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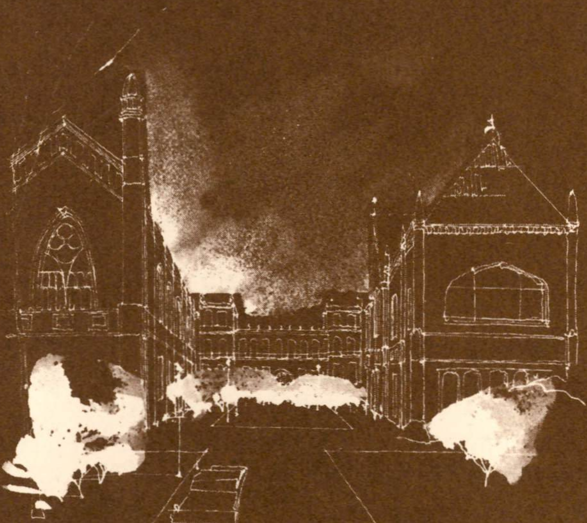
The Care and Feeding of Econometric Models

By ARNOLD ZELLNER



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The Care and Feeding of Econometric Models

IT IS ACCURATE to state that we are witnessing the emergence of an econometric model building industry. Models of internal firm activities, firms, banks, households, markets, regional economies, national economies, and even the world economy have been or are being constructed.[1] In part, the growth in modeling activities is due to the fact that mathematical modeling involves the capability of representing the interaction of many factors or variables in an explicit, logically consistent, mathematical manner.[2] Such a mathematical representation often helps in achieving an understanding of the system being modeled whether it be a firm, a market, or a national economy. In addition, models may be useful in forecasting future values of variables such as a firm's sales or GNP for an economy,[3] and in appraising the probable effects of alternative policies. That statistical and computer methods are available for "checking out" models using empirical data is also of prime importance since otherwise models might be mere mathematical flights of fantasy. By confronting models with actual data, we are in a position to appraise their performance.

AS IN OTHER areas, it is important to distinguish between theoretical and applied work in the modeling area. For example, in the automobile industry we have engineers who design and help build automobiles. While they utilize the principles of physics, they are not primarily concerned with discovering new physical laws or theories. Rather they are concerned with applying and adapting known laws of physics,

Footnotes are presented at the end of the paper.

etc., to enable them to build good automobiles. Similarly, in the econometric modeling area there are theoreticians who are concerned with producing better economic theories, statistical methods, and computer techniques. While this work is of fundamental importance, it should not be confused with the work of applied econometric modelers who are in the main attempting to apply and adapt existing theory and methods to produce useful models. Often this applied work is very much an art and involves approximations and ad hoc procedures to bridge gaps in our economic knowledge and inadequacies of current statistical and econometric methods.

Frustrating and irritating as these approximations and ad hoc procedures may be to theoreticians, it is accurate to say that they are needed in many instances because theorists have not as yet produced solutions to quite a few problems faced by applied workers building econometric models. And in fact, it may be that approximations and ad hoc procedures which work in practice will be rationalized in future theoretical work.

In this paper we shall be in the main concerned with the activities of applied econometric model builders who are striving to produce good models on the basis of currently available theoretical results, statistical and computer methods, and data.

Given that we are concerned with the activities of applied econometric model builders, it is pertinent to note that such activities can and do take place in different institutional settings. Some model builders operate in consulting firms, some in governmental agencies, some in academic institutions, and others in private firms. While the institutional setting and arrangements can have an important influence on modeling activities, in this paper we shall merely mention this fact without going into these considerations in detail. Rather, we shall

review aspects of model building activities abstracting from many institutional constraints which can be important in particular instances. In order to catalogue the various specific activities needed in econometric modeling, it is important to have a good perspective of the general characteristics of a modeling operation, including its initiation and subsequent development.

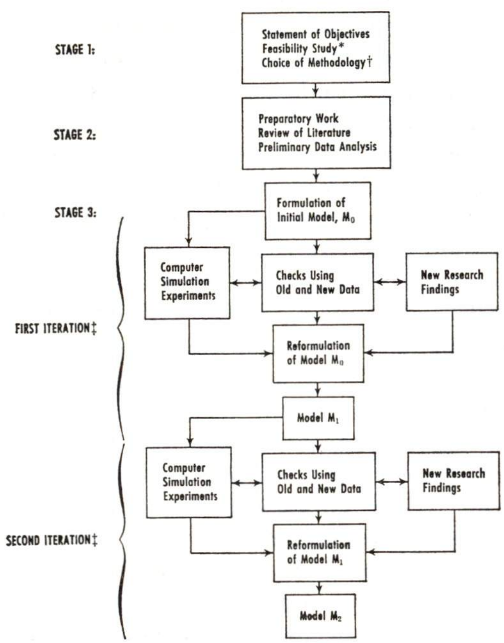
Overview of Modeling Activities

Often specific problems arise which potentially can be dealt with by a modeling approach. For example, a firm may be having personnel problems, and perhaps a personnel model incorporating its personnel policies (e.g., hiring, firing, retirement, and salary policies) would be helpful in reducing costs and in finding ways to get better performance in other respects. Or a government may wish to know how proposed changes in a transport system may affect economic growth; perhaps a modeling approach would be useful in solving this problem. In these two examples, and in others, it is important to develop as clear-cut a statement of the problem as possible. Then the question to be asked is: what are the relative costs and advantages of alternative approaches available for solving the problem? Obviously, for some problems a modeling approach may not be feasible, perhaps because it is too expensive relative to the estimated benefits, or because the requisite knowledge and/or data needed for a modeling approach are unavailable. If, however, a modeling approach is considered appropriate, then an issue which must be faced is: should the modeling work be done "in-house" or by contract with (say) a consulting firm? In making this decision, it is of course important to assess relative costs and probabilities of successful problem solution. This specific problem deserves serious study. For present purposes, we shall not consider it further but shall turn to a description of modeling activities in general.[4]

THE SCHEMATIC diagram in Fig. 1 is a useful representation of some key elements involved in modeling activities. As shown at the top of the diagram, in Stage 1 it is important, as mentioned above, to set forth the problem and objectives as clearly, simply and specifically as possible. Then a feasibility study should be undertaken to determine whether or not the project is feasible and to appraise alternative methodological approaches. If a modeling approach is decided upon, then in Stage 2 a good

FIGURE 1

SCHEMATIC OF RESEARCH STRATEGY



* It is assumed that this study shows the project to be feasible.

† It is assumed that a "modeling" approach is selected.

‡ The iterative procedure may disclose problems in the original formulation of goals, feasibility, and methodology so that refining and reformulation of the effort may not be confined solely to the model itself.

deal of preparatory work must be undertaken. This will involve a review of the literature bearing on similar modeling projects, etc., and preliminary data analysis. This preparatory work's object is the formulation of an initial model, denoted M_0. It is understood that the initial model will be checked for mathematical consistency and consistency with economic principles. Then, just as an airplane model is subjected to wind-tunnel experiments, the initial model is put on the computer and subjected to simulation testing. In addition, checks using old and new data are made and relevant research findings are brought to bear on the initial model. All of this activity is aimed at producing an improved version of the model, say M_1. Then the whole process is repeated to obtain a better version, M_2, and so on. In this way we attempt to "iterate in" on a model which is capable of achieving the objectives of the model building project. If the objectives involve operation of the model over long periods of time, then of course the iterative procedure can be pursued as long as the model is in use. In addition, as the model evolves it may be found that it is possible to broaden the objectives of the project, or it may be necessary to narrow them.

In the approach to modeling set forth above, it is clearly the case that many specific activities are involved which require knowledge from a variety of disciplines, for example, economics, econometrics, statistics, mathematics, computer sciences, and other disciplines relating to the problem being analyzed. There will be a definite need for coordinating and administering a broad range of activities and a staff of several specialists and technicians.[5] It appears useful to have a model manager to administer model building activities. To do this effectively and to have the whole set of modeling activities proceed smoothly and in an orderly fashion require most importantly that the model manager be a good administrator with respect to planning operations, budgeting, and personnel relations. In addition, modeling activities require well-organized systems of documentation. Some observations on the specific nature of these latter requirements are made in the next section.

Documentation and Modeling Activities

Good documentation of modeling activities is of the utmost importance in providing for orderly and cumulative progress. In an important sense, this is similar to the requirement that a laboratory scientist record his experiments and work in his lab notebook, or that a business have an accountant maintain a good set of books. While it is difficult to generalize about what records should be kept, it is thought that a model manager will find it useful to maintain at least the following files:

1. Literature File
2. Model File
3. Data File
4. Statistical Inference File
5. Forecasting File
6. Simulation Experiment File
7. Computer Program File
8. Budgeting and Planning File

We shall now discuss the nature of these files.

1. *Literature File:* As its name implies, this file includes items from the literature which are particularly relevant for modeling activities. Generally speaking, it will be necessary to include works from the areas of economic theory, empirical economics, statistical methods, computer methods, mathematics, etc., in the Literature File. In addition, the specific nature of a modeling effort will usually imply the need for coverage of other areas of the literature. For example, if the modeling project is a regional one dealing with water problems, it will be necessary to have the Literature File include relevant works from the areas of regional economics, economics of water, hydrology, etc.

To be useful to modelers, the Literature File should be kept in an orderly and careful manner. In some cases, a special library can be formed; in others, existing library facilities can be employed. In either case, it will be useful to develop a good classification scheme for works in the Literature File and to have information relating to items in the file keypunched on computer cards. Given that this is done in an intelligent manner, it is possible to develop bibliographies relating to specific topics merely by sorting cards. Also, with the Literature File on computer cards, it is possible to have copies of the file made easily.

2. *Model File:* This file contains specific information regarding the model and model changes. This file is of great importance since it incorporates information relating to the iterative steps taken to improve the initial and subsequent versions of a model. When the initial model, M_0, has been formulated, its equations and variables, along with their definitions, should be incorporated in the Model File, perhaps in the form of a dated computer listing. As work with the initial model proceeds, as described above, equations of the initial model may be changed. Altered versions should be entered in the Model File, appropriately dated and identified with references to other files wherein explanations and justifications for changes are provided. For example, an equation's coefficients' values may be changed as a result of reestimation based on new data. Reference would then be made to an entry in the Statistical Inference File (to be described below) which provides the details of the reestimation.

