to a lesser extent Korea is to protect - to provide for the common welfare by protection rather than encouraging the new. Most countries are now supporting basic technology, that is technology that is important to industrial development but not important to space, defense or health.

I suspect there may not be as much as a couple of million dollars available for trying to understand the nature of manufacturing in the generic sense. That is not to say that firms do not do innovative work, but it is to say that basic teaching aimed at improving the productivity of the country, which is how to make things of quality, measure their performance, and have them delivered is simply not supported in the U. S. There is also resistance in the private sector to such support, perpetuated by the myth that most firms and most product development occurred in this country without government interference. Anybody who reads the history of the economic development in this country would understand that many of the developments were encouraged by some sort of government policy and interference. The land grants stimulated the railroad. The formation of the land-grant colleges, the agricultural research program, and agricultural extension service are basic to our agricultural proficiency -- a model which every country in the world has followed to improve the productivity of agriculture. Many other examples of government involvement exist, including the mining technology laboratories of the Bureau of Mines; the activites of NASA, and NACA before it became NASA; in aeronautical technology; the investment of this country in nuclear power; the electronics developed during World War II; the gas turbine engine for aircraft during World War II; alloy steels during World War I; and the beginning of the steel industry in the United States subsidized by the Northern forces in the Civil War. How can we say that the government does not play a substantil role in technological change and how can we remove the existing bias so that we can at least intelligently discuss an appropriate role for government which does not take over product process development, or the ownership of firms? As I see it, we are now in a world in which most of our competitors, both for mature products and for newly-developed ones, are increasing their understanding and willingness to face facts with regard to how innovation and technological change occur. I believe we have enormous advantages, particularly with respect to the atmosphere for risk-taking and entrepreneurship which other countries do not have. We still have the largest single homogeneous market in the world. We are rich. There is no excuse for the faltering performance of the last five years which has seen the American people become gradually poorer other than our own reluctance to talk about the subject in realistic constructive ways, rather than in ideological terms.

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QUESTION: Would you comment on the schizophrenic attitude of industry toward government involvement?

HOLLOMON: Having worked both in government and industry I'll say something that I do not think is very useful because I don't know what can be done about it. Most people in this country have little understanding of how their government works. I spent six years in government and I have spoken to people in industry who refer to government people as "them." That is one aspect, of course, involves the excesses which industry and others are guilty of in the face of free goods, free air, free water, free places to dump refuse -- instances where industry, because of the system we have, did not act for the social welfare.
I don't think about the government and about industry-I think about the people that I know and how they react. For example, most people in industry do not know how to lobby. You don't lobby by asking someone for him. Most people try to persuade somebody to do something for themselves. My experience has been to act effectively on their behalf and in return you gain their trust and confidence in your advice and judgement.
I think the situation with respect to the American economy has to deteriorate further before any meaningful progress in improving both industry and government.

RECEIVED December 18, 1979.

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Recognition and Awards for Innovation

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Providing the best possible incentive and reward system for those involved in the innovation process is a matter of great importance both for our inventors and for our country.

Evidence for the decline of innovation in the United States has been documented in many excellent articles in the last few years(1,2,3,4,5). Invariably in discussing this decline, the loss of competitive position to other nations, based on patents issued, is cited: foreign inventors are obtaining a higher percentage of U.S. patents, up from 17% in 1961 to 37% in 1976. Or, according to Figure 1, 20 years ago 6 patents went to U.S. inventors for every one to a foreign inventor, while today the ratio is less than two for one(6).

A recent study by Stauffer Chemical shows a drop in patent output of the chemical industry, consistent with this trend(7). Patent records were examined for the 12 largest U.S. chemical companies over the period 1967-76, and also for the 8 largest European chemical companies.

From 1967 to 1976 patents granted to the U.S. companies dropped 40%, while patents to the European companies went up 50% (Figure 2). If we look at the 12 companies individually (Figure 3), we see that the declining pattern holds for all except one company. Stauffer seems to be out of step, but the reason for this has not been determined.

This decline in patent output for the U.S. companies is not matched by a corresponding drop in total R&D spending, which, in fact has gone up slightly (Figure 4).

So, we have more evidence showing a decline in U.S. innovative capacity. Some of the possible reasons for this decline are listed below:

- Greater emphasis on defensive R&D, to protect established positions.
- More emphasis on short term, incremental improvements.
- Less funding available for research of the type which can lead to inventions, due to regulatory demands (other countries have an advantage over the U.S. in the regulatory arena).

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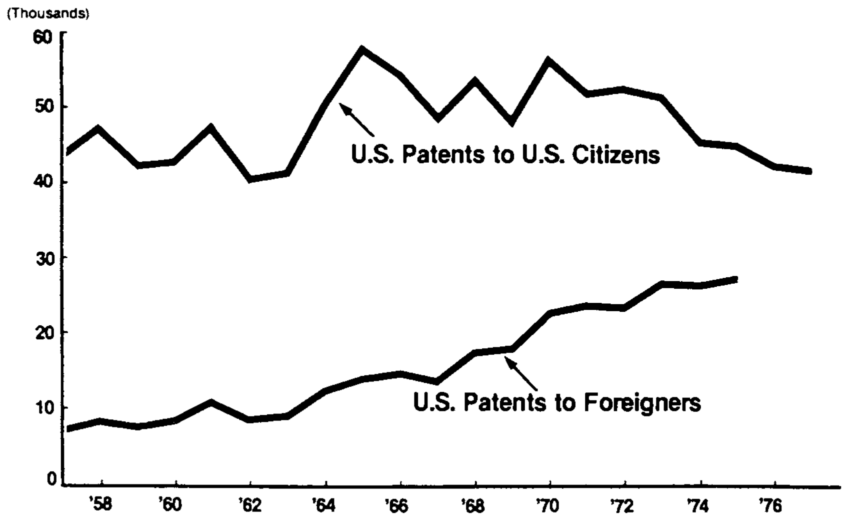

Figure 1. U.S. patents history

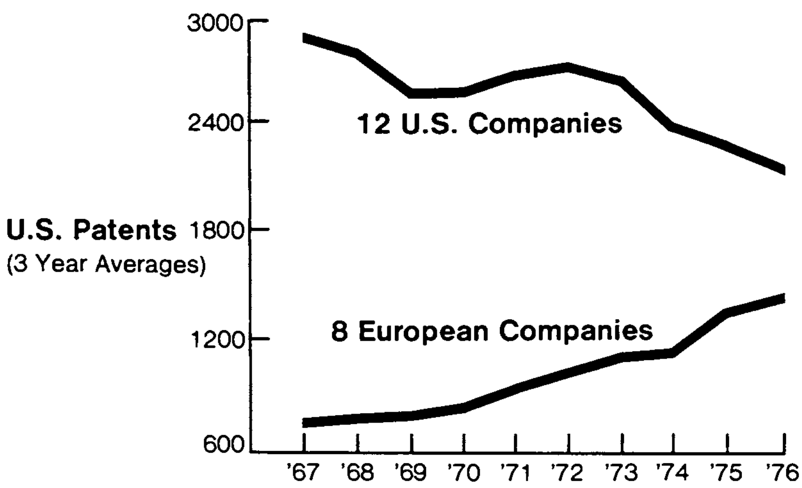

Figure 2. U.S. patents—chemical industry

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

	1967	1970	1973	1976
Dupont	664	604	608	484
Dow	488	421	426	324
Am. Cyanamid	243	239	237	215
Monsanto	467	398	327	235
Union Carbide	375	232	234	227
Stauffer	65	80	124	131
Allied	189	171	188	146
Olin	106	89	107	100
Celanese	71	100	112	74
Ethyl	72	86	106	73
Hercules	95	86	104	61
Rohm & Haas	60	44	64	70
Total	**2895**	**2548**	**2638**	**2140**

*Patents issued to domestic subsidiaries are included.
Source: IFI/Plenum Data Co.

Figure 3. U.S. patents issued 1967–76 (3 year averages), including patents issued to domestic subsidiaries. From IFI/Plenum Data Company.

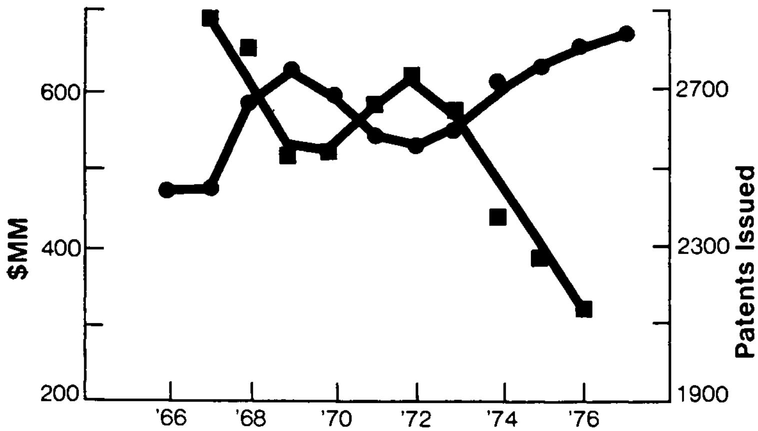

Figure 4. U.S. chemical companies' R & D expense in millions of dollars (1966 constant) (●); 3 year average of patents issued (■)

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

- More active foreign competition.
- More critical selection of patent applications to prosecute; greater tendency to treat new technology as "knowhow".

So, there are many possible reasons for the decline. But in my opinion it is not because of a shortage of creative talent; nor does it reflect a lack of incentive on the part of our inventors.

In other words, the problem in innovation is not at the front end of the process. It is further downstream, as increased risk and uncertainty in today's business climate reduce the willingness and ability of companies to develop and commercialize new products.

I suggest that new types of formal compensation programs for inventors, particularly if forced through legislation, as has been suggested, will not improve the innovation picture so long as other much more important conditions remain unchanged.

Quite a bit of attention has been given to the compensation-for-inventors issue since about 1970, when fairly widespread concern arose about two perceived problems: that companies didn't care about their technical employees, as evidenced by the many layoffs which had occurred, and that the American Chemical Society was neglecting the welfare of its individual members(8,9,10,11).

In light of the broad concern for treating employees fairly, proposals were made, with some ACS support, that special compensation be granted to inventors for patents which lead to commercial success, and legislation was introduced based on this profit-sharing concept. The model mentioned most often was that of West Germany, although many other countries also have similar programs, including France, Italy, Holland, the Scandanavian countries, and with passage of legislation last year, the United Kingdom.

It was the German model which was followed in HR 2370, introduced by Representative Moss (California) in the 93rd Congress and reintroduced in subsequent sessions, although not in the current one. I won't go into the details of the German approach since it is thoroughly described in the literature(12,13,14). But, I would like to comment on how well it has worked out. Overall, employees and the labor unions are quite satisfied with the law, and their managers have learned to live with it, although many state that they wish they didn't have to.

There are two main areas of difficulty, however. One has to do with the cumbersome bureaucratic procedures which are required, and, related to this, the practical problems of determining "exploitability" and "value", key terms in the compensation formula.

The second area of difficulty goes to the very heart of the profit-sharing concept. According to many professionals who have worked in the German laboratories, the desired objective of stimulating invention is not achieved, for several reasons: the communication barriers which are raised between individuals; the animosity generated because the inventor receives favored treatment over many others who contribute to the innovation, and the adversarial relationship which the profit sharing approach fosters between the employee and the company. Dr. P. C. Henriquez, who has had considerable experience with the profit-sharing model, provides a long list of objections to it(15).

These are opinions from those who have actually lived with the system. What can we learn from looking at hard facts, specifically from patent statistics? Does the prospect of being identified with a commercial success, and sharing profits from it, actually stimulate invention or not? We do not obtain a clear answer by examining the patent output of German inventors, which has not changed significantly for several years (Figure 5). At least in Germany, there has been no pattern of increased inventive activity as a result of the law(16).

Yet, it is obvious that there has been a loss of competitive position to West Germany. For example, Figure 6 shows a comparison of the number of U.S. patent applications to German residents with the number of German applications to U.S. residents(16). Comparisons for other developed nations show the same picture. In fact, two countries alone, Germany and Japan, accounted for almost one-fifth of all 1976 U.S. patents.) We have to try to explain what has happened.

The explanation does not lie in the different compensation systems. Instead, what we see is evidence of the growing technological capacities of other developed nations, along with their increased emphasis on penetrating the U.S. market, which, after all, is the most attractive in the world. At the same time the inventive and innovative talents of U.S. companies are being consumed by regulations-related problems. These concurrent trends work to the detriment of our international competitive position.

The Industrial Research Institute has recently issued a position paper, based on a survey of its member companies regarding five policy statements about compensation and innovation (17). These statements were submitted to the 250 companies of the I.R.I. with a request to indicate favorable, unfavorable or neutral reaction to each. The 129 replies are tabulated below for each statement:

- All members of the innovation team, not just the inventors, must be financially rewarded by reasonable salaries determined by fair and equitable policies, and, when justified, by special awards according to the significance of the innovation.

  Favor 117 Disfavor 11 Neutral 1

- I.R.I. believes that awards required by law for industrial inventors whose principal assignment is R&D will not increase the number of significant innovations, and may be counterproductive. In fact, such a practice would probably lead to secretive work and reduce innovation within the industrial research organizations.

  Favor 105 Disfavor 24 Neutral --

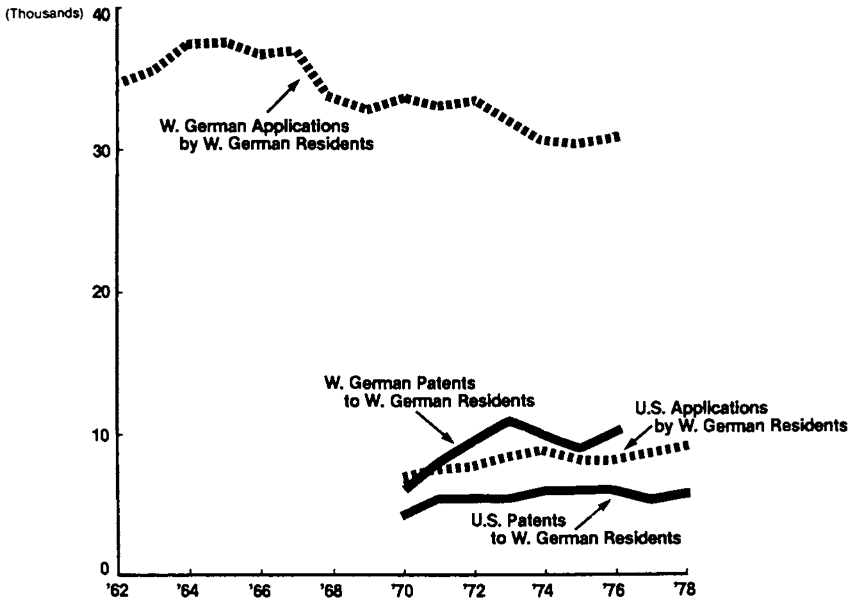

Figure 5. Patent activity in West German companies

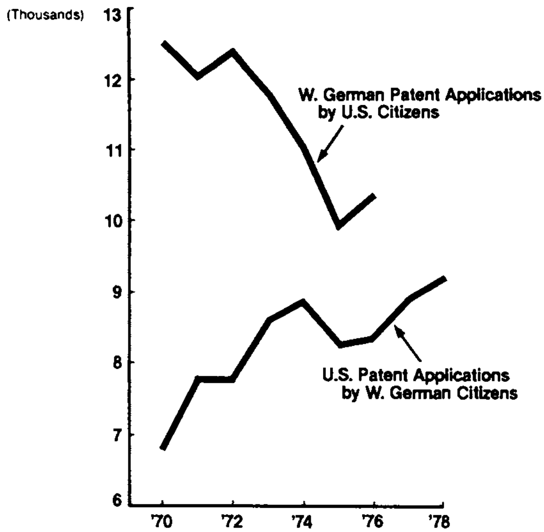

Figure 6. Patent activity in West German companies

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

(More than 80% reject the statutory approach to compensation.)

- People whose assignments are in areas other than R&D or design, yet who are involved in significant innovations, may deserve and should receive special consideration.

  Favor 116 Disfavor 13 Neutral --

- Industry should also provide inventors an opportunity to acquire patent rights on any of their inventions not of interest to the company.

  Favor 112 Disfavor 16 Neutral 1

  (This is a simple and straightforward policy, which many companies have. There is general agreement that more companies should have it, but there are few cases, so it tends to get overlooked.)

- The Federal government should establish policies which encourage innovation and risk-taking. The current excessive regulatory activity, burdensome tax policies, and high rate of inflation have increased the uncertainty about the future and reduced the potential rewards from innovation. The climate must be improved to increase industrial innovation.

  Favor 118 Disfavor 9 Neutral 2

  (This is a very important statement which elicited many additional comments from respondents.)

So, of those who manage industrial R&D, an overwhelming majority favor traditional practices and policies in compensation programs, and reject a legal or even a standardized approach. And, they believe the key to improving our situation regarding innovation is tied to government policies and practices.

The I.R.I. position statement speaks for research management. Now let's shift to another point of view, that of the inventor. Many of you may have seen the report, just published in Chemical and Engineering News, of the first survey of ACS membership (Figure 7) (18).

A series of questions was submitted to approximately 20 thousand ACS members and almost half responded, one-third of whom were "employed inventors" (i.e. at least one patent to their credit). The results of the survey are summarized in Figures 8 and 9.

Total membership (Feb, 1979)	109,372
Eligible for survey	82,471
Representative population	19,936
Response	9630
Employed inventors	3136

Figure 7. Overview of ACS membership survey

33% ACS members are inventors

76% Inventors are in manufacturing companies

23% Patents are in commercial use

Half of inventors received no recognition

Half received award, money or "favorable consideration"

Figure 8. Results of ACS membership survey

Statement: "On the whole, my employer has been fair in recognizing my contribution to this patent (last received)"

Agreed to	Strongly	34%
	Moderately	41%
Disagreed to	Moderately	15%
	Strongly	10%

Recognition ⟶ 90% Positive

No recognition ⟶ 37% Negative

Satisfaction correlates with salary level

Figure 9. Results of ACS membership survey

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

One-fourth of the respondents felt employers were unfair and 10% were very definite about it. But, three-fourths felt employers were fair and one-third shared this opinion without any reservation.

Only 10% of those who received some form of recognition felt employers were unfair, but 37% of those who felt employers were unfair were in the group which received no recognition. So, a little recognition, not necessarily money, goes a long way. Finally, not surprisingly, the degree of satisfaction went along with how high the respondent was on the salary scale.

Aside from the generally favorable vote for the traditional forms of compensation, the other interesting result is that the fact of recognition seems to be more important than the form. Acknowledgment by others that you've done something special is a powerful force. Unfortunately, the survey did not include a question directed to the importance of peer opinion as a factor in motivating inventors. (In a survey carried out several years ago, the two most important motivating factors were "recognition and appreciation" and "freedom to work on areas of greatest interest", while "monetary rewards" was well down the list (19).

Based on the membership survey, the ACS Task Force on Compensation for Employed Inventors is presently formulating recommendations for the ACS Board.

Now let's turn to another recent survey: this one of present corporation practices in recognizing and rewarding inventors, conducted by the Association of Corporate Patent Counsel(20). After all, the alternative to legislation is for companies to recognize their obligation to their creative people and to establish compensation and recognition programs accordingly.

In the ACPC survey (Figure 10) 58% of the 142 companies contacted reported that they had some kind of award plan. This was taken as an indication that the use of inventor award plans is increasing, since the corresponding figure in a comparable 1972 survey was only 48%. Several industry sectors were included in the survey. Those indicated in Figure 10 are of interest to those in the chemical profession.

About one-third of the inventor award plans provide modest cash amounts, while two-thirds involve some other form of recognition, instead of, or in addition to, cash awards (Figure 11). Standard awards, whether monetary or in some other form, are of predetermined value.

Special awards that go beyond honoraria are given by 44% of those companies which have inventor award plans, or about one company in four. Special awards are discretionary in amount -- perhaps related to commercial value -- and are generally awarded only for inventions judged by management to be of special economic benefit to the company.

The cost of such plans is not considered a problem: less than $50M for 78% of the companies. Also some of the negative aspects of the German profit-sharing model do not seem to be serious in the more traditional approach (Figure 12).

Interestingly, only about 30% of the companies that have plans

142 companies

Have award program		58%
Petroleum	67%	
Chemical	56%	
Pharmaceutical	22%	
Cash only		32%
Other		68%

Figure 10. ACPC industry survey

Decorative memento—plaque,
paper weight,
jewelry
Award banquet
Resort weekend
Company and community publicity
Special awards of value (discretionary)

Figure 11. ACPC industry survey—other awards to inventors

Negative aspects expected

- Secrecy
- Administrative difficulties
- More patent staff
- Jealousy

But encountered only slightly

Figure 12. ACPC industry survey—problems resulting from special awards

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

believe their inventors are more productive because of the plans; the rest either do not believe that or simply don't know. So how do they justify having an inventor award program? The principal reason give in the survey was to communicate the employer's desire for inventive work, it is a visible sign of the importance research management places on new ideas and patents. Also there is some feeling that it helps the inventor to put up with the often boring administrative detail required by the patent process (Figure 13).

As stated in the I.R.I. position paper, (17) and supported in the ACPC survey, "these various approaches show a clear recognition on the part of industrial research organizations of the need to motivate and reward both inventors and innovators; but it is apparent that what may be a reasonable approach for one company or industry may well not be effective for others". In other words, there are various reasons for having plans, and various kinds of plans, and each company should tailor its own plan to suit its circumstances.

Based on these three surveys, one reflecting opinions of research managers, one from inventors, and one of present corporate programs, are there any new recommendations we can make?

General: Employers have an obligation to provide a stimulating environment for invention and innovation, one which provides psychological and emotional support for the creative person. A good recognition and award program helps to do this. And those companies who do not have such a program should seriously consider putting one in place.