As changes in the initial model accumulate, a new version, M_1, will emerge. Its equations and variables, with definitions, should then be entered in the Model File along with future changes and modifications. As the model begins to "stabilize," it will become useful to institute systematic review procedures. For example, an annual review of the model can be scheduled and changes instituted on an annual basis. Having a basic model available throughout the year to which continuing work can be related is important. Also, since it is often the case that revised national accounts data become available once each year, reestimation and further testing can be scheduled so as to utilize this new information when it appears.

The Model File at any point in time will contain a complete description of the initial model, subsequent variants, and a detailed description of various model changes along with references to other files describing the rationale and reasons for such changes. Having all this information available in a computer listing is very useful to workers working with the current variant of a model.

3. *Data File:* As the name implies, this file contains the data employed in a modeling project. Naturally, it is important that the Data File be kept carefully. Sources of data, variables' definitions (including units of measurement), variables' symbols, etc., should all be incorporated in the Data File. In addition, since data are often first available in the form of preliminary estimates and then revised, it is important that entries in the Data File reflect revisions of the data. Then too, the Data File should be broad enough to include the results of studies bearing on data accuracy, relations between provisional and revised estimates, etc.

4. *Statistical Inference File:* This file is maintained to provide detailed information regarding statistical operations with variants of a model, for example descriptions of statistical tests and estimation of parameters. It is important that such operations be fully described. Among other things, it is relevant to indicate

and explain the objectives and results of a statistical operation and the methods, data, and computer programs utilized. In addition, the variant of a model under study should be specified (a reference to the Model File may suffice). With such information entered in the Statistical Inference File for each statistical operation, it is possible for current workers to appreciate what work has been done on statistical problems in the past and to plan future work more effectively.

5. *Forecasting File:* If a model is used for forecasting, it is extremely useful to maintain a file containing information about past forecasts, forecast errors, and analyses of forecast errors. Naturally in describing forecasts, it is necessary to indicate the variant of the model employed, how and with what data it was estimated, any assumptions utilized in obtaining forecasts, the way in which forecasts were obtained, the forecast period, etc. Also relevant here are comparisons of the model's forecasts with those provided by other models or by other methods if they are available. By having the information systematically entered in the Forecast File, a model's forecasting performance can be appraised on a continuing basis.

6. *Simulation Experiment File:* As indicated in the previous section, simulation experiments are usually performed to provide information about the operating characteristics of a model. They are also performed to appraise the effects of alternative policies on a model's outputs. Since simulation experiments constitute such an important role in modeling activities, it is critical that they be well-described and documented. It appears useful to write a "lab" report for each simulation experiment and to incorporate such reports in the Simulation Experiment File. These dated reports should include at least a description of the simulation experiment's purposes and objectives, the variant of the model employed, the

simulation program, the conditions of the experiment, and the results and an interpretation of them. If a simulation experiment suggests changes in the formulation of a model, this should of course be noted. The Simulation Experiment File, properly maintained, can be of great value to workers attempting to improve a model and using a model for appraising the possible effects of alternative policies.

7. *Computer Program File:* Modeling activities usually involve use of several computer programs. For example, computer programs for statistical estimation, for statistical testing, for accessing data files, for transforming variables, for performing simulation experiments, etc., are generally required in modeling work. It is thus useful to have a Computer Program File in which programs being employed are completely described. Then too, changes in computer programs and studies to evaluate the numerical accuracy of computer programs should be well-documented and included in the Computer Program File. By following such procedures, the work of those engaged in modeling activities will be made more effective and efficient.

8. *Budgeting and Planning File:* This file is one that a model manager will want to maintain so as to insure that modeling activities proceed effectively and remain within budget constraints. At any point in time, there will be a number of sub-projects which must be completed. The scheduling of such projects and the assignment of personnel to complete these projects is a major responsibility of the model manager. It may be possible for him to develop a flow diagram of the work in progress with estimates of completion dates for specific subprojects. Regular meetings with the modeling staff, say at monthly intervals, to review progress and to assess job priorities and scheduling will probably be useful. The Budgeting and Planning File should include reports of these meetings as well as proposed work plans with budget allocations. By monitoring modeling activities in this way, the probability of realizing the objectives of a modeling effort within budgetary constraints should be raised.

With these remarks made about aspects of documentation, we shall now turn to a discussion of available procedures for appraising model performance.

Procedures for Appraising Model Performance

The best procedure for appraising a model's performance, whether it be forecasting performance or policy analysis performance, is a serious study of the results of its actual performance in use.[6] Does the model forecast accurately enough? That is, are its forecast errors small enough to be tolerable? Does it catch turning points? As regards policy uses of a model, has the past use of the model been helpful in understanding the effects of policy changes (for example changes in fiscal and monetary policies at the national level)?[7] For a model of a firm it is relevant to ask: has the model been of value in forecasting? Has it been useful in furthering understanding of firm operations and producing and evaluating changes in firm policies and practices?

Answers to the above questions are relevant for assessing the possible benefits derived from use of a model. To complete the picture the cost side must be considered. What are the costs associated with developing and operating a model? In this connection, the salary component of costs will undoubtedly be a major one. Competent and resourceful individuals are needed to develop and operate a model effectively. Thus in appraising the record of a particular model, which has seen actual use, it is important to assess salary costs realistically, as well as other items of cost. In an important sense, a modeling project should be viewed and evaluated as an investment. While certain costs and benefits may be difficult to estimate, it is still worthwhile to carry through calculations to arrive at a rough rate of return for a modeling project, particularly at the firm level.

IT IS UNFORTUNATE that detailed, long records of the performance of a number of models are not available at present. This is due to the fact that many models have been developed only recently, and also because records of performance are often not made public. More fundamentally, "laboratory and field" experimentation is usually not possible. While airplane designers can employ test flights to evaluate design performance under preassigned conditions, this important procedure is not generally available in the case of econometric models. Procedures for checking out the latter models are somewhat indirect, and hence there is considerable uncertainty about the actual performance characteristics of an econometric model which has not as yet been used extensively in practice.

Some model checks which are currently in use will now be reviewed. First, and of fundamental importance, an econometric model should be checked for logical consistency. Are the equations of the model consistent? Does the model have a unique solution? Are the units of measurement for variables appropriate? These are basic mathematical considerations which may appear obvious; however, they are of such vital importance that it is deemed worthwhile to mention them explicitly.

Second, a model should be analyzed carefully to obtain an understanding of how it works. Then the workings of the model should be compared with what is known in theory about the entity being modeled. For example, a model of a national economy should incorporate and not be in conflict with established principles of macroeconomic theory. In addition, the judgment and knowledge of those who are familiar with the entity being modeled should be utilized to evaluate the basic model mechanisms.

Third, as mentioned above, simulation experiments can be employed to aid in the understanding and evaluation of a model.[8] For example, changes in exogenous variables such as federal government spending, tax rates, etc., can be fed into a model to determine its responses. Are they of reasonable magnitude? Is the timing of such responses reasonable? Do any variables assume unusual values? For example, if the functional forms of certain relations are in error, it is possible that an interest rate variable may assume a negative value. In addition, simulation experiments designed to approximate certain historical episodes can be performed. Does the model yield outcomes that approximate well the actual outcomes? Further, it is important to study a model's performance under extreme conditions (large changes in exogenous variables, for example). When the conditions of a simulation experiment are such as to strain a model, some of its weaknesses become apparent. Also, it is the case that extreme conditions may be encountered in using the model in practice. Since periods of extreme conditions are often vitally important, establishing a model's operating characteristics under such conditions is vital.

Fourth, some statistical procedures are available for checking a model using actual data.[9] Of course, it is often the case that data available for statistical checks are not as extensive as desired and do not have the properties that they would have if we could actually design and carry through experiments. Be that as it may, the actual "non-experimental" data that we do have can often be used fruitfully to check for possible inadequate or erroneous formulations. For example, it is good practice to study the properties of residuals from statistically fitted relationships of a model.[10] Intensive residual analysis can often result in the discovery that a functional form of a relationship is in error, an important variable may have been omitted, or a lag structure may have been misrepresented. When such discoveries are made, equations of the model will have to be reformulated and reestimated.

For models that are not too complicated, formal statistical tests of hypotheses can be carried through. For example, it is often of interest to determine whether or not the coefficients of a model are constant in value through time. By splitting the sample in half, with one half relating to an earlier period and the other to a more recent period, it becomes possible to test the hypothesis that corresponding coefficients have the same value in two periods. Large sample tests of identifying restrictions are also available. Unfortunately, the small sample properties, power, etc., for many test procedures applied to relatively complex time series models are not known at present. Also, it is the case that for moderate to large-sized models, limited data must be used to investigate a rather broad range of hypotheses, to find good relations, and to estimate them. When the information in the data is used for a variety of tests, etc., results are often not very sharp and the information in the data will often have to be supplemented by judgment, theoretical principles, and other "outside" information. For example, given the objectives of a modeling project, many use a simplicity criterion in formulating a model—that is, an attempt is made to formulate the simplest model which is consistent with accomplishing the objectives of the project.

Formal statistical methods for comparing non-nested models are being developed but have not as yet been perfected[11] to the point where they are operational for models with (say) 20 or more equations. For such large

models, the comparison of alternative versions is still pretty much an art.

Fifth, intensive examination of the forecasting experience and policy uses of models is without doubt the most crucial criterion for assessing the performance of models. On the forecasting side, comparisons can be made with the forecasts yielded by alternative models and by informal techniques. Where poor forecasting is encountered, it is imperative that the source or sources of difficulty be located and the model be improved. On the policy side, a model should be helpful in appraising the effects of alternative proposed policies. A model's performance in this dimension can be checked against outcomes actually observed in particular historical episodes and in current episodes as they unfold in time. For example, with a model of a national economy, it is relevant to set up conditions resembling those actually encountered in a major depression—for example, the 1929 downturn. Given that the outside factors or exogenous variables behave as they did in that downturn, does the model yield paths for endogenous variables, say GNP, the price level, interest rates, unemployment, etc., which resemble those actually encountered historically? This sort of testing should be extended to "credit crunch" periods and other exceptional historical periods. If there are failures in approximating the behavior of the economy in such episodes, this is important information for evaluating a particular model.

Summary and Conclusions

In the present paper, we have attempted to provide an overview of modeling activities. To have these activities proceed as smoothly and effectively as possible requires not only a good and well-trained group of modelers but also managerial talents of a high order.

The manager of modeling activities is often a key person in a modeling effort. His activities, as well as those of the modeling group, will be facilitated by maintaining good documentation. Various documentation files have been described above which will probably be of considerable value in modeling projects. Then too, emphasis has been placed on spelling out as precisely as possible the objectives of a modeling project, since the objectives are important in providing orientation and guidance for the model builders. Further, considerable planning of sub-tasks in a modeling activity is needed in order to insure smooth progress and dovetailing of subprojects within inevitable budget, personnel, and time restrictions.

As regards evaluation of the final product, the model, various techniques including simulation experiments, statistical methods, and heuristic and theoretical checks have been mentioned. However, in the last analysis, the ultimate check is actual use and performance of a model in performing the tasks, e.g., forecasting, policy analysis, etc., for which it has been built. Simply put, the proof of the pudding is in the eating.

FOOTNOTES

[1] For a review of a collection of early models of national economies, see M. Nerlove, "A Tabular Survey of Macro-Econometric Models," *International Economic Review,* May 1966, 127–175. Chapter 4 of H. R. Hamilton, S. E. Goldstone, J. W. Milliman, A. L. Pugh III, E. R. Roberts, and A. Zellner, *Systems Simulation for Regional Analysis,* MIT Press, 1969, provides a review of a number of regional projection models. The recent economic literature contains papers dealing with the Brookings-SSRC and Federal Reserve-MIT econometric models of the U.S. economy.

[2] A discussion of mathematical models in the social sciences, with particular emphasis on economic models, appears in H. R. Hamilton, et. al., *op. cit.,* Chapter 2.

[3] See, e.g., D. B. Suits, "Forecasting and Analysis with an Econometric Model," *American Economic Review,* March 1962, 104–132, reprinted in A. Zellner (ed.), *Readings in Economic Statistics and Econometrics,* Little, Brown and Co., 1968, 583–611. Suits presents a comparison of actual forecasts of annual GNP and other items with actual outcomes for the period, 1953–1960.

[4] The description which follows is based on material in Ch. 13 of H. R. Hamilton et. al., *op. cit.*

[5] A discussion of these problems appears in H. R. Hamilton et. al., *op. cit.,* Appendix A, "The Management of a Multidisciplinary Research Project."

[6] See, e.g., J. Mincer (ed.), *Economic Forecasts and Expectations: Analysis of Forecasting Behavior and Performance,* National Bureau of Economic Research, Columbia University Press, 1969, and the references therein for analyses bearing on the appraisal of the forecasting performance of models.

[7] G. Fromm and P. J. Taubman, *Policy Simulations with an Econometric Model,* The Brookings Institution, North-Holland Publishing Company, 1968, presents a good discussion of policy simulations with references to the earlier literature.

[8] There are many unsolved problems in this area regarding the design and interpretation of simulation experiments. Thus simulation experimentation in connection with econometric models is still pretty much an art. See T. H. Naylor, J. L. Balintfy, D. S. Burdick, and K. Chu, *Computer Simulation Techniques,* John Wiley and Sons, Inc., 1968, for a useful discussion and references to the literature.

[9] The current econometrics texts provide some results (not as extensive as we would like) on this point. See, e.g., A. S. Goldberger, *Econometric Theory,* John Wiley and Sons, Inc., 1964; J. Johnston, *Econometric Methods,* McGraw-Hill Book Co., 1963, C. R. Christ, *Econometric Models and Methods,* John Wiley and Sons, Inc., 1966; E. Malinvaud, *Statistical Methods of Econometrics,* Rand McNally and Co., 1966 and the references cited in these works.

[10] Residual analysis for regression models has been studied fairly intensively. See, e.g., J. Putter, "Orthonormal Bases of Error Spaces and Their Use for Investigating the Normality and Variances of Residuals," *Journal of the American Statistical Association,* Sept. 1967, 1022–1036; J. B. Ramsey, "Tests for Specification Errors in Classical Linear Least-Squares Regression Analysis," *Journal of the Royal Statistical Society, B, 31,* No. 2, 1969, 350–371, and

references cited in these works. Procedures for systematic residual analysis in the context of "simultaneous equation" econometric models have not received much attention in the literature.

[11] See, e.g., G. E. P. Box and W. R. Hill, "Discrimination Among Mechanistic Models," *Technometrics,* February 1967, 57–71; H. Thornber, "Applications of Decision Theory to Econometrics," unpublished doctoral dissertation, U. of Chicago, 1966; and Ch. 10 in A. Zellner, *Bayesian Inference in Econometrics,* lecture notes to be published.

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The U.S. government's pyramiding investment in research and development in the 1950's invoked the law of supply and demand, say Dr. Herbert Hollomon (seated in photograph) and Alan Harger. The loser was American industry—unable or unwilling to compete. Can we now restore to research its true value and to American industry its tradition of technological innovation?

J. Herbert Hollomon
Consultant to the President and Provost of M.I.T.

Alan E. Harger
Administrative Assistant to Dr. Hollomon

America's Technological Dilemma

During these times of rapid change, of the increasing awareness of social problems, of declining trade balances, of inflation, and of unemployed scientists and engineers, thoughtful attention must be directed to the science and technology policy of the U.S. One important aspect of this policy has to do with the way in which technology is used by society, particularly how it affects civilian or industrial activity.

Many people have struggled to quantify the influence that new technology has upon industrial development, economic growth, and social advance. Qualitatively, the dependence of a modern economy on the use of new technology is accepted: technology becomes embodied in more effective production machinery, in more skilled labor, and in products and services that better serve social needs. The direct connections between research and development, and the resultant particular practical benefits, are more difficult to specify. However, it is these connections which must be understood if science policy (national or corporate) is to be effective.

In any attempt to assess the direct consequences of investment in research and development, it must be clearly established that the particular investment has been directed toward the purposes which are being considered. For example, suppose we are looking for the sources of general economic health in the nation; we must recognize that the research and development which have been aimed toward space flight and defense are unlikely to have had as significant an influence as an equivalent research and development activity directed toward, let's say, improvement in productive efficiency in the automotive industry.

Clearly, the effects of research and development on a nation as a whole cannot be understood without distinguishing among the various economic sectors. In the United States, for example, where most workers are engaged in service activities and most research and development is devoted to manufacturing, the overall rate of change in productivity cannot be expected to correlate with the amount of national civilian-oriented research and development.

Other factors influence the consequences of research and development. Most important is the delay, of almost indeterminate length, between an investment in research and development and the appearance of its results in the world. Some recent studies have indicated that this time delay has shortened, but even so, any major new technological development does not diffuse throughout the society in less than five to ten years.

In a recent analysis, Harvard's Richard B. Freeman has found (after taking the time delay into account as best he could) a good correlation between the growth rates and profitabilities of different industrial sectors and the research and development that were performed in those sectors in prior years (1). Figures 1, 2, and 3 illustrate

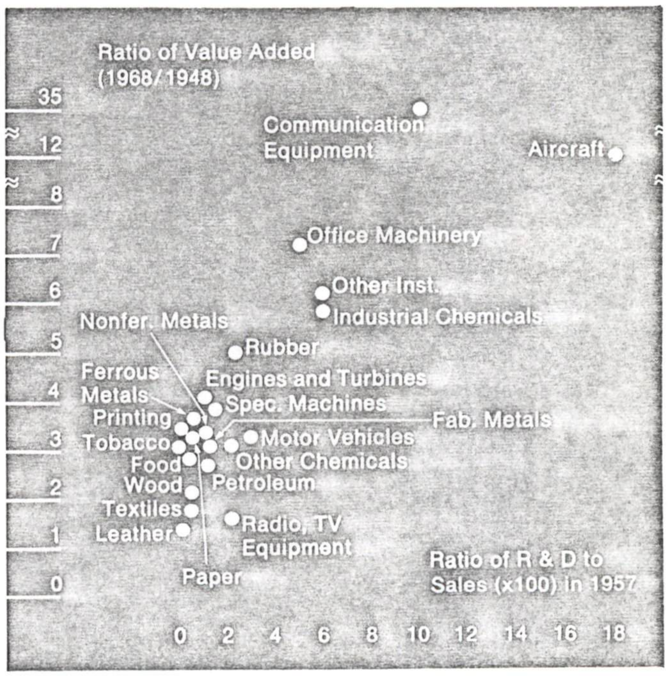
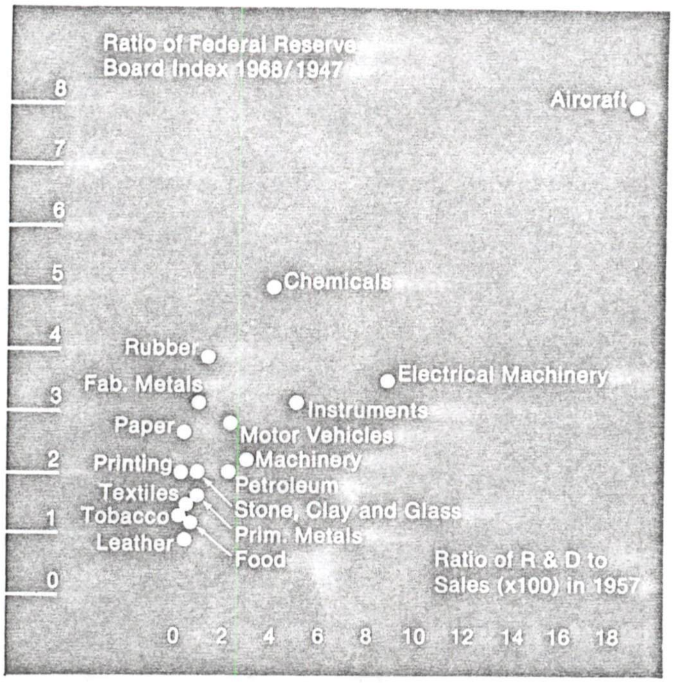


Figure 1. The gross association between research and development intensity and growth in output in various industries is shown here and in Figures 2 and 3 (on the following page). Research and development intensity is indexed by the ratio of R. and D. expenditures to sales. In Figure 1, increases in value added—a term denoting the difference between the value of a manufactured product and that of the starting materials—indicate output changes unadjusted for price increases.