Specific: Team awards should be considered by employers for successful innovations. On a national level, the I.R.I. has suggested that an "Innovation Medal" be established, comparable to the medal of science, but for recognition of team as well as individual contributions.

Speaking of national level policies regarding innovation, a very important study on the subject was completed this summer: the Domestic Policy Review on Industrial Innovation by the Commerce Department, for President Carter. This was a massive undertaking with a substantial input from some of the best talent we have in our companies.

Some selected statements from the draft report of the Subcommittee on Patent and Information Policy are shown in Figure 14 (21). The statements show a complete rejection of the concept of any legislated or standardized approach based on profit-sharing.

An interesting aside concerning the recent passage of the new patent compensation legislation in Great Britain: this move was taken by the government against the recommendation of the Banks Committee, which had been appointed to consider changes in British patent law (22).

- Communicate employer's interest
- Stimulate disclosure
- Encourage inventor to help in patent process
- Reward the inventor

Figure 13. ACPC reasons for inventor award programs

- Corporations should be encouraged to motivate their employees to participate in all phases of the innovation process.
- Encouragement could be in the form of awards, promotions, release of unused inventions to the inventors, etc.
- Legislation requiring corporations to give employees a greater stake in their inventions—would not have a positive effect on innovation.
- An attempt to apply a uniform system (as in some European countries) would result in a significant decline in overall innovation.

Figure 14. DPR comments and recommendations (draft)

The Banks Committee did a very thorough study, taking evidence from countries where such laws were already in place, before drawing the following conclusion, (paraphrased): "although inventive activity -- should be encouraged to the fullest, and employees' inventive efforts should be recognized and rewarded by their employers, the disadvantages of a statutory award scheme outweighed any foreseeable advantages".

In spite of the Banks Committee report, the new law was passed, again illustrating perhaps the triumph of political appeal over reason. It will be interesting to observe what happens to future patent output in England, since traditionally, it has been a very productive nation, in terms of patents issued.

It is too early to know what actions will be taken by the Administration based on the Domestic Policy Review, but it should be recognized that a substantial technological "constituency" has now been created. In number of votes, this constituency is limited; but it should be very influential, considering the proven relationships between innovation and productivity and inflation. This new constituency is essential for the achievement of the social and economic objectives of the nation, and it is expecting some kind of program from the government regarding innovation. The DPR received too much attention, is too comprehensive and too thoughtful to be ignored!

<u>Summary:</u>

There is <u>no</u> justification for establishing a formal system in this country mandating extra compensation for employed inventors. There is no evidence that invention or innovation would be encouraged, and the consequent administrative complexities, communication barriers and employee relations problems which would result, make the profit-sharing concept unappealing.

The alternative is the free enterprise approach, in which individual companies recognize the contributions of outstanding inventors or innovators in the traditional ways, with increased salaries, promotions, and special awards, monetary or otherwise. There is considerable room for diversity in such programs, with each company able to tailor its program according to its own technology, staff and objectives.

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RECEIVED December 10, 1979.

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Effect of Patent Policy on Innovation in Industry and Government

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U.S. Patent and Trademark Office, Washington, D.C. 20231

Reports of the Small Business Administration were the subject of an article in the WALL STREET JOURNAL dated July 25, 1979 under the heading "Reports Say U. S. Stifled Research." The Small Business Administration reports to which I refer were prepared for consideration during the well known Domestic Policy Review.

One step recommended by the SBA to cure that perceived unfortunate result was to change federal patent policy so that, under stated conditions, small businesses would take title more frequently to patents which result from federally-sponsored research. This was said to spur small businesses to innovate even more actively, a result undoubtedly beneficial to our nation.

As many of us know, this is one side of a dialogue that has been in progress since we all were young. Like the phoenix arising from the ashes, this seemingly endless debate about who should own the patents arising from federally-funded research contracts reasserts itself into the public consciousness periodically.

The view contrary to that taken by those who feel that the contractor should own the patents stemming from federal contracts is characterized by the slogan, "Since the government paid for it, the government should own it." This view is frequently articulated by Admiral Rickover who, interestingly enough, felt that he personally should own the copyrights covering speeches he gave as an admiral.

The fact that is hard to swallow is that in 1975 the United States government owned over 28,000 U. S. patents available for licensing, far more than anyone else; about 1,200 of those 28,000 were licensed -- about the same number as were licensed in 1963 when the federal government owned only 14,000 patents. Furthermore, for an average yearly value, computed for the years 1963 through 1975, the federal government has been filing well over 2,000 applications for patents every year.

What is the federal government going to do with these patents? This is the heart of the federal patent policy controversy. At the threshold we must ask -- what is a patent? A patent is a right, granted by the federal government, to exclude others from making, using, or selling the subject matter patented. It does not grant the right to practice the invention patented, nor the right to practice any invention at all. It is solely the right to exclude others from making, using or selling something.

With the government owning over 28,000 United States patents, it can either (1) use the right to exclude; (2) let others use the right to exclude; or (3) not use the right to exclude.

If the federal government decides to use the patent rights, that is to say, the right to exclude, shall we see the government excluding individuals or companies from, for example, making or selling certain products in the United States? Are the power and resources of the federal government, and especially the Department of Justice, to be put to that use? Indeed, suppose the federal government decided that a certain product covered by a federally-owned patent should be made only in a depressed area in Appalachia so that the economic condition of the citizens in that area might be improved; is the government then to sue companies in Los Angeles, Chicago, or Atlanta for patent infringement to preclude their manufacture of the patented goods so that the Appalachian production would not be disturbed by competitive market forces?

The constitutional right of the federal government to exclude a U. S. national from making a product in the United States by virtue of a federally-owned patent, arising from research which that U. S. national helped to finance through his taxes, has never been decided. There are many who feel that the federal government has no such right under the Constitution. There are many others who feel that even if the federal government does have such a right, it should never be exercised to preclude a U. S. national from operations here in the United States.

The battle lines may well be shaping up over this argument at the present time. It might very well be soon that the force of the federal government will be brought to bear against an infringer of a United States government-owned patent here in this country. For example, on May 16, 1979 Elmer B. Staats, the Comptroller General of the United States, told the Senate Committee on the Judiciary that it was "the government's responsibility to obtain domestic and foreign patents . . . and to enforce the patents against unlicensed users."

I invite your attention to my second alternative -- namely that the federal government can permit others to use the over 28,000 patent rights (a) by licensing or (b) in effect, transferring title to others. If the government merely licenses some person (for example, in Appalachia) and another person infringes the patent, it may be argued, as the Comptroller General did, that the government should protect this licensee and bring suit against the infringer -- provoking, therefore, the legal and political controversy mentioned earlier.

At the other extreme -- my third alternative -- is that the federal government should not use patent rights to exclude others from making, using or selling in the United States.

If my third alternative is followed, the questions arise, Why are we spending all the time and effort necessary to obtain those patent rights? What is the purpose of this enormous waste, and what is the return on our investment of the tax dollars in this exercise in futility?

The crowning irony in all of this is that it is the U.S. policy to file patent applications on inventions made by its employees and contractors -- a policy which is expensive and almost certainly exceedingly wasteful under present conditions.

On the other hand, it apparently also is the U. S. policy to have no consistent policy on who should obtain the rights to invention made under federally-sponsored R & D. At this time there are some twenty separate, different statutes and as many implementing regulations applicable respectively to the different federal agencies. The confusion, resentment and frustrations -- as well as the expense -- faced by business are real and discouraging. For over a quarter of a century we have been unable to make up our minds about what to do with federally-owned patents. As the Small Business Administration study concludes, invention utilization by at least some small business concerns is hampered by certain present federal patent policies. Some ten years ago, the Harbridge House Report, sponsored by the Federal Council for Science and Technology, reached the same conclusion. At this time when our national innovative efforts may well be waning, why don't we do something to settle this matter? We have been struggling as a nation with confusion surrounding this problem for over 35 years. I have a copy of a memo Franklin Roosevelt wrote in 1943 indicating that two years earlier he had asked the National Patent Planning Commission to solve the problem, but that early in 1943 he had also asked the Department of Justice to do the same thing. The memo withdrew his request to Justice, which continued the work anyway. Confusion then -- as now.

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

Fortunately Senators Bayh and Dole have taken a step forward recently by introducing S. 414, "The University and Small Business Patent Procedures Act." At least this act would improve the situation for universities, nonprofit organizations, and small businesses, by providing uniform procedures throughout the government with respect to ownership of patent rights arising out of federally-sponsored research for such groups. While this certainly won't solve all of the problems, it is a distinct step forward.

In addition, Senators Schmitt, Cannon and Stevenson introduced S. 1215 which, among other things, would provide that the contractor in most instances could retain title to patents arising from government-sponsored research. This bill also is a very clear move in the right direction.

I would sincerely hope, however, that the basic and fundamental issue of the federal government's right to use its powers to enforce patents against U. S. nationals will soon be carefully considered in all of its ramifications. I do not think that this is a matter which should be backed into, but rather one which should be faced squarely and decided before the legislative branch of the federal government, rather than in a court proceeding in which all of the issues important to the public might not be presented. If we do not face up to this basic issue of the right of the federal government to stop U. S. nationals from manufacturing a patented product in this country, then we shall inevitably face a situation in which someone is going to be hurt. If we agree with Admiral Rickover when he says that "the rights to inventions developed at public expense should be made available for use by any U. S. citizen," how do we reconcile that concept with the fact that the right of a U. S. citizen to practice such an invention can be precluded by the federal government's use of a patent which it owns? Do we mean that the government should stop obtaining patents, dedicating those it owns, and merely publishing its research results henceforth? If not, what do we mean? Do we feel that there are circumstances in which the federal government should use a patent to stop, for example, your company from making some product for one of your customers? If so, what are those circumstances?

At the very least, it behooves us to solve in a rational and careful manner this issue which is truly fundamental to the relationship between the federal government and its citizens.

RECEIVED November 16, 1979.

The Council for Innovation

MICHAEL MICHAELIS

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We must revive American industry and commerce through technological innovation. The private sector has -- by far -- the most at stake. It must take initiatives to become an integral part of the political process of making and carrying out public policies for innovation. In every other industrialized country such a partnership between industry and government is being deliberately encouraged. We cannot afford to do otherwise.

Innovation provides leverage on productivity, job creation, balance of trade, and inflation. Innovation is a key to solving pressing social and economic problems. American pre-eminence in innovation used to be envied by the rest of the world. But, during the last 15 years, U.S. innovation has come to lag behind its historical levels. And, during the same time, other industrialized countries have made great strides in catching up to and -- in some industry sectors -- in overtaking us. These simultaneous events have been a major contributor to our present economic and social ills, which we cannot hope to alleviate unless we boost our rate of innovation and target it on our most pressing needs.

Public debate on what to do is swirling hot and heavy. Many in industry blame the government. Academics blame industry and the government. And government blames industry and is beginning to recognize some of its own shortcomings.

As Matters Stand......