Figure 2. The association between research and development intensity and growth in output in various industries (cont.): in this plot, output increases adjusted for price changes are measured by increases in the Federal Reserve Board Index of Production, and R. and D. intensity is indexed as in Figure 1.



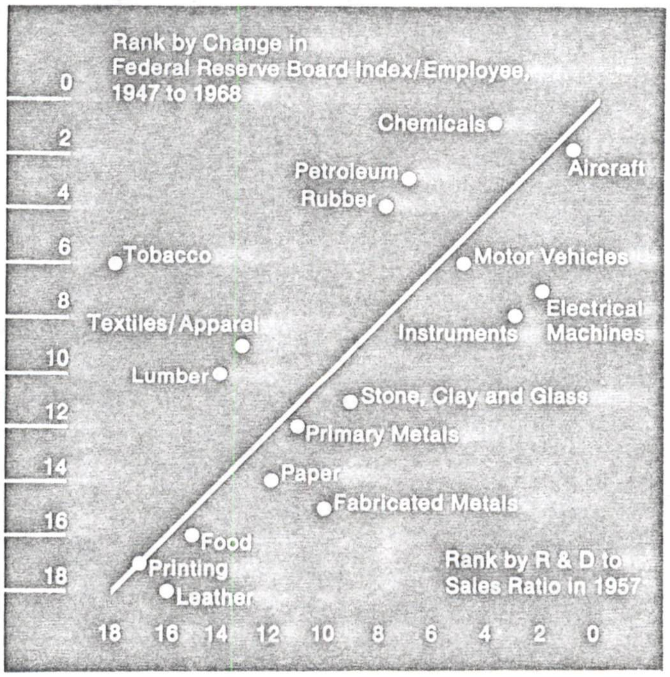


Figure 3. Changes in labor productivity are measured by the industries' indices of production (*see above*) divided by their number of employees. The rank-order relationship in this figure—like the relationships in Figures 1 and 2—indicates a positive and significant *correlation* between growth in industrial output and research and development intensity. (The three plots are after Freeman, ref. 1.)

the correlations. Professor William N. Leonard, of Hofstra, has shown that research and development spending by companies (excluding federal research and development) relates significantly to growth rate of sales, assets, and net income, in 16 industries which, combined, perform nearly all manufacturing activity (2).

Since World War II there have been many other analyses, both for particular industries and for the economy as a whole, that relate the effects of research and development to their economic consequences. It is clear that, for our type of national economy at least, industry under-invests in research and development relative to the total social return it generates in comparison with alternative investments. This under-investment arises because an individual firm cannot appropriate all of the benefits of any new technical development, but must bear most of the cost of that development. In other words, many of the results of a particular development are not of direct benefit to a firm, but indirectly affect other firms that use the results of the development. Furthermore, when a development is highly risky, a firm may forego investment in it because of the cost of failure, even though the rewards of the most probable outcome would fully justify the investment. Or to put the matter another way, individual firms will underinvest in order to minimize their risk, even though the expected rewards from investment in development, on an average basis for many firms, could be quite high. This situation becomes more serious the larger the initial development cost and the more radical the new technology. For instance, in the development of nuclear power the risk may be such that no firm exists with the capability of investing at the early stages of the technology. Only society as a whole can afford the risks or the uncertain costs resulting from technical uncertainty.

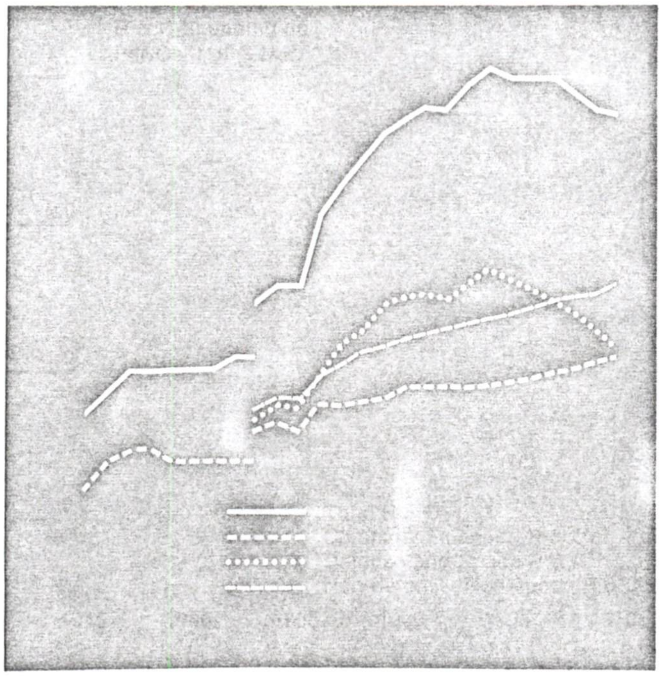
A summary of these studies of the effects of research and development, commissioned by the National Science Foundation (3) indicates that the contributions of research and development to economic growth and productivity, even with this under-investment, is positive, significant, and high.

Industry vs. Space and Defense

During and following World War II, the United States invested heavily in research and development, as illustrated in Figure 4. The most rapid increase occurred between 1953 and 1959, and resulted largely from increases in federal funding (Figure 5); since 1964 there has been a decrease in total effort relative to the G.N.P. It is clear that, as the federal government began to invest more and more in research and development, industry did not follow suit as rapidly; and that, conversely, as the federal government investment decreased, industrial investment in research and development tended to rise.

The recent growth of the U.S. research and development effort is less dramatic when measured, not in dollars, but in the number of the scientists and engineers involved (Figure 6). The costs of technical work have risen much more sharply than the general

Figure 4. Research and development spending in the U.S. since World War II. (Sources: 1945-1953 figures—Office of the Secretary of Defense, in the Census Bureau's *Statistical Abstract of the United States—1960,* Washington, 1960; 1953-1970 figures—National Science Foundation's *National Patterns of Research and Development Resources,* NSF 70-46, Washington, 1970)



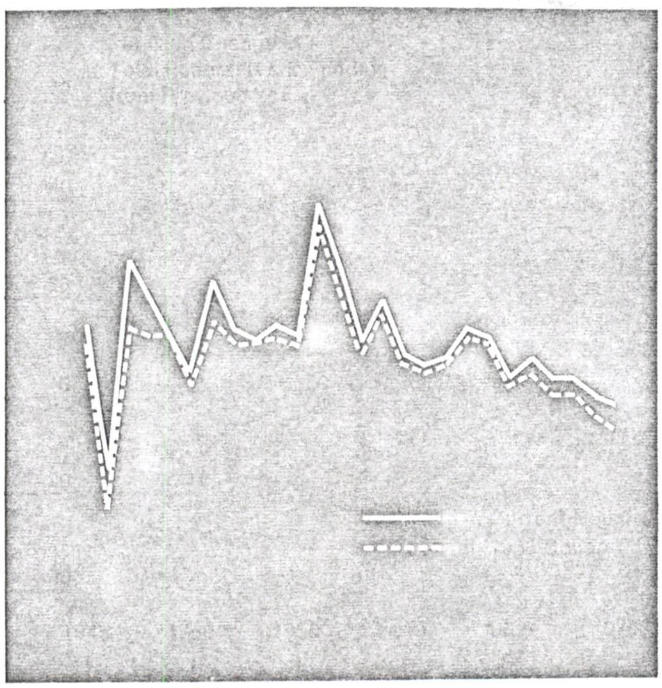
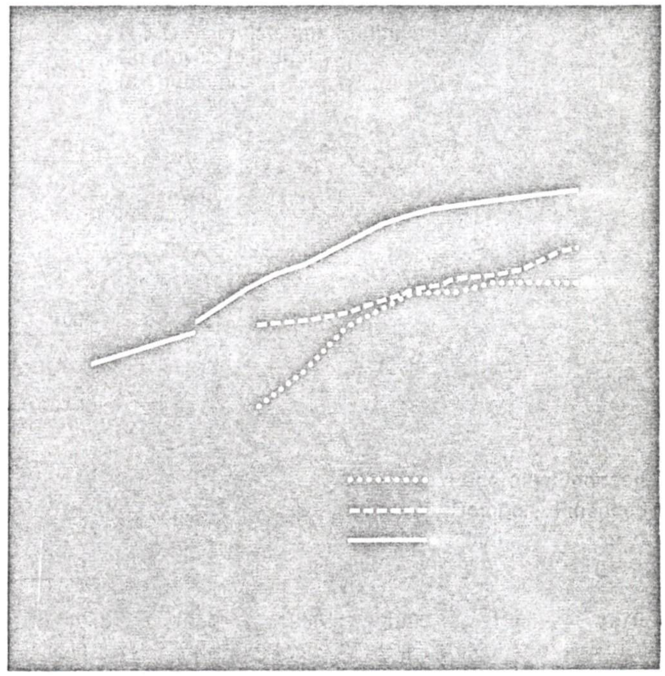


Figure 5. From the same data used in Figure 4, the year-to-year changes in total federal research and development support are shown. ("1958 dollars" were arrived at using the implicit G.N.P. deflator, since there is no specific R. and D. deflator available.)