Some hopes were raised last year when President Carter requested a Cabinet-Level Coordinating Committee to undertake a Domestic Policy Review of Industrial Innovation. Industry, labor, and public interest groups participated in Task Forces charged with developing recommendations for public policies to stimulate innovation. These were presented nine months ago and since then federal agencies have debated their merits and have brought their own recommendations forward. The action now

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appears to be in the hands of the White House Domestic Policy Staff and the Office of Management and Budget. As we meet today, final touches are presumably being put on a memorandum to the President by his chief domestic policy assistant, Stuart E. Eizenstat. Based on this memorandum, the President is expected to present a message this fall, addressing the twin problems of improving the climate for innovation and providing direct government support. The message will likely call for a broad range of actions, including the establishment of Cooperative Technology Centers, tax relief for small innovative firms, innovation-oriented government purchasing, patent reform, and adoption of regulatory performance standards.

Let me hasten to add that this speculation on the likely outcome of the Domestic Policy Review is mine alone and is not based on any privileged information. I have had no such information.

Regardless of my accuracy -- or otherwise -- as a prophet, I believe that the Domestic Policy Review has greatly helped in raising awareness of the innovation issue -- throughout both the private and public sectors. But let us also remember that the issue is not a new one. Previous Administrations, going back to 1962, tried to tackle it. The "Civilian Technology Panel" in the Kennedy White House (which I had the privilege of serving as Executive Director) was the first attempt to shed light on what was even then already perceived as a growing problem. Then, as now, we had the benefit of advice from leaders in industry and labor in shaping our recommendations to the President.

The "Charpie Report" to the Secretary of Commerce in 1967 presented succinct and timely proposals from a blue-ribbon panel of private citizens on "Technological Innovation: Its Environment and Management." Many of these proposals were quite similar to those made by the private-sector Task Forces in the current Domestic Policy Review.

I could go on to the Presidential message to Congress on Science and Technology of March 1972 calling for an assessment of institutional and policy barriers to innovation and means for overcoming them.

However, enough! Suffice it to say that all those past efforts -- and the early ones were proactive when the issue had not yet become a critical one -- failed because of the lack of sustained actions to implement recommended policies.

Industry Initiative

This time we cannot afford to fail again. One of the principal reasons we failed in the past -- as I see it from my vantage point of having participated in some of those efforts -- is that government and industry parted company after each brief moment of joining together in the effort to develop policy recommendations. Even now, some of those from the private sector -- and particularly those from manufacturing industries -- who participated in the Domestic Policy Review are on record with pessimistic views on the outcome of this exercise. What I would say to them -- and the proposal I make to all of us in the private sector is

"Take the initiative".

By that I mean, don't wait for government to call on you for expert advice. Instead, keep the momentum going by establishing what I have called

"The Council for Innovation".

As I conceive it, this Council will comprise and be supported by a broad cross-section of Business (large and small), Finance, Labor, Academia, and Public Interest Groups. All have a vital stake in the direction and rate of innovation. The Council will be devoted to strengthening the process of collaboration between the private and public sectors in pursuit of innovation. The Council will be uniquely valuable by helping to make that continuing process an action-oriented one.

Through on-going, face-to-face working sessions with Executive Officials and Members of Congress, the Council will pursue its goals of helping to resolve issues that impede innovation. Specifically, the Council will, continually,

- assist in the development and implementation of public policy options, which, in the judgement of private sector leaders, hold promise for spurring innovation
- monitor the effectiveness of these public policies and of the ensuing innovative actions by the private sector
- seek to foster actions, by both government and industry, to stimulate innovation in such a manner as to increase productivity and employment, international competitiveness of U.S. business and strength of our currency, and the social well-being of our people.

The Council for Innovation will continually review the voluminous and growing body of literature, unpublished reports, and perceptions -- expressed by leaders in both the private and public sectors -- pertaining to the impact of public policies on innovation. The Council will collate and synthesize this information so as to derive new public policy options to stimulate innovation.

These options will be reviewed by leading authorities in the private sector, and those options selected for their urgency in national affairs and their prospective positive impact on innovation will be submitted to relevant Federal Agencies and/or Congressional Committees, together with substantive back-up material.

In the ensuing face-to-face working sessions between private sector representatives and government, resolution of many policy issues that affect innovation will be sought. They range the gamut of fiscal and tax policies; environmental, health, safety, and other regulations; antitrust and other provisions affecting industry structure and competition; government procurement and cooperative agreements with industry; direct support of research and development; and economic and trade policies.

At all times, the focus of these efforts is to be on reality rather than theory. For instance, where certain policy issues impede the progress of specific innovation projects or programs, these will be so referenced. They will include those situations where American interests may be threatened by foreign competition, as well as those where American ingenuity and entrepreneurship have the opportunity to establish and maintain worldwide pre-eminence. In the latter case, attention will be devoted to policies that aid in the establishment of new business enterprises, historically a disproportionately large wellspring of job-creating innovations.

The Council's work will be closely linked to related efforts of organizations, such as, the Committee for Economic Development, the Business Roundtable, the Conference Board, and the Industrial Research Institute. If feasible, the Council may, indeed be affiliated with one or more of them.

The Council for Innovation will have a small permanent staff, augmented by numerous persons whose distinguished careers -- and whose recent retirement -- provide both the experience and available time to make their unique contributions. Eminent members of academia, labor unions, public interest groups, churches, and other private sector organizations will be enlisted by the Council for consultation or preparation of "position papers", as will outstanding research and consulting organizations for contributions of their special expertise and experience.

In its ongoing work, the Council will address imperative priorities identified by the private sector -- while, of course, remaining aware of governmental priorities and needs to which it will readily respond as its working partnership with government grows and flourishes.

In short, the Council will render a service to both the private and public sectors by helping them to develop compatible and mutually reinforcing strategies for accomplishing innovations of use to society. It will recommend and foster actions with due regard for both political and business realities.

Action Now

I believe the time is right for this private-sector initiative. Leaders of this sector now correctly perceive the opportunities for -- and restraints against -- innovation to be primarily institutional issues rather than technical ones. And leaders in the public sector seem to concur as evident from statements by Members of Congress and Executive Branch officials. Most importantly -- particularly so since the issues are institutional -- the need for collaboration by the private and public sectors is recognized by both. It can become a reality if the private sector takes the initiative I have suggested. We cannot sit back and just wait for government alone to formulate policies and actions. When we see the need for, say, tax policies to stimulate savings and investments; when we believe that broad performance standards would meet regulatory requirements while allowing industry to make innovative choices of how to comply; then there is only one way: the private sector has got to become part of the political process and contribute a balanced view as a continuing and integral part of government.

If there is one practice that stands out as we observe the activities of those countries most successful in competing with us in the world's technology markets, it is that everyone of them has taken deliberate steps to foster close cooperation between government, industry, labor and other private-sector institutions. Hundreds of millions of dollars are spent in Germany and Japan by government agencies working with industry in supporting underlying technologies of value to many sectors. These are efforts that single corporations would not support because their results are not fully appropriatable by any one of them. In other countries, governments also directly subsidize product and process development, and provide special assistance to small firms who so often determine the vigor and dynamic quality of the economy. The specifics differ according to political systems, tradition, and culture. Nor should we intend to pattern our methods on theirs. But we must get on with fashioning our own tools of collaboration -- to be the functional equivalent of our competitors' -- lest we deny ourselves the full strength of American entrepreneurship and innovativeness. As Senator Stevenson said recently, "We did not suffer inflation until we lost our vision and self-confidence and we won't defeat inflation until we are again a nation of builders, producers, and inventors."

I see us as a sleeping giant -- with the emphasis on "sleeping". I also see us as a society with an industrial complex that has repeatedly demonstrated unrivaled ability to change direction when the need to do so becomes imperative and when to do so entails great risk with the promise of commensurate rewards.

I suggest to you that we are at such a watershed now and that "business as usual" will not suffice. It used to be that government was regarded as an adversary by the private sector. That was the watch word. It isn't any more. Now it is essential to establish a cooperative relationship. And nowhere is

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that more important than in the realm of industrial innovation. We do not pursue innovation for its own sake. Rather it is a means to revive American industry through increasing productivity, creating jobs, beating inflation. In turn, the economic climate impacts on innovation -- adversely now, but potentially favorably again in the future, if we find the way to break this vicious circle.

You will note that I have not provided you with statistics and data to illustrate specific issues in industrial innovation such as capital availability for seed money and for new ventures; regulatory problems; patent law and government procurement practices. Others at this symposium have made those points.

Rather, I have concentrated on what appears to me of overriding importance: the perceptions and attitudes of those -- in both the public and private sectors -- who have a direct decision-making stake in innovation. Part of the problem is in the minds of these people. There is a degree of uncertainty -- of pessimism indeed, as it contrasts with past optimism -- which results in not committing corporate and national resources to the riskier, long-term projects that are the lifeblood of innovations. Regardless of whether or not such a lag exists now, this perception of an innovation lag -- this pessimism -- could become a very severe and self-fulfilling prophecy. That catastrophe can be avoided, I believe, if the private sector can persuade itself that it must take the initiative to step forward and work continually as a partner with government in pursuing those public and private policies and actions that will stimulate innovations of use to our society. It is to this end that I propose that the private sector create the Council for Innovation.

RECEIVED November 13, 1979.

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The Outlook for Innovation: A Policy View

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A very good friend who is now the president at Ohio State University once gave a speech with a title that I wished I had thought of first: "On a Clear Day You Can See Practically Nothing."

Certainly it is very hard to see what is in store for new directions in technological innovation. If we look closely at our national policy-making system in the United States, testing for signals in response to the consensus evidence of a troubled technological enterprise, we come up with very little. Studies are piled upon previous studies. We have had a Presidential call for a new surge of innovation. We have Congressional hearings and volumes of expert testimony. We have government and private sector reports which try to diagnose the pathology of the innovation environment. We have a sort of arrest-of-life in our policy machinery as we all wait and wonder whatever happened to the Cabinet study of government policy changes that would stimulate innovation. If there is policy movement anywhere, it is occurring in the Congress at the initiative of House committees and people like Adlai Stevenson, who will soon give up the Senate seat. On the other hand, there is unmistakable concern in the Executive Branch to find a credible policy route -- and a plitically workable one -- to deal with the issues.

A fundamental question is whether the issue of lagging innovation really lends itself to systematic and sustained policy treatment by government in the present unsettled climate. My sense of it is that there isn't enough political capital in the issue to generate that kind of action. The nature of the issue is economic to begin with, but the economic policy problems which preoccupy policy managers are the obvious ones of intransigent inflation, recession, government spending, an overloaded credit structure, and sinking productivity. It is almost too much, in the face of these parallel calamities, to expect policy makers to

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converge on the innovation issue as a major element in either the overall economic problem or its solution. When government has been stymied in dealing with the energy policy question for six years, can we seriously imagine that it can pull itself together on measures to put in place a new and stable long-term policy climate which encourages innovation?