Figure 6. Post-war growth of research and development in industry in terms of the number of scientists and engineers employed. The 1953-1961 company-federal estimates are by the authors, and 1962-1968 company-federal estimates are from the National Science Foundation. (Sources: 1945-1950 figures—Department of Defense, *The Growth of Scientific Research and Development,* Washington, 1953; 1950-1957—National Science Foundation (jointly with Bureau of Labor Statistics), *Employment of Scientists and Engineers in the United States, 1950-1965,* NSF 68-30, Washington, 1968; 1958-1968—National Science Foundation, *Research and Development in Industry—1968,* NSF 70-29, Washington, 1970.)



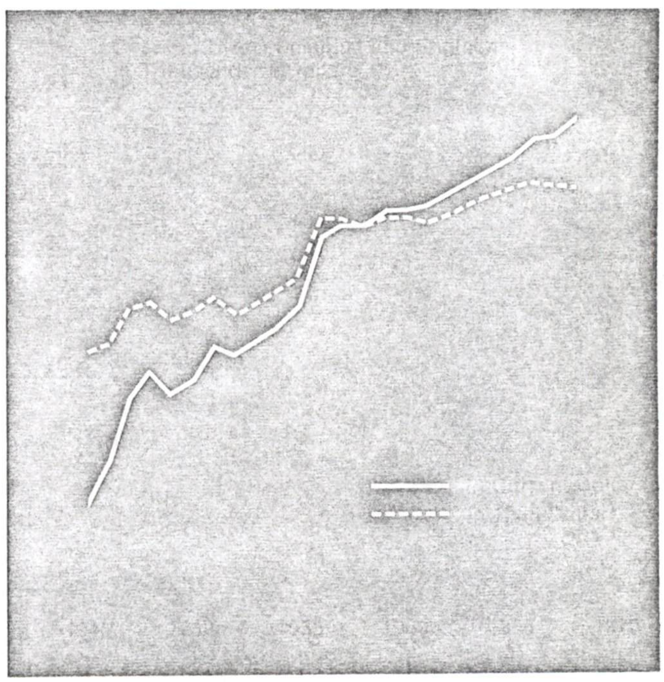
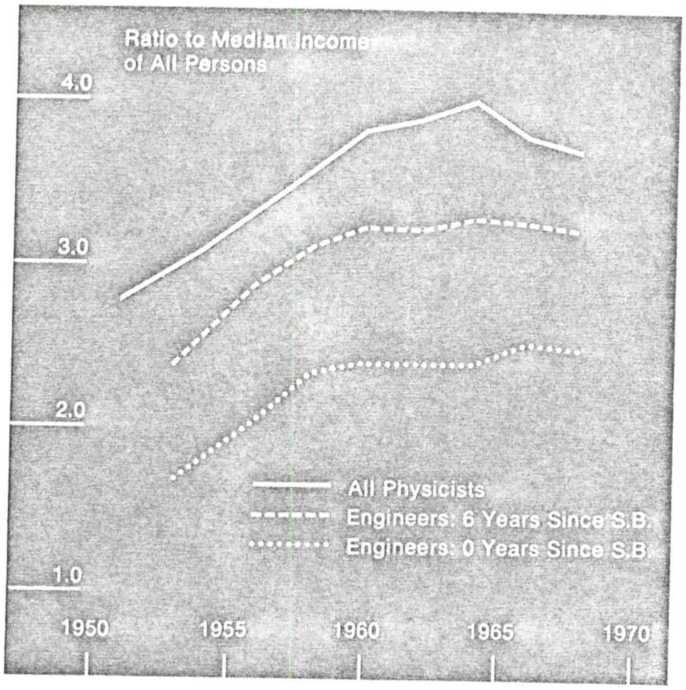


Figure 7. Increases in the cost of research and development per R. and D. scientist and engineer in industry coincide with the increases in federal support traced in Figure 5. (Sources: 1945-1952—Department of Defense; 1953-1956—National Science Foundation/Bureau of Labor Statistics; 1957-1968—National Science Foundation)

Figure 8. Salaries of physicists and engineers as a ratio of the median income of all persons. The rapid rises of the 1950's were a dominant contribution to the cost increases shown in Figure 7 (Sources: median income—Census Bureau's yearly *Current Population Reports, Series P-60 (Consumer Income)*, 1951-1968; engineers—Engineering Manpower Commission, *Professional Income of Engineers, 1970*, New York: Engineers' Joint Council, 1970; physicists—American Institute of Physics, *Physics Manpower—1966* and *Physics Manpower—1969*, Publications R-196 and R-220, based on data from the National Science Foundation's National Register)



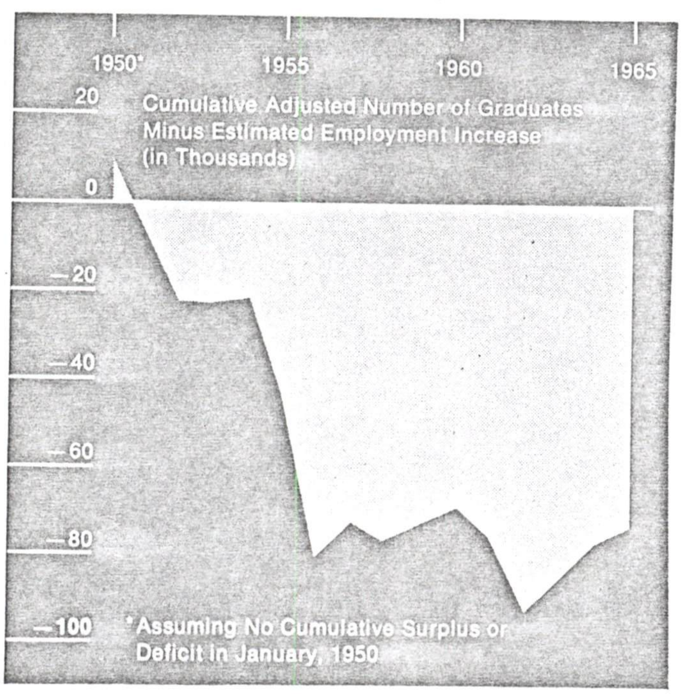


Figure 9. Between 1950 and 1965, nearly 100,000 more engineers were created (on the employment record) than became available as new graduates. This graph traces the cumulative progress of the appearance of "engineers" for whom no engineering degrees were awarded. (Sources: employment figures—National Science Foundation/Bureau of Labor Statistics; degrees—U.S. Office of Education *Digest of Educational Statistics*, OE-10024-70, Washington, 1970 edn.)

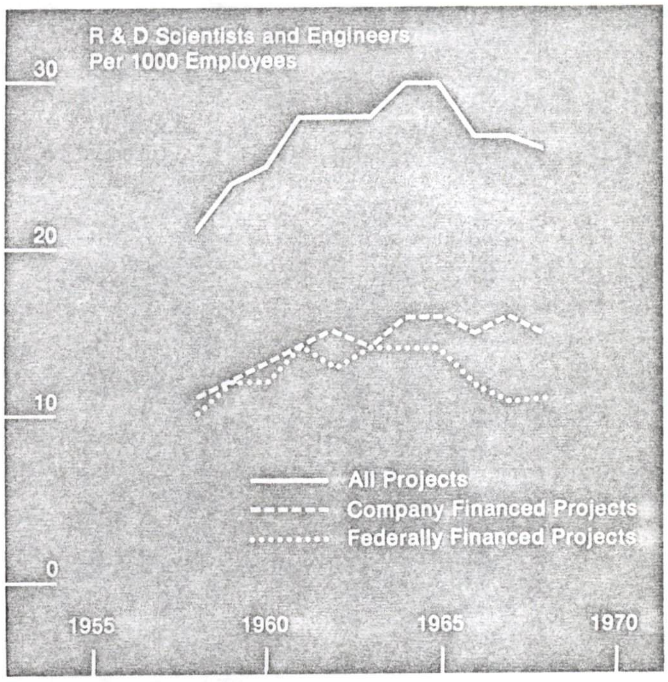
rates of inflation and of improvement in productivity. Indeed, the rapid growth of federal research and development has itself done much to raise the costs. The major increases illustrated in Figure 7 correspond to the increases in federal research and development support (Figure 5). A dominant source of the rise in costs was the increase in salaries of scientists and engineers relative to others (Figure 8).

During the period 1950 to 1960, the rapid increase in space and defense research and development increased the demand for new technical people (4). Apparently there was, within industry, a transfer of technical people from industrial to governmental projects. Because of this competition and the great increase in research and development support, salaries rose, and the cost of research and development, and probably of other technological activities, rose significantly.

Figure 9 illustrates a dramatic effect of this extraordinary demand. Between 1950 and 1965, nearly 100,000 more engineers were created than were available as graduates with engineering degrees. During these years, the increase in the number of engineers reported to be employed was substantially greater than the number of new engineers entering the labor force from higher education. Thus, it appears that industry must have been upgrading technicians to take the place of trained people who were transferred to federal programs. A related consequence of the rapid growth of research and development must have been a decrease in the average level of training, if not skill, of the remaining industrial engineers.

Since 1950, there has been an increase in industrial funding for research and development. However, its impact has been limited by rising costs. Figure 10 illustrates the year-by-year change in the number of R. & D. scientists and engineers per 1,000 employees in those companies performing research and development. Even these figures are somewhat inflated, for some of these scientists and engineers were no doubt engaged in research and development related to products sold for defense and space purposes. The figure illustrates that research and development for industrial purposes has remained about constant for nearly ten years.

Figure 10. For those companies reporting research and development activity, these curves show the number of R. & D. scientists and engineers employed per thousand employees. (Sources: 1958-1961—authors' estimates; 1962-1968—National Science Foundation)



Other factors have probably affected the industrial investment in technology. Interest rates have continually risen in the United States during this period, and, according to some economists at least, this has retarded capital investment. Not only is capital investment required in order to infuse new technology into the economy, but also large investment commitments in general tend to stimulate research and development. In addition, it is likely that the combination of high government demand and rapid obsolescence of technology in the space and defense fields attracted a disproportionate fraction of venture capital to these industries, and was an important contributing factor to the rising price of capital.