Part of the situation, I tend to believe, is that deep in their hearts the policy makers recognize elements of sharp domestic discord in a comprehensive program to get innovation back on the track. Entirely aside from the doubtful outlook for sizable corporate risk ventures in the near-term climate of scarce and expensive venture capital, with the especially heavy burden this places on small entrepreneurs, we have to recognize that the politically volatile issues of regulatory rollbacks or moratoria, tax arrangements which appear to favor business, and an easing of antitrust policies all tend to be unappealing on the eve of a national election. Timing is anything but a neutral factor in launching policy innovations.

Going further, I think we might have to concede that it would not be easy to either monitor or demonstrate the effectiveness of any specific policy shift upon the process of technological innovation, especially in the initial years. All of the possible government policy changes that have been talked about would, as all of us know, crosscut managerial judgment, market opportunity, competitive forces in play, and externalities. Whether innovative performance in industry picks up because of -- or in spite of, or regardless of -- public policy actions, or is due instead to the successful private management of market forces, would be devilishly hard to pin down. The dynamics of innovation are studied and preached at length by our friends in the business schools, and I am an avid reader of their outputs, but what it comes to is that there's not much that we can be sure of. That in itself may be a good thing because if we ever worked it out we would probably louse it up. But my point is that almost any broad menu of governmental policy fixes to the innovation syndrome would have to be advocated and argued largely on faith rather than certainty, and this is no small obstacle to getting policy action.

I have just alluded to advocacy, and it was intentional. There has to be a powerful and convinced advocate for a strong set of policy changes, particularly where these would require legislation or trigger public interest controversy. In turn, the best of advocates must be backed up by a strong and unified constituency because if anything is certain it is that opposition would be mounted by other constituencies which are both strong and unified. Do any of us think we see such an advocate, training in the gym every day for the big fight? Do we think we see a constituency straining at the gates to cheer on the advocate of innovation-related public policy changes? Big policy changes -- and they are all that matter, not futile tinkering at the fringes of the problem -- big policy changes call for very big effort, and this means a majority coalition that won't split. It means a coalition of large and small industry, labor organizations, economists, professional groups, media, and elected representatives. It means a coalition that isn't simply slapped together for a couple of years of lobbying, but one that is well-grounded with information and one that can be sustained over the five to ten years that it would take to turn around the current situation and get the rate of innovation up to where we would like to see it.

These are some of the dimensions of the outlook, as I see them. My own guess is that it is not in the cards for government to come forward and wage a crusade for heroic policy changes in the interests of technological innovation. But I also think we can expect something positive in the way of gradual, step-by-step reform and reorientation in public policies which affect risk-taking and large new ventures. Incrementalism is built into our political system, and given the tilt of public opinion towards conservatism in government I think that the incremental path is the only one with a chance. What this then says is that the outlook may be for an orderly, multi-year effort starting with administrative measures and leading to selected legislative changes. Even these will require commitment and steady policy management in government, and especially a consensus in the senior policy councils of successive administrations.

Meanwhile, there is a tremendous educational job to be done if the ground is to be prepared for sequential actions on behalf of innovation. The ground has not been well-prepared as of now. Almost nothing has been done to focus the problem of innovation and its constraints in the print medium outside of the Wall Street Journal and Business Week. If we face a policy hiatus until the elections are out of the way, the time can be used best by business and labor working together to inform and convince the public and the Congress that our economy, nationally and internationally, is going nowhere but downhill on all the present evidence of technological innovation, and that government and the market economy must work together while there may still be time.

It can be argued, of course, that even if government is not ready to work for high-leverage policy changes of a direct sort, there may be some indirect impetus to innovation in the 1980s from the buildup of defense spending, military R&D, and investment in new energy technologies. This is possible and even likely. But it is not a basic answer and it contributes little to correcting the chronic economic mess of continued inflation, pressures on capital and savings, and other disincentives to new company formations. At best, these development might put a floor under falling innovation and productivity without actually turning the syndrome around.

As I said at the beginning, my friend at Ohio State spoke well and truly. Even on a clear day you can't see very much.

RECEIVED November 13, 1979.

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Congressional View of Innovation and U.S. Research

HONORABLE DON FUQUA

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There has been, over the last several years, increasing discussion and concern over what to many experts is a stagnation in America'a ability to innovate in industry and compete in the world marketplace. Red flags of warning have come from industry itself, professional societies, the academic community, the Administration, and Congress. The subject has been extensively discussed and dissected by a diverse community of experts.

However, trying to pinpoint the cause of the malaise is a little like trying to figure out why a child doesn't do well in school. It's never any one thing, but rather a combination of things that have a cumulative effect: poor study habits, lack of confidence, too many distractions, etc. With America's dilemma, the causes and their relationship are similarly complex, involving patent policy, tax laws, anti-trust regulations, trade agreements, industrial inhibition to do long-term research, and the paucity of organizational structures for industry, government and academia to cooperate and assist each other, to name just a few.

So I first say here that there are not going to be any easy, quick-fix solutions. What has seemingly been eroding American posture and prominence in the marketplace is being carefully studied and will have to be cautiously adjusted by a series of efforts which will eventually have the collective effect of reversing the disturbing trends. We bring to this process experience, skill and the determination to see that the appropriate changes take place. I am confident we shall succeed.

There is no strict yardstick I know of for measuring the health of innovation in the United States, but there are several indicators to watch. Research and development are expected to account for 2.2 percent of the nation's Gross National Product (GNP) both in 1979 and 1980. This ratio declined steadily from its 1964 peak of 3.0 percent to a 1973 level of 2.3 percent. Since 1973 it has remained relatively level. Based on R&D funding and GNP projections into the eighties, this ratio would remain at about its present level into the near future. Other nations, specifically West Germany and Japan, are devoting grow-

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ing shares of their national resources to R&D while the U.S. proportion of GNP devoted to research seems to have leveled off. Perhaps this trend bore heavily on the fact that in 1978 Japan produced a surplus in manufactures of $63 billion, and West Germany a $49 billion surplus while the U.S. showed a deficit in manufactures of about $6 billion. It is also significant to note that in energy self-sufficiency the figures are just the reverse, with Japan being only 5 percent energy self-sufficient, West Germany about 40 percent self-sufficient and the U.S. about 75 percent self-sufficient.

Our performance in patented inventions may be one of the best single measures of what is happening in our R&D output. The disquieting fact is that the number of patents granted to U.S. residents declined by 21% between 1971 and 1976. At the same time, patents to foreign residents grew by 16% and became 37% of all U.S. patents granted in 1976. This trend continues. By and large, our indicators signal a weakening condition, which is in fact substantiated because America ranks near the bottom of industrialized nations in productivity growth.

The Science and Technology Committee actively investigated many of these issues in hearings, studies and symposia during the 95th Congress and has continued to do so in the present Congress.

This year, as a continuation of our efforts, we conducted a three-day inquiry into the R&D portion of the federal budget. Because of the large share of federal R&D support and the manner in which federal policies and regulations increasingly affect private investment in R&D, the dominance of the Federal Government and its impact on the elements of our science and technology enterprise are probably greater than ever.

The Science Committee is charged with "special oversight" of government-wide research and is the only committee with the full scope of Congress' responsibility for oversight of R&D policy. The hearings that we held were specifically directed towards understanding the R&D budget better -- to learn how it is fashioned, managed, monitored and evaluated, if indeed all of these were applicable. However, in this initial thrust we also explored the concept of a two-year budget cycle in R&D and as a result, I have recently introduced legislation to that effect. The Research and Development Authorization Estimates Act (H.R. 7790) is designed to inspire further thought and consideration of moving the Federal Government toward a two-year budget cycle. This bill, which is directed only to the authorization process for research and development, is not the answer to all the complex, burdensome budget procedures which face the Congress and the Executive, nor is it anything but a miniscule step in the vast cycle that eventually results in innovation and increased productivity. However, it was noted in these hearings that a two-year or multi-year authorization would be helpful in establishing Congressional intent on the level of support for R&D programs that have long lead times. These long-term programs are often the very ones that suffer most from the vagaries of changing emphasis while they are also the ones which require stable and steady support to bear fruit. In addition, these are the programs that frequently open up whole new avenues of opportunity that can have a ripple effect throughout the entire economy.

Coupled with our recent work on the R&D budget cycle, the Committee's Science, Research and Technology Subcommittee, chaired by Congressman George E. Brown, has set up a multifaceted program of inquiry in the area of innovation and productivity for this Congress. As part of this agenda, recent hearings were held to examine the linkages between the nation's universities and industry with a view towards improving those linkages to promote increased innovation and productivity and to determine what the appropriate role of the Federal Government is in building these linkages. Although we so often fall back on the single suggested panacea of increased funds for research and development, this seems to be missing an important point. It was noted by various witnesses that while universities are suited for the making of new discoveries, industry and the business community are more suited for providing the wherewithal for their development. By simply providing for increased funds for R&D, we do not solve the fundamental problem whose resolution depends mainly on developing new and innovative approaches for rapidly converting research results into marketable products and marketable services. At this time there are few institutional mechanisms to promote the desired results.

Congressman Brown has recently introduced a House bill, the National Science and Technology Innovation Act (H.R. 4672), closely modeling a bill by Senator Stevenson, which calls for the establishment of "Centers for Industrial Technology." These centers would be a specific form of university/industry linkage, and testimony was taken at these university/industry hearings on the concept of the specific centers as outlined in the bill.

When testifying at the hearings, Dr. Myron Tribus of M.I.T. mentioned an interesting sidelight. He said that Japanese universities are purported to guide their brightest students toward problems of design and production. In the United States, quite the reverse seems to be true. We try to direct our brightest students to go into research careers. The result being that the United States takes a lion's share of Nobel Prizes, while Japan runs a favorable balance of trade.

This suggested scenario is seemingly verified in that the U.S. has evolved into a nation specializing in leading-edge technologies. This is, for all practical purposes, the "technological frontier" where both risks and costs are high and where research would have the most immediate impact. However, our eventual short-fall in the market place is caused by the inevitable reality that leading-edge technologies mature and the technological know-how becomes common knowlege. Other nations then have available to them, without any risk, the information that enables them to not only produce a finished product comparable to our own, but as we have seen in the case of CB radios and color TV's with small modifications in design and production, these nations actually create a product that beats our own out of the export market.

Understanding these and other patterns is crucial to making proper constructive adjustments.

I might mention at this point that our productivity should neither be perceived nor measured solely in goods or products, but also in services. Marketing the service of how to use a modern technological package, such as a computer program system, can give us the double mileage of profiting from the sale of equipment, which in some cases is a single-shot deal, and also profiting from the sale of its application, which is frequently a non-depletable resource. This should be a fertile area for the United States because of our emphasis on leading-edge technology.

We also know that American patent policy is somehow woven into the complex of innovation/productivity. There are currently two major issues in government patent policy: one is the ownership of inventions resulting from federally funded R&D, and two, the general revision of the U.S. patent laws. In regard to the first issue, a significant question arises as to whether the existing government patent policy promotes the progress of science, as required by the U.S. Constitution or whether, in fact, government patent policy has stifled both invention and innovation.

In general, it has been the government's policy to retain title and rights to inventions resulting from federally funded research and development made either by government contactors or grantees or by in-house government employees. Significantly, the U.S. Government holds title to about 28,000 such inventions, but only about 5% of these have been used -- not an impressive showing.

However, I want to issue a note of caution here because we may not be getting an accurate reading on either the cause or the extent to which innovation may be declining if we only consider the government's policy regarding patents and do not look to the industrial community's response to the realities of the market place. Althought the legal life of a patent is 17 years, its "real life" is often closer to 3 or 4 years. By this time, the competition may have come up with a modification in the original product and is granted its own patent for a product or process different enough from the original to warrant a separate patent, but similar enough to the original to make the initial 17-year protection relatively ineffective or even useless.

No one knows better than this audience that competition and survival in the market place are often accomplished by circuitous action. Many companies with major research components do not patent their best ideas but keep them on the shelf until the product is ready to go. This often gives the innovator more time to retain singularity and uniqueness -- and thus profit from its research effort. Such secretiveness may, in some ways, stifle the exchange of ideas and information that in turn stimulate more new ideas and information which are the life blood of innovation. But the balance is a delicate one -- that is, vis-a-vis going the patent route -- and I make no judgments about it at this time.

Just as every puzzle and pattern is composed of innumerable interlocking pieces, so the research-innovation-productivity fabric is a collage of interlocking components. We have begun by laying out the pieces and examining their character and their influence. We are hopeful that the Baruch Study recommendations will further clarify our direction. What comes next depends heavily on a coalition of dedicated people. If the problem encompasses government, industry and academia then so too do the solutions involve all three sectors. Let us find a way together to prevent monopoly, but foster cooperation, to promote science, but not hoard its fruits, to trade in the world market, but not give away our advantages, and to learn from the successful experiences of other nations as they have done from us.

As we begin the decade of the 80's, America is poised at the threshold of a new era when we will make a major transition in energy sources at the same time that we will re-evaluate old policies and patterns to create a more synchronous network in which to achieve our goals. The task is a formidable one and we in the Congress look forward to your help.

RECEIVED November 13, 1979.

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The Next Step for the Administration for U.S. Research and Innovation

FRANK PRESS

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My assignment is to discuss "The Next Step for the Administration for U.S. Research and Innovation". That seems to call for a very precise statement. Unfortunately, that's not possible at this time. The reason is that the long-awaited Industrial Innovation Study, which the President commissioned last year, and which did not arrive at the Executive Office until the middle of June, is now in the final stage of being prepared for the President.

This final stage is an essential and critical process -- particularly in the case of such an extensive study, one in which more than 150 recommendations were generated by the 500 representatives of business and industry, academia, labor, government, and public interest groups who participated in and contributed to the study. From these 500 were culled 40 to go to the White House. And a select number of these have been prepared by my Office and the Domestic Policy Staff for Presidential review.

I cannot discuss these specifically. However, let me do what might be the next best thing. I will broadly cover some of the issues and possibilities raised by the study. This may open up for this panel some pro and con discussion on these.

I think it is important to start with the reminder that we are talking about <u>industrial</u> innovation. Therefore the focus of our work is primarily at the level of the firm, and on the various ways that the decision makers in the country's industrial firms, can be provided with better incentives and opportunities to stimulate innovation. It is at this level where we think new products and processes can best be generated.

In our social and economic system this is where the action will come from, when the conditions for such action are made favorable. It is these conditions that are important. All the recent talk about the loss of our country's ability to innovate is sheer nonsense. That ability -- the same ingenuity, imagination, and innovative skills our people have always had -- is still present, perhaps greater than ever. If these elements seem to be in a temporary latency, it is largely because the climate and rewards that stimulate them, have not been present. Some of this was probably to be expected as the country has responded -- and as we tend to do, overreacted -- to the number of environmental and economic changes that have become apparent during a period of remarkable growth we have gone through.

Now the picture is changing again, and I think we are going to see a surge of new innovation -- innovation based on new research, new emerging technologies, new opportunities here and abroad, and new attitudes and action by the government. The innovation study we have been through, will in part set the tone for this from the government standpoint. Its results will not, and were never expected to be a cure-all. But the study, as I've indicated, has been the basis for a great amount of valuable input that, directly and indirectly, will initiate change in Federal activities and attitudes. Some of that change -- as in the case of regulatory reform -- is already well underway. More of it will be forthcoming, both as a result of the innovation study and other Administration initiatives.

I think it is important to make another general point about the innovation study. While much work has gone into this study, and there has been much public attention focused on it, it must be viewed as only the opening skirmish in what will be a long battle. We can't solve everything at once -- we need to learn, and experiment. No one conceived and plotted the path of our previous innovative gains with any master plan, and it is unlikely that this will take place in the future.

Nevertheless, there are certain strategies that seem to be called for. Let me touch on a few of them. The first has to do with increasing the use of scientific and technical knowledge. Most of our important innovation today, and into the future, is going to be of the type based on advanced scientific knowledge. This will be true in the case of high-technology products, in which we excel now but where others are in hot pursuit of us. It will also be true in the case of lower technology products, where our advances in manufacturing processes could help offset lower production costs abroad, reduce resource costs here, and possibly reduce the costs of externalities that have driven up the price of our domestically produced goods in recent years.

We have to advance knowledge and know-how, but we also have to make them more accessible to those who can most effectively put it to work for us -- principally private industry. This requires creating a better flow of information between the government, universities and industry. It also calls for better intelligence, as to industrially relevant technologies being developed abroad. It would be a mistake for us to ignore this in the belief that while others have monitored and milked our advances, we have no need to act similarly. There is not only need, but precedent for doing so. There are numerous examples -- some historic -- in which _we_ have borrowed and successfully innovated on the discoveries or inventions of others. We need to be better in touch with what others are doing, and make this information more accessible here. What role government should play in this, in conjunction with industry's efforts and interests, is a matter that might be considered.

Much has been said, and a few efforts successfully made, related to bringing industry and university researchers together. I think we can expect more action along these lines, some of it perhaps spurred by Federal incentives. But since the university-industry interface has been the subject of much discussion recently, I don't want to dwell on it now, other than to emphasize its future importance.

Another important aspect of the matter of moving information to stimulate innovation deals with what has become known as "generic technology". The concept of generic technology is that there are certain basic technologies -- broad advances that are in between the basic research, supported largely by government, and the development stage attractive to industry -- and that these are the technologies on which firms within an industry build their new products and processes.

The creation of such generic technologies is a high-cost, high-risk proposition. But these technologies underlie major advances in an industry. And they can have a major impact on the nation's economic growth. The realization of this has led certain countries to go into government-industry cooperative programs to develop certain generic technologies. These countries are making a conscious and concerted national effort to do directly what we in this country have done somewhat indirectly, when the government developed a military-related technology that became the basis of a civilian technology.

The question is, to what extent can or should this idea be extended -- and if so, how? Is it as applicable to environmental, chemical and biological areas, and to a variety of manufacturing processes, as it has been to aerospace, electronics and computer technologies? Is this a role for the Federal Government to play in our system? And to what extent is it redundant with our current support of many existing R&D programs?

There is a lot to be considered in this matter, including anti-trust matters and the element of competition.

Let me turn to another strategy -- this one involving the improvement of market information -- and particularly foreign markets -- as a stimulus to innovation. This, by the way, is one the Japanese have openly chided us about, pointing out that we need to study foreign markets more assiduously, much as they have done prior to designing and developing products specifically for such markets.

While we have exported whole industries, technologies and management systems, historically we have never been aggressive exporters of consumer products. In general, our exports have represented a much smaller percentage of our GNP than European countries or Japan. Perhaps this was because our domestic markets have been more lucrative. In any case, much of our exporting in the past has been based on the notion that others had needs paralleling ours, or would aspire to the products we used. But this has held only to a certain extent -- perhaps long enough to deceive us today. Despite the fact that much of the world has sought to emulate us, there are cultural differences and changing needs that we have overlooked. We simply have not done our homework on the physical and psychological needs of a changing world.

There is no reason, however, why all this cannot be corrected. And when one considers, among other things, the huge growth potential of the developing world over the coming decades, and its future market possibilities, there should be incentive for such a correction.

So, just as we need an improved system of ascertaining and assimilating foreign science and technology information, we need a similar effort devoted to foreign market information. To what extent this should involve the government working with the private sector, and the mechanisms and approaches that might be used, are important considerations.

One aspect of improving domestic marketing information has to do with the Federal market and its pull for innovation. Changes in the ways in which the Federal Government purchases goods and services can have a significant effect on industrial innovation. There is evidence indicating that Federal purchasing procedures that spur competition on the basis of product performance, encourage firms to develop new products and processes. This not only benefits the government, but it can benefit the consuming public when the effect leads to improved and innovative products for the civilian market place.

There are other ways that Federal practices can spur broader innovation, and we are considering them. (Patent procedures, small business incentives, new institutional arrangements, automotive initiatives, etc.)

Let me conclude with some brief comments on one more approach, or strategy, that is critical to improving innovation.

Just as important as providing various incentives for industrial innovation, is reducing the disincentives to the innovation process. It is no secret that, in general, industry views as one of the major disincentives to innovation, the vast and complex Federal regulatory regime that has evolved over the past decade or so. I hope it is no secret also, that the Administration is attuned to industry's views on this, and that regulatory reform has been one of its major efforts.

I won't attempt to review all the elements of this. As you know, they have focused on reducing the complexities, uncertainties, and administrative burdens associated with understanding and complying with regulation. They have also focused on achieving a better balance between the economic costs and benefits associated with regulation.

In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

In addition, I think we are now seeing a new philosophy being pursued, particularly with regard to environmental, health and safety regulation. It is one that recognizes that the desired goals of such regulation might best be achieved through an incentive-oriented approach. Such an approach, rather than commanding that specific technologies be applied to achieve the specific standards, allows the industry to choose its own paths to achieving the same end results. In the case of air pollution that may involve something like the "bubble approach" EPA has introduced, in which a plant can set its own effluent release from each point source as long as the plant's total effluent release complies with a Federal standard set for the entire complex.

A similar approach can be applied to health and safety regulation, in which broader, more overall goals are set and companies allowed to seek their own means of compliance.

One of the important things to recognize regarding this approach to regulation, is that it provides new incentive to industry to innovate. It takes some of the repressiveness and uncertainty out of regulation, and relies more on market forces to achieve the desired goals in environmental quality, health and safety.

In short, we feel there can be a new regulatory climate created through regulatory reform -- reform that not only reduces complexity and uncertainty, but that is innovation-oriented. Such regulation, rather than having a repressive effect on industry, and on the country's economy as a whole, could, with the proper industry-government cooperation, become a stimulus to innovation.

We need to turn regulation around this matter. We must do this because it is important to reconcile our need for economic growth, and the new environmental and social goals our people now aspire to. There are many who will claim we can't have it both ways -- we must limit economic growth, or we must sacrifice the so-called "quality of life" goals. Perhaps in the extreme this is true. But in the real world we can progress along both lines. We have in the past, and we can in the future.