During the last several years, the decline of the federal effort has not been compensated for by the slight increase in industrial activity. The result has been unemployment of scientists and engineers, particularly those that were connected with space and defense. Crude estimates indicate the total unemployed to be of the order of 100,000.

To reiterate, the rapid and large growth of federally supported research and development, occurring particularly between 1953 and 1960, appears to have had several major effects on the technological activity of the United States and its industry. The most important effect of this growth was the rise in overall cost of research and development. This increase occurred not only in the costs of research and development to the government, but, very significantly, in the cost of this activity to industry. A major factor in this cost rise was the increased cost of the technical personnel engaged in it. The rise in the rank of starting engineers and scientists in the income distribution, relative to the rest of the population, dramatically illustrates this increase (Figure 11).

Starting salaries for engineers with bachelor degrees, for example, rose during the period of rapid research and development expansion from the 77th percentile in the rank of income of all people in the United States, to about the 86th percentile. During this same period, it is estimated by Freeman that about 20 to 30 per cent of the increased activity supported by the federal government was made possible by a transfer of people from industrially supported projects. The remaining increase was accomplished by absorbing the supply of new

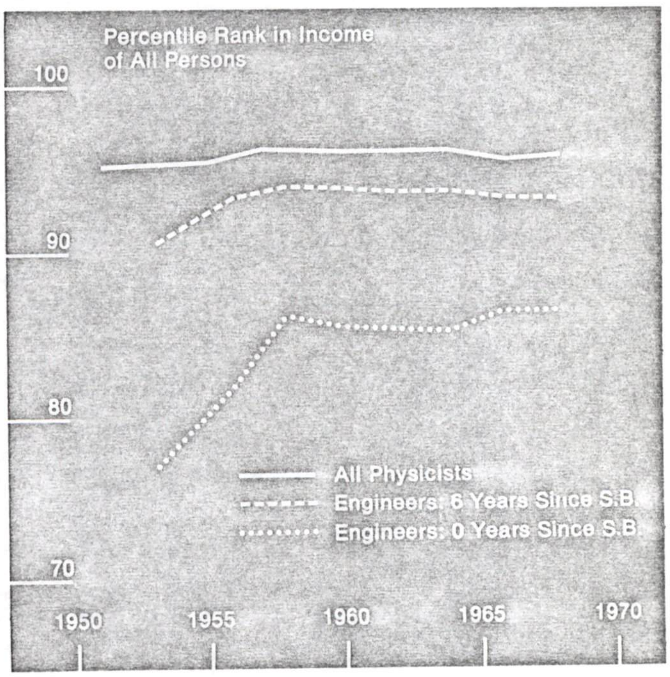


Figure 11. If incomes of all persons are arranged in a ranking order, any given income can be assigned a percentile position, indicating the percentage of the population having a lower income. Shown here are the percentile positions of median salaries earned by engineers and physicists. (Sources: as Figure 8)

Figure 12. Changes in salary within the engineering profession as a whole affect the number of students choosing engineering majors. This graph shows the success of a prediction of the proportion of all freshmen who choose engineering, made on the basis of engineering salaries, relative to other professional salaries, one year earlier. (Richard B. Freeman, *The Market for College-Trained Manpower,* Cambridge: Harvard University Press, 1971)

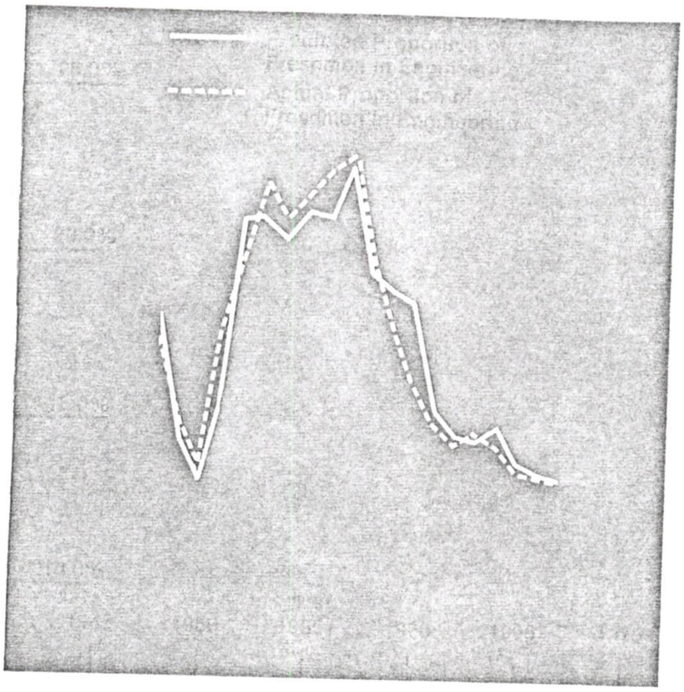


Table I. The combined fraction of male college graduates choosing science, mathematics and engineering has changed little since World War II, although the relative proportions of these fields have changed somewhat. (Hugh Folk, *The Shortage of Scientists and Engineers,* Lexington, Heath Lexington, 1970)

technical people.

University as Supplier

The increase in demand generated by federal funds had a significant effect on the choice made among fields by those attending universities. The fraction of college graduates opting for science, mathematics, and engineering has changed very little since World War II (Table I). Hugh Folk has pointed out that the choice of a broad field by students does not appear to be affected by demand, which influences only the choice of lucrative activities *within* broad fields. Changes in salaries and stipends affect the choices between specialties, and determine in part whether or not students opt for graduate education in special fields. However, though those in science and engineering have been mostly supported by federal funds to universities, the proportion of scientists and engineers among all PhD's has not increased appreciably. Apparently, the federal funds merely permitted the universities to redistribute their resources to a rapidly rising social demand for graduate education proportionately in all fields of knowledge. Changes in salaries and stipends affected choices toward engineering and toward physics, for example. Figure 12 illustrates the relationship between the actual number of freshman enrollments in engineering, year-by-year, and the changed incentives predicted from salary changes.

There has been some shift between engineering and mathematics, but, in any event, the response of the new supply of technical people to economic factors is sluggish and cyclical. The yearly new supply of graduate scientists, mathematicians, and engineers has varied from 33,000 to a high of 61,000. In recent years, this new supply has been about equal to the reported increase in new employment of scientists and engineers, implying little upgrading of people who did not have a "certificate" as scientists or engineers.

There has been great growth in the support of research in universities by the federal government, with by far the largest share derived from the support of biomedical research in university medical schools and affiliated hospitals. However, for the physical sciences, and especially engineering, the largest share has derived from the Defense Department, AEC, and NASA. This support surely biased university activity away from industrially related research, especially that connected with the less glamorous industrial problems.

The Practical Loss

While it is probably impossible to assess all the effects of federal policy over the past several decades, there are several possibilities that appear reasonable. It seems reasonable to expect that, ten years or so after a relative decline in technical activity, its consequences should begin to be evident. For example, the rate of increase in productivity might begin to diminish. Although the dependence of productivity upon a wide range of other factors (the availability of capital, for example) is well recognized, eventually a reduction in investment in technical activity devoted to industrial purposes should be reflected in a decreased rate of im-

Table II. Approximate proportions of national resources, at market prices, devoted to research and development. For the U.S. and European countries selected, the figures are averages for 1959-1965; for Japan, the figures are for 1963. The data appear to indicate a significant U.S. advantage in defense and space research and a rather lesser advantage in civilian-oriented work. (Sources: Japan—*International Statistical Year for Research and Development, A Study of Resources Devoted to R. and D. in O.E.C.D. Member Countries in 1963/64,* Vol. 2, O.E.C.D., Paris, 1968; other countries—Boretsky, ref. 6.)

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Table III. The same information as in Table II, for civilian-oriented work only, translated into cost-equivalent terms and into full-time-equivalent technical man power. The last column expresses each national civilian research and development effort (in cost-equivalent terms) as a proportion of that nation's G.N.P., also converted into cost-equivalent terms. A number of nations, on this basis, have been making more intensive research efforts during the early '60's, for civilian purposes, than has the U.S. (after Boretsky)

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provement in productivity. And, indeed, in the last few years, productivity increases have declined (5).

There is another way in which we can deduce the effects of the post-war research and development policies. Boretsky (6) has compared the technical activity of Europe and Japan with that of the United States for the period 1959-65 (just following the rapid growth of the United States effort). Table II compares the total research and development efforts for these years as fractions of national G.N.P.'s at market prices, for the United States, Japan and the major European countries. The defense and space portion of the total effort and the civilian effort are also included for comparison. Superficially at least, this table would indicate a significant advantage of the United States for all research and development, and a somewhat lesser advantage in its "civilian-oriented" activity.

However, when research and development efforts are translated into cost-equivalent terms, and into the number of scientists, engineers, and technicians employed (Table III), the results are startling. The last column in Table III expresses cost-equivalent expenditures for research and development as fractions of the G.N.P.'s, the latter converted to equal-purchasing-power terms. When the comparison is thus made on the basis of cost-equivalent expenditures, the relative advantage of the United States investment in civilian research and development disappears. Even more significant, about 30 to 35 per cent more scientists, engineers, and technicians were engaged in civilian-oriented research and development in the eight European countries studied than in the United States. This group of countries has a slightly greater population than the United States, but a one-third smaller G.N.P. When compared on this basis, the relative effort in Europe was substantially greater than that in the United States—the reason being, basically, that the relative cost of research and development personnel is less in Europe than in the United States.

Furthermore, there was no substantial investment in defense and space research and development in any of the European countries except the United Kingdom; there was not a disproportionate rise in salaries, and there was no marked displacement of scientists and engineers from industrial to national projects. Although European data for more recent years are not readily available, it seems likely that—in view of the slow growth of research activity in the United States relative to other O.E.C.D. countries in these years—the disparity is now even greater. As early as 1955, the number of scientists and engineers engaged in non-space, non-defense activity in Europe must have been higher than in the United States.