One key to doing this is placing more emphasis on our human resources -- on providing more support and incentive to those individuals and groups in our society who are at the forefront of advancing knowledge, pursuing new ideas, and moving them out into world. And we have to combine these resources better, with the physical resources of our government and industry. This calls for many changes of attitude and a new level of cooperation among the various elements of our society -- between government, industry, the universities, small businesses, labor and other sectors.

I think such changes are taking place, though perhaps not as rapidly as many would like. But I believe you will see the desire for such changes -- along with some practical attempts to achieve them -- reflected in the Administration's "next steps for innovation". We hope, and believe, that others will respond accordingly. If we can all pull together, there is no reason why we cannot pull ahead in industrial innovation, and in all the innovation we need to revitalize America's leadership in the world.

RECEIVED November 13, 1979.

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Assessment of Government Impact on Innovation

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The ability of the U.S. to meet its economic and broad social goals is dependent, and increasingly so, upon the development and commercialization of new technology.

Development and commercialization of technology in this country occurs primarily in the private sector and most frequently in industrial organizations. But, at the same time we should acknowledge industry's dependence upon universities, federal laboratories and other non-industrial research organizations to provide much of the needed science base, and (in the case of universities) to train the necessary scientists and engineers.

Although the development and commercialization of technology occurs primarily in the private sector, the Federal government has become increasingly involved over the last two decades. Since World War II it has been accepted that the health and well-being of the national science and technological capability was an area in which government should have developed and articulated policies. In the early post-war years, such policies primarily addressed relatively narrow areas such as university research or matters of weaponry and disarmament. More recently, however, government policy has addressed itself to the health and well-being of much broader areas of national science and technology, including technical areas related to health, environment, and energy. This broadened area of government involvement is extending government policy-making to include the health and well-being of not only university and in-house government research but also much industrial research as well.

Against this background, several technical resource factors affect the nation's ability to develop and commercialize new technology:

First — Availability of technical resources and skills which match the needs of the process;

Second — Achievement of appropriate <u>balances</u> in the commitment of these resources:

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In Innovation and U.S. Research; Smith, W., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 1980.

a. Balance between the creation and utilization of knowledge,

b. Balance among projects motivated by scientific vs. economic vs. political values and objectives,

c. Balance between short- and long- term objectives.

Innovation is also impacted by the effectiveness of the coupling among the various sectors of the national R&D resource.

What is the situation with respect to these factors today?

Qualified scientists and technologists are a limited resource; any action which causes this limited resource to be allocated to one kind of activity will make it unavailable for other purposes.

-The number of students who are able and willing to enter into a scientific or technical career is strictly limited and since World War II has declined as a percentage of the total student population.

-The qualities needed to be outstanding in science and technology are even more critically limited. As de Solla Price argues persuasively in Little Science, Big Science, outstanding capability in science is a small fraction in any pool of scientists.

Like capital, labor and many raw materials, scientific and technological capability must be thought of, nurtured and expended, like the valuable and limited national resource that it is. There is considerable evidence that this resource is being used less effectively than it could be, due to a number of imbalances in its development and strategic deployment. To some extent, these imbalances are the direct result of Federal actions; to some extent, they result from reactions, in universities and in industry, to Federal actions. BUT, TO A LARGE EXTENT, THEY APPEAR TO BE INDIRECT AND UNINTENDED RESULTS OF APPARENTLY UNRELATED FEDERAL GOVERNMENT POLICIES AND DECISIONS. Since World War II there have been a number of major shifts in the make-up of the national scientific and technological resource and in the way it has been allocated.

These shifts are of fundamental importance because they have seriously affected the ability of a limited resource to help meet the nation's economic and other social goals.

a. We have committed inadequate technical resources to the utilization of knowledge as opposed to its creation. As an indication of this trend, the ratio of engineering first degrees to science doctorates has declined from over 10:1 prior to 1950 to under 5:1 since 1951. Similarly, the ratio of applied research and development to basic research has been in decline. In 1953, each dollar of basic research was accompanied by almost eleven dollars for applied research and development; by 1979, this figure had fallen to under seven dollars for each dollar invested in basic research.

b. The balance among scientific, economic and political values and objectives as motivators of scientific and technological development has shifted away from the scientific and economic, and toward the political. Professor Gilpin, in his 1975 report to the Joint Economic Committee of Congress, said:

> "As in the case of government financing in general, there were problems; the emphasis on particular areas and the neglect of others caused serious distortions and imbalances in the overall national basic and applied research effort. Government over-financed 'big technology' and 'big science' to the detriment of technologies and sciences of equal or greater relevance to social welfare and civilian industry."

c. Speculative, longer term but potentially more valuable research has given way to shorter term and frequently less rewarding research.

Underlying all three of these shifts has been a changed and much reduced role for the industrial sector in the process of priority setting and resource allocation.

The much increased role of Federal agencies in the support of science and technology since World War II has been followed in recent decades by a change in private sector involvement as industrial priorities shifted in response to changed economic conditions.

In general, private sector resources will be allocated for the development and commercialization of technology when, in the perception of a potential sponsor, the combination of expected costs and benefits is attractive relative to other investment opportunities. Economic conditions in the U.S. have become less favorable for the development and commercialization of new technology: the cost of these activities has risen; the appropriable benefits have declined. Simultaneously, regulatory requirements have forced the allocation of substantial technical and capital resources to the defensive activities needed to maintain the viability of existing technical and capital investments.

The nation's universities and industries have drifted apart as the Federal government has increased its influence on the development and utilization of the nation's limited scientific and technological resources.

Fortunately, there are notable exceptions to this picture, and bold experiments in forming new kinds of university-industry partnerships are being undertaken. Some universities are noted as being highly responsive to industrial needs; the Harvard-Monsanto program for biological research is a most ambitious undertaking. Yet, overall, the challenge of restoring an effective coupling of universities with the industrial sector is still before us.

IN NET, THE FEDERAL GOVERNMENT NOW PLAYS THE MAJOR DIRECT AND INDIRECT ROLE IN THE DEVELOPMENT AND COMMERCIALIZATION OF TECHNOLOGY BY ITS IMPACT ON THE AVAILABILITY OF THE NATION'S TECHNICAL RESOURCES, THE BALANCE BETWEEN THE COMMITMENT OF THESE RESOURCES, AND THE COUPLING AMONG THE VARIOUS SECTORS.

What changes in Federal policy will help correct this situation? There seem to me to be three key objectives which must be met if we are to continue to meet our social and economic goals:

First — The nation's limited R&D resources must be developed and strategically deployed in a way which is congruent with the nation's economic and other social priorities.

Second — There must be additional stimuli for the utilization of new technology by the private sector.

Third — The performers of basic research must have the freedom to respond to society's total needs, including those identified by scientific and economic, as well as political, considerations.

1. What option does the Federal government have as it works to establish and maintain the nation's scientific and technological capability?

Traditionally, the Federal government has exercised this role through support of education and basic research, primarily in universities. However, it is instructive to reflect that the predominance of the Federal role in supporting university research has been a relatively recent phenomenon.

We must never forget that the support of education and basic research requires the confrontation of overwhelming uncertainty. When to invest? Which field of science or technology? Which student or investigator? Which institution?

For this reason three key sources of influence should guide this selection process:

-Stimulation by science itself; that is, deciding to educate and do research in fields "just because they are there" and research has become possible.

-Stimulation by market need or opportunity; that is, deciding to educate or to do basic research in fields that judgementally will provide the skill and knowledge base for future technology development.

-Stimulation by government institutions to carry out education and research in areas of political interest.

The balance among these three stimuli is an important issue calling for additional public debate leading to changed policies for education and basic reseach funding.

The most effective way to restimulate education and basic research in response to market needs would be to improve the coupling between the academic and industrial sectors.

-I would recommend encouragement, from the highest levels of the Administration, directed at the leadership of both industries and universities, for the formation of such partnerships. "Jawboning" may be going out of style, but there are few leaders of universities or industries who can ignore a direct, well-reasoned appeal from high in the Administration. They may not respond exactly as desired, but they won't ignore the issue.

-Universities need additional incentives to encourage them to seek industry funding. Such incentives could take the form of unrestricted matching grants from the Federal government.

-A similar but smaller role could be played by tax incentives for industry support of university research, similar to those proposed by Senator Javits. The use of tax incentives as opposed to more direct government involvement would ensure the key role of market influence on the project selection process.

I do not mean to treat lightly many issues which must be resolved if university/industry partnerships are to be productive. However, these issues will be resolved once the basic policy and incentives are in place and understood.

2. What option does the Federal government have to restore and maintain adequate incentives for the commercialization of technology by the private sector?

Historically, this Federal role has been exercised primarily through tax and patent policy. These institutionalized mechanisms have served the nation well in the past. Unfortunately, there has been a deterioration in the effectiveness of both patent and tax policies, as new barriers and disincentives have been introduced.

The Industrial Advisory Committee to the President's recent Domestic Policy Review has submitted reports expressing an industry viewpoint on many of the issues involved, and suggesting some 150 recommendations for Federal policy or procedure changes to improve the situation.

The subcommittee dealing with patent policy very appropriately and strongly recommended increased funding for the Patent Office.

The subcommittee dealing with economic and trade policy properly recognized that the role of government with respect to incentives for private sector innovation must be to pursue policies which reduce inflation and thereby restore a sound economic climate while at the same time reinforcing policies which permit successful private sector innovators to retain appropriate rewards for the risks they undertake.

Federal policies in this area should recognize the special capabilities of small business; but also should take note of the complex relationships that exist among small and large businesses, and between individuals and corporations.

3. What should be the Federal role in helping to ensure that

private sector innovation is in accord with the public interest?

Historically, the Federal government has exercised this role through regulation of industry structure and competition. More recently, this Federal role has been expanded to include regulation designed to meet health, safety and environmental goals.

This Federal role has been rationalized on the premise that the private sector -- responding primarily to economic incentives -- will not act in accordance with the public interest. Regardless of the merits of this argument in individual instances, it is increasingly clear that there are costs to society for these kinds of Federal activity and often because of their impact on technological innovation these costs can be very substantial.

- Economic regulation can distort the character of the technological innovation which takes place in regulated industries.
- Barriers to the entry of new firms, increasingly the direct or indirect result of regulation, deny or delay to society the benefits of their important contribution to technological innovation.
- The impact of the more recent health and safety regulations on the commercialization of new technology by existing companies is being increasingly recognized and documented.
- We should note that because scientific and technical resources are limited, Federal actions which require these resources to be committed in response to regulatory activity make them unavailable to respond to other needs of society.

In addition to the major costs to society of government intervention it has become clear that the ability of government agencies, both here and abroad, to intervene effectively is extremely limited. Technology development to correct "market failure" requires joint consideration of market need, economic realities and technological capability. The almost impossible task of interpreting changing consumer demands and economic realities -- without the pluralistic capability of the market place -- critically undermines a government agency's ability to centrally respond to "market failure."

Despite the difficulties involved, the Federal government does have an essential role in the achievement of social benefits that would not otherwise occur as a consequence of the development and commercialization of technology in a free market. However, we must reexamine the way in which this role is implemented. Two principles could usefully guide this reexamination.