A comparison between Japan and the United States is even more depressing. During the 1959-65 period, the Japanese spent a significantly larger portion of their G.N.P., on an equivalency basis, for civilian research and development than did the United States. With one-half the United States population and one-fifth the United States G.N.P., Japan employed 70 per cent as many professional research and development personnel in their civilian effort as did the United States.

Spin-Off?

Many would argue that the analysis thus far has neglected the indirect effects of the space and defense research and development efforts of the United States. It is clear that the research and development that has been supported by the government must have been beneficial to at least some industrial activities. Further, the government provided a market for sophisticated technical goods, which no doubt stimulated research and development activities which were transferable to civilian products. But, granted that this indirect effect of space and defense oriented work presumably exists, the question is, how significant is it?

Boretsky analyzes this matter in what seems to be an effective way. Consider the efforts of ten people engaged in federal research and development; how much effort aimed at a particular industrial objective, on the average, are these ten equivalent to? Boretsky argues that their absolute maximum equivalent is 3-1/3, and the minimum is perhaps one-half a civilian researcher. In other words, 5 to 33 per cent of a given amount of space and defense research and development might be considered to be the "direct" effect of that effort on the economy.

Assuming a "spin-off" as high as 20 per cent (for both Europe and the United States) a new measure of the effective number of scientists and engineers can be derived. It turns out that the United States still lags

behind Europe and Japan on a comparative population basis. In the specific field of nuclear technology not related to military applications, Boretsky makes a more startling comparison. He estimates that 50 per cent more scientists, engineers, and technicians are involved in this work in Europe than in the United States.

This disparity in technical effort, existing for more than ten years, may have begun to be reflected in our trade with Europe and with Japan. Consider the trade balance in the technologically intensive products of chemicals, machinery, electrical equipment, transportation equipment and instruments. In 1968, the United States had a favorable balance of trade of these products with Europe of $1.5 billion. From 1962 to 1968, however, the rate of growth of imports of these products from Europe averaged 20 per cent, and the rate of growth in their export from the United States averaged only 9 per cent. During this same period, the United State's trade balance with Japan in these products turned from a $300 million surplus to a $500 million deficit. While United States imports from Japan were growing at 32 per cent a year, United States exports to Japan were increasing at only 7 per cent a year.

If the trend continues, Boretsky estimates that by 1973, in technologically intensive products alone, there will be a trade deficit with Europe of almost $2 billion. The situation with respect to Japan is even more disturbing: he estimates that the United States "technological" trade deficit to Japan will be almost $5 billion by 1973.

It is clear, of course, that monetary factors and relative labor cost factors are also important to trade balance considerations. It is only in high-technology products with rapid potential for growth (and in agriculture, where the U.S. has long maintained a technological lead) that the United States has had much of a potential advantage—and it is here (*except* in agriculture) that we find the downturn.

Clearly, analysis of a matter as complicated as the relationship between technology, the economy, and social welfare can never be complete, nor can conclusions drawn from incomplete analysis ever be taken with assurance. Nevertheless, it appears that in the United States we have substantially under-invested in the kinds of technical effort that are necessary for the improvement of our industrial output and the quality of our life. In recent years this under-investment in technology for civilian pursuits has been made substantially greater as a result of the large commitment of the United States to activities related to defense and space. The natural working of the economic system which would in any case have led the industry to invest too little in technical activities has been further distorted because of the higher cost of research and development resulting from the federal effort. Even in the government sector of research and development, all the European countries and Japan spend more than 20 per cent of government research and development for civilian purposes, whereas the United States spends less than 6 per cent. Thus our competitors supplement the industrial investment in research and development for civilian purposes to a much greater degree than do we.

The Choice of Strategies

We are now faced with a dilemma. There are 100,000 scientists and engineers out of work; there are large unsatisfied social needs; we are suffering adverse effects from our past uses of technology; and our economic growth is faltering. At the same time, the costs of education and of research and development continue to rise, sustained apparently by the social and political structure that we have set up.

Direct research and development investments by the federal government—whether for defense, space or social welfare purposes—will, if they are too large, draw off technical activity which could be turned to industrial improvement, just as we experienced in the 1950's. Substantial increases in the availability of new scientist and engineer graduates would eventually lower their relative prices, but there would be a period of costly and inhumane readjustment. On the other hand, restrictive policies to discourage young people either from opting for technical education or from continuing at university for advanced graduate education are, of course, in the long term, self-defeating.

Like any complex public problem, this dilemma will not be resolved by any single public policy decision. Addressing the social tasks directly, perhaps the most important single action that is required is a substantial

increase in support for the improvement, both in quality and efficiency, of those public services in which private industry plays only a small role, such as education and the delivery of health care. Likewise, those socially desirable activities in which private incentives for technical work are small or non-existent, such as the improvement of living conditions in the cities and of the safety of our transport system, require significantly increased support.

To simply spend enough to re-employ unemployed scientists and engineers by immediate federal research and development funding in these social fields, is not the answer, for we do not know enough about the task; nor would such a move (which would in any case face great social obstacles) encourage industry to play its own part. For the present, in these fields we must not only invest in research and development, but we must devise ways of changing the structure of the delivery systems of social services and of the education of technical people, to facilitate the adoption and diffusion of new techniques. A major effort of direct government support to meet these social needs is required.

A second major effort would be the encouragement of university research related to improving industrial productivity, to reducing the waste and pollution of industry, and generally to problems associated with the productivity, products, and adverse effects of industrial production. This federal support to universities would redress the present academic bias, especially in engineering, toward the kinds of work that tend to improve our defense and space capabilities.

In some way, also, government must underwrite industrial research and development itself, since the economy has always tended to under-invest in it, and its present over-costliness results from past federal policies. This can be done either directly by subsidy or indirectly through tax rebates. The entire set of corporate and government policies that encourage potentially high-export industries needs to be reviewed.

Whether a society effectively uses technology for productive and beneficial purposes depends upon a large number of factors. The supply of technically trained people, the willingness to invest in them, the capital necessary to embody the technology in useful machines and processes, the level of general education, the skill of the potential labor force, the economic and political structure of the society, all play roles. The effective use of technology requires that a large number of appropriate conditions be met simultaneously; a single missing ingredient (for example, the absence of available capital, or the necessary management attitudes) may completely halt either technological innovation or the spread of technology within the society.

If we are to meet the social needs of our time and to continue to provide the material needs of our population, new policies and directions of our governmental, industrial and academic institutions are required.

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J. Herbert Hollomon, currently serving as Consultant to the President and the Provost of M.I.T., was formerly President of the University of Oklahoma. Under President Kennedy he served as Assistant Secretary of Commerce for Science and Technology, and as Acting Undersecretary of Commerce under President Johnson, Dr. Hollomon is a graduate of M.I.T. (his doctorate is in metallurgy). He founded *Acta Metallurgica*, and co-authored, with L. Jaffee, *Ferrous Metallurgical Design*. He is a founding member of National Academy of Engineering, and is presently on the N.A.E.'s Committee for Transportation.

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The U.S. government's pyramiding investment in research and development in the 1950's invoked the law of supply and demand, say Dr. Herbert Hollomon (seated in photograph) and Alan Harger. The loser was American industry—unable or unwilling to compete. Can we now restore to research its true value and to American industry its tradition of technological innovation?

J. Herbert Hollomon
Consultant to the President and Provost of M.I.T.

Alan E. Harger
Administrative Assistant to Dr. Hollomon

America's Technological Dilemma

During these times of rapid change, of the increasing awareness of social problems, of declining trade balances, of inflation, and of unemployed scientists and engineers, thoughtful attention must be directed to the science and technology policy of the U.S. One important aspect of this policy has to do with the way in which technology is used by society, particularly how it affects civilian or industrial activity.

Many people have struggled to quantify the influence that new technology has upon industrial development, economic growth, and social advance. Qualitatively, the dependence of a modern economy on the use of new technology is accepted: technology becomes embodied in more effective production machinery, in more skilled labor, and in products and services that better serve social needs. The direct connections between research and development, and the resultant particular practical benefits, are more difficult to specify. However, it is these connections which must be understood if science policy (national or corporate) is to be effective.

In any attempt to assess the direct consequences of investment in research and development, it must be clearly established that the particular investment has been directed toward the purposes which are being considered. For example, suppose we are looking for the sources of general economic health in the nation; we must recognize that the research and development which have been aimed toward space flight and defense are unlikely to have had as significant an influence as an equivalent research and development activity directed toward, let's say, improvement in productive efficiency in the automotive industry.

Clearly, the effects of research and development on a nation as a whole cannot be understood without distinguishing among the various economic sectors. In the United States, for example, where most workers are engaged in service activities and most research and development is devoted to manufacturing, the overall rate of change in productivity cannot be expected to correlate with the amount of national civilian-oriented research and development.

Other factors influence the consequences of research and development. Most important is the delay, of almost indeterminate length, between an investment in research and development and the appearance of its results in the world. Some recent studies have indicated that this time delay has shortened, but even so, any major new technological development does not diffuse throughout the society in less than five to ten years.

In a recent analysis, Harvard's Richard B. Freeman has found (after taking the time delay into account as best he could) a good correlation between the growth rates and profitabilities of different industrial sectors and the research and development that were performed in those sectors in prior years (1). Figures 1, 2, and 3 illustrate

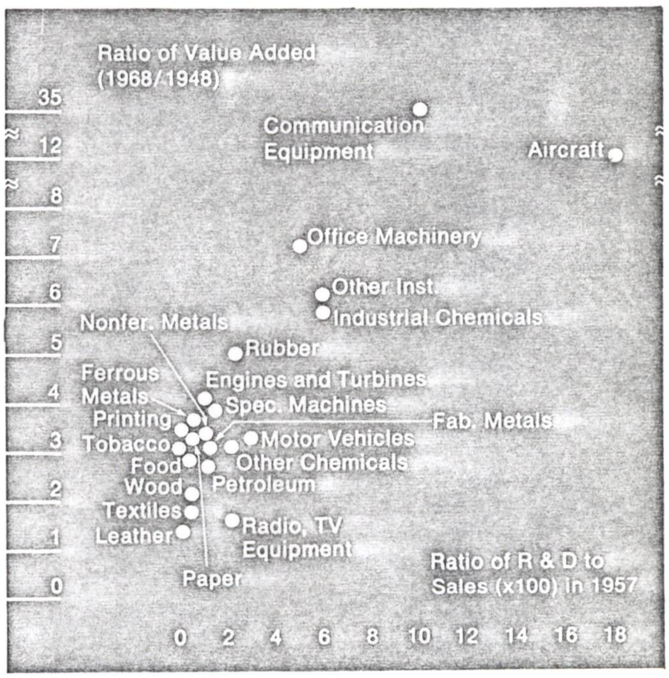
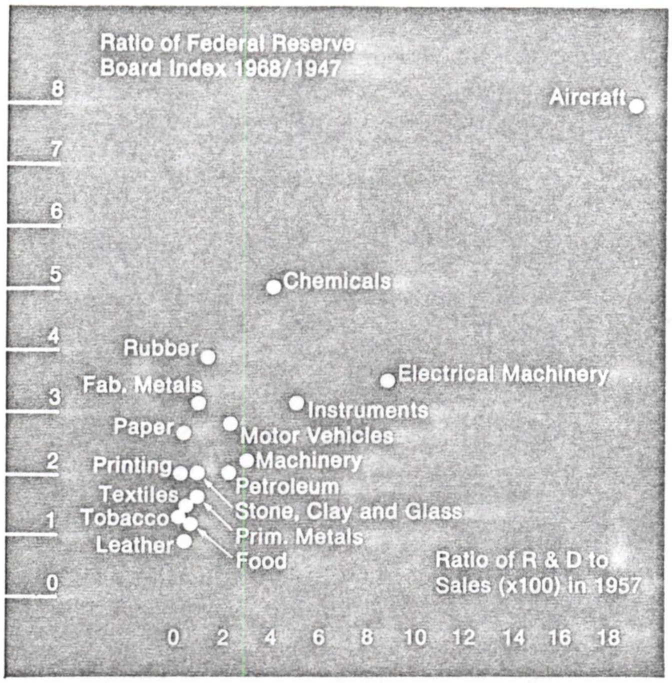


Figure 1. The gross association between research and development intensity and growth in output in various industries is shown here and in Figures 2 and 3 (on the following page). Research and development intensity is indexed by the ratio of R. and D. expenditures to sales. In Figure 1, increases in value added—a term denoting the difference between the value of a manufactured product and that of the starting materials—indicate output changes unadjusted for price increases.

Figure 2. The association between research and development intensity and growth in output in various industries (cont.): in this plot, output increases adjusted for price changes are measured by increases in the Federal Reserve Board Index of Production, and R. and D. intensity is indexed as in Figure 1.



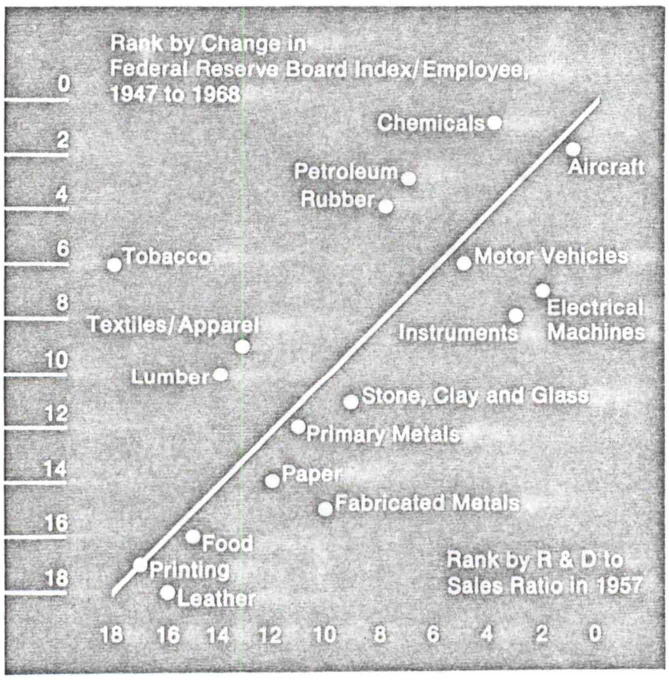


Figure 3. Changes in labor productivity are measured by the industries' indices of production (*see above*) divided by their number of employees. The rank-order relationship in this figure—like the relationships in Figures 1 and 2—indicates a positive and significant *correlation* between growth in industrial output and research and development intensity. (The three plots are after Freeman, ref. 1.)

the correlations. Professor William N. Leonard, of Hofstra, has shown that research and development spending by companies (excluding federal research and development) relates significantly to growth rate of sales, assets, and net income, in 16 industries which, combined, perform nearly all manufacturing activity (2).

Since World War II there have been many other analyses, both for particular industries and for the economy as a whole, that relate the effects of research and development to their economic consequences. It is clear that, for our type of national economy at least, industry under-invests in research and development relative to the total social return it generates in comparison with alternative investments. This under-investment arises because an individual firm cannot appropriate all of the benefits of any new technical development, but must bear most of the cost of that development. In other words, many of the results of a particular development are not of direct benefit to a firm, but indirectly affect other firms that use the results of the development. Furthermore, when a development is highly risky, a firm may forego investment in it because of the cost of failure, even though the rewards of the most probable outcome would fully justify the investment. Or to put the matter another way, individual firms will underinvest in order to minimize their risk, even though the expected rewards from investment in development, on an average basis for many firms, could be quite high. This situation becomes more serious the larger the initial development cost and the more radical the new technology. For instance, in the development of nuclear power the risk may be such that no firm exists with the capability of investing at the early stages of the technology. Only society as a whole can afford the risks or the uncertain costs resulting from technical uncertainty.

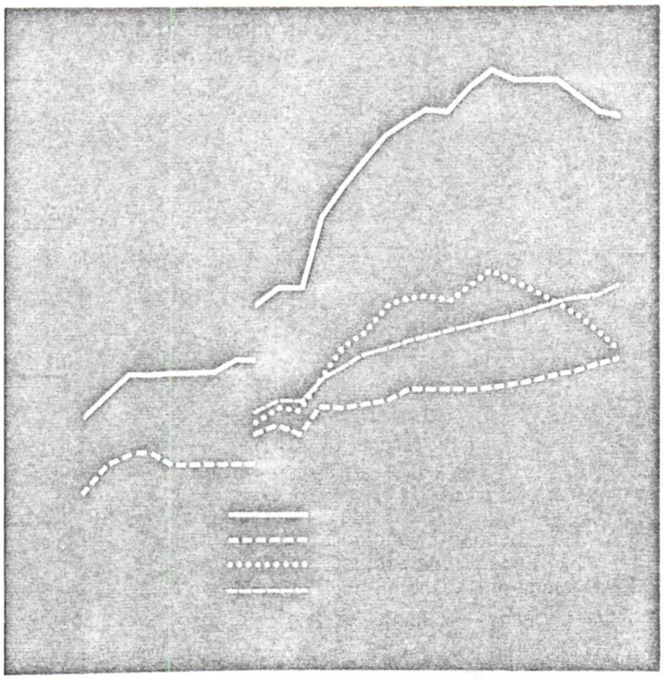
A summary of these studies of the effects of research and development, commissioned by the National Science Foundation (3) indicates that the contributions of research and development to economic growth and productivity, even with this under-investment, is positive, significant, and high.

Industry vs. Space and Defense

During and following World War II, the United States invested heavily in research and development, as illustrated in Figure 4. The most rapid increase occurred between 1953 and 1959, and resulted largely from increases in federal funding (Figure 5); since 1964 there has been a decrease in total effort relative to the G.N.P. It is clear that, as the federal government began to invest more and more in research and development, industry did not follow suit as rapidly; and that, conversely, as the federal government investment decreased, industrial investment in research and development tended to rise.

The recent growth of the U.S. research and development effort is less dramatic when measured, not in dollars, but in the number of the scientists and engineers involved (Figure 6). The costs of technical work have risen much more sharply than the general

Figure 4. Research and development spending in the U.S. since World War II. (Sources: 1945-1953 figures—Office of the Secretary of Defense, in the Census Bureau's *Statistical Abstract of the United States—1960*, Washington, 1960; 1953-1970 figures—National Science Foundation's *National Patterns of Research and Development Resources*, NSF 70-46, Washington, 1970)



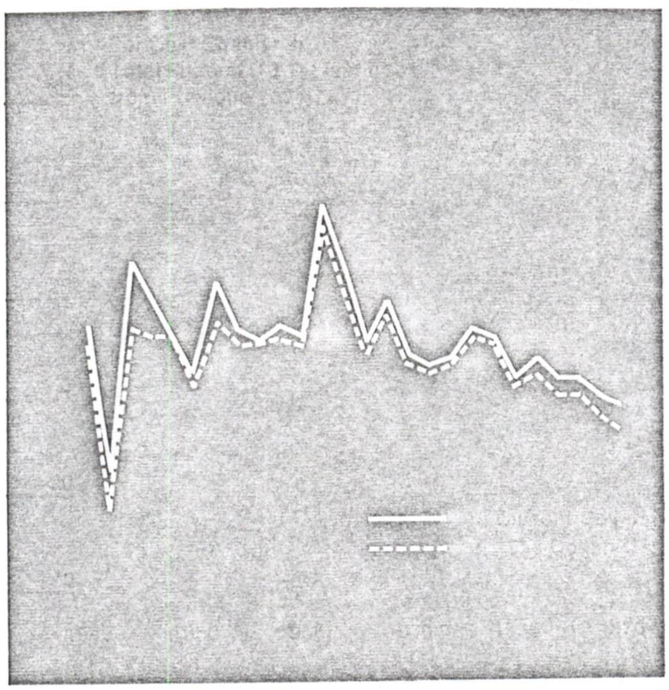