First, direct Federal intervention should be avoided, whenever possible, by relying upon market forces to produce the desired benefits. To the extent that broad Federal policymaking can ensure an accord between the public interest and the goals of private technology commercialization, little additional Federal action will be required. Such congruence will result when the sponsors of technology development and commercialization are responsible for an appropriate part of their "externalized" costs, and at the same time have the ability to retain an appropriate share of the benefits of their activities. Such an approach will release the power of the pluralistic capability of our economic system, while minimizing the costs and problems associated with direct regulatory action.

Second, avoid regulatory action which incurs visible or hidden costs that are not justified by the societal benefits that result. It is particularly important that such costs as stifled technology development and other undesirable second order effects, including diversion of technical manpower, be carefully assessed before regulatory action is taken.

In summary, the Federal government has become the major influence on the development and commercialization of technology by its impact, largely direct, on the availability of the nation's technical resources and by its impact, largely indirect, on the deployment of those resources.

Imbalances in the deployment of the nation's technical resources have occurred which are affecting the nation's social and economic well-being. These include the imbalance between the utilization and creation of knowledge, the influence of political as opposed to scientific and economic values and the balance between short- and long-term considerations in project selection.

The coupling between the universities and government has strengthened since World War II while communication between the universities and industry has languished. This situation needs to be corrected so that University and Industrial Research can become more responsive to society's total needs, including those identified by scientific and economic as well as political considerations.

The government's major direct and indirect role in the creation and deployment of the nation's technical resources needs to be fully recognized as future Federal policies are developed. In particular, it is difficult to overstate the importance of developing economic and regulatory policies which will significantly restimulate the private sector's involvement and investment in technology development and commercialization.

RECEIVED November 13, 1979.

Summary

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Consensus, even approximate, is difficult to achieve when examining the views of such a large and diverse group of informed and distinguished authors as appear in this book. Their views and comments form a fabric which rather clearly represents the complex situation of U.S. technology and innovation today and the recommended changes necessary to improve the situation. Yet, consensus on most points did emerge.

The United States is in trouble technologically. Trends reflecting the slowing rate of innovation in the United States, no matter how they are measured, are unmistakable when compared to the growth in the rest of the world or to our own past record of achievement. The deceleration in innovation and technology growth actually means a declining rate of investment and economic development, a relative decline in U. S. productivity compared to the rest of the world, and a declining competitive economic posture of the United States. This is not an isolated aspect of our economy, as innovation and technological growth and improvement are the heart of our previous growth and will be even more important as we proceed from a nation abundant in resources and land to one that is not so blessed as these strengths are used up.

The continuing deficit in our trade position, our increased dependence on offshore resources (oil), the decline in market competitiveness of our goods and currency, increased unemployment, and inflation all parallel the slowing rate in U.S. technological growth. This is no coincidence, for all of these factors are interrelated. If the number one priority of Government is the economy, and the maintenance of our standard of living, then innovation and the technological strength of the U. S. must be part of this high priority.

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Unfortunately, due to the five-to ten-year lag time involved in research, development and commercialization, improvements and beneficial changes to increase U.S. innovation cannot have a significant positive effect for that same long period of time. Therefore innovation is given a lower priority as if it were some independent problem not related to the current economic problems of the United States. As at least one author noted, "It will have to get worse before it can get better."

The collection of papers on Innovation and U.S. Research included in this book represents a major departure from previous volumes in that the industrial perspective is emphasized. In the innovation process, the last step is usually the commercialization or implementation of a process or technology by the private sector for use by or for benefit of the public or public sector. It is this very vital role that industry must perform that requires that the industry perspective be examined in the context of the total U.S. approach to innovation.

To have innovation, to encourage innovation, and to achieve the benefits from innovation, we must have an encouraging environment. There are at least two levels for which a discussion of the environment is important. On a national level, the economic environment must encourage investment and corporate growth. Government has a role to play by not overregulating to stifle new-product growth, by encouraging investment capital with appropriate tax policies, by effective management of the patent system, and by adopting a more cooperative role with U.S. industry with respect to increasing its technological competitiveness. The industrial corporation responds to the national economic environment.

The second level of environment that must be improved to increase innovation is that within the industrial organization. An uncertain and discouraging economic and regulatory climate over several years has produced within a significant number of U.S. corporations an environment which is equally discouraging for innovation and new products. This corporate environment consists of minimum risk, over analysis, difficult approval barriers before a new product is approved, inflexible corporate structure, and a lack of commitment to internal research and development generated products. This internal corporate enviroment can be changed by a commitment of the chief executive officer to new products and technology, recognition of the contribution of innovators, an involved technical management, and proper organization.

The national research and development enterprise has been observed as always seeking equilibrium. It is important to examine what sort of equilibrium we wish to achieve and adjust the inputs to achieve it. There was generally a lack of interest by most authors in significantly increased Government expenditures for research and development in current programs as a means to increase U.S. innovation.

The impact of R&D and innovation on our national economy can be emphasized by the realization that half of our economic growth in the past thirty years was based on new technology. We cannot deliberately slow the pace and survive; we can, however, guide the direction for new growth and innovation.

The lack of U.S. government encouragement of innovation and investment contrasts with many other governments which began a number of years ago to work actively with industry to encourage investment in innovation. This may be the cause of the strong showing of new technology and competitive products coming from Japan and Europe. The Japanese example deserves special examination by the U.S. because the Japanese government has been able to increase significantly the competitive position of Japanese industry through close cooperation.

There have been a number of studies and assessments of innovation and the present U.S. situation. The 1978-79 Domestic Policy Review (DPR) on Industrial Innovation produced a heightened awareness of the problems requiring solutions to enhance U.S. innovation. Related studies by the Committee on Economic Development (CED) and by the Congressional Research Service (Library of Congress) have focused clearly on the problems. The report by CED provides a number of specific recommendations. Another study by the small-business community points up many similar recommendations. At this point in time, the Congress has picked up a number of recommendations from these studies and will continue to offer legislation to improve the national environment for innovation. This legislation will come in small steps, but both houses of Congress are clearly involved and concerned.

The impact of the private rate of return due to new products (innovation) averages about 30 to 40% in the chemical industry, but the social rate of return, i.e., the impact on our total economy, may be three times as great. This leverage effect may be particularly important in new critical technology areas such as energy. The Congress and the Executive

Branch must appreciate this significant impact with respect to the leveraged gains possible in the increase and expansion of new technology.

The corporation, whether large or small, is the vehicle for accomplishing most innovation in this country. In addition to the necessity for the real commitment of the chief executive officer mentioned earlier, other additional requirements include the assumption of a more aggressive role by technical management, a realization that R&D with longer term results is worth supporting, that the classical method of analysis of new R&D programs is not appropriate, and that project teams are an effective way of bringing on new products successfully. The smaller technological firm avoids some of the problems of the larger organization due to the closeness of the CEO to the actual R&D, and is an effective means to bring on new technology. However, the larger corporations in the chemical industry have been principally responsible for the introduction of the major new process technology and significant large-volume plastics and chemicals. This is probably due to the need of significant resources in capital, major project management and human and technical resources required for these major developments.

The proper organizational approach for enhancing innovation depends on the corporation. However, overorganization is to be avoided and flexibility is to be encouraged. Project management and the project people involved are crucial. The use of effective assignments to fit the right people to the right position and recognition of their accomplishments is important. Innovative people should not be assigned to positions where innovation is not important. The effective use of the dual ladder for scientific and management promotion can play a significant role in the recognition of accomplishment.

The corporation must pay careful attention to its patent policies. Although direct, immediate cash reward to an inventor may not have a direct effect on R&D productivity in an organization, individual recognition over the long term is important, together with the right internal corporate environment to increase innovation. This problem is particularly acute in government laboratories which have also adopted project accountability and evaluation methods which are restraining new research and development. Patents coming from government R&D are essentially not utilized due to the system of non-exclusive licenses and the lack of enforcement or effectiveness of government patents. This in turn may be a further disincentive for the output of government-owned patents. This situation invites loss of U.S. technology to foreign companies (competitors).

The large corporation must be persistent in maintaining new product growth and feel anxiety for the future in order to keep making the necessary changes for adjusting to changing inputs. The smaller technical corporation is in constant anxiety, but must have a favorable national economic environment to innovate at an optimum rate.

By focusing the innovative process on market needs, we will enhance the success of the innovative project. Other factors for success include close interaction with the potential customer, a balanced team approach, and management commitment.

The innovative individual is the starting point of the process of innovation. The corporate climate must be encouraging for this person to be productive. This individual must be in a state of discomfort with respect to present technology, products and ideas. The innovative person must be challenged with a problem worth solving while in a position that is responsible for the solution. There must be flexibility in how the problem is solved, while the overall program goals are strictly managed.

Innovators tend to show strikingly unique similarities in their backgrounds, including early intellectual independence of parents and the flexibility to generate many options. To the innovative person the thrill is in the research, and no bounds are drawn between the work and the home. Horizontal thinking is important for innovative problem solving. A management by objectives approach can be effective in encouraging the innovator.

Determination of the appropriate role of government is open to discussion, but there is agreement that the government must avoid over-regulating, must take a less hostile attitude toward U.S. industry and study the successful approaches of Japan, France, and Germany in new product and technology development and commercialization.

Many science and technology issues are being debated in Congress and in the Executive Branch with numerous recommendations being suggested, sometimes at cross purposes. Industry needs to spend more time in communicating practical recommendations to all sectors of government. A number of organizations are in a position to do this now, but there may be a need for an organization comprised of industrial spokesmen just for innovation as is proposed by one of the authors in the book.

We are not sure where our economy and growth is headed in the 80's, but without increased innovation, the U.S. will be in trouble. Innovation must have a strong advocate - a strong constituency. This requires a coalition of large and small business, the media, the academic community, and perhaps government research. This effort will effect a step-by-step change, but it must begin now. Industry must rededicate itself to releasing its own energies to this effort to innovate and become more competitive. It may require restructuring of some corporations to improve this effort. Venture capital is becoming more available and with the proper national environment so might capital investment by larger corporations. Other fences also have to be mended. Industry and the academic community have drifted farther apart over the past fifteen or twenty years, which needs to be reversed in order to obtain the maximum results from the R&D resources of the U.S.

The group of authors represented in this book are among the more informed people with respect to industrial innovation. It is important to recognize that many of the specific problems and difficulties which have slowed U.S. innovation along with the corresponding specific recommendations and analyses in this book have also been noted previously by others. This indicates that many aspects of the problems with U.S. Innovation along with a correspondingly difficult recommendation are already recognized but require an acceptance by all in order to begin the task of improving U.S. innovation. There are apparently no easy novel answers.

To recount the story of the nobleman, who when informed by his gardener that a tree may take a hundred years to grow, responded that they must hurry and plant since they had no time to lose, the same may be said of the United States at this point. Our technological strength, which had produced a strong economy and high standard of living, affects all of us. We cannot see and identify all of the present problems with which our country must cope, but the problem of decreasing innovation and technological strength keeps reappearing as the root cause of many other supposedly isolated problems of the U.S. We must start now to improve this strength.

RECEIVED December 18, 1979.

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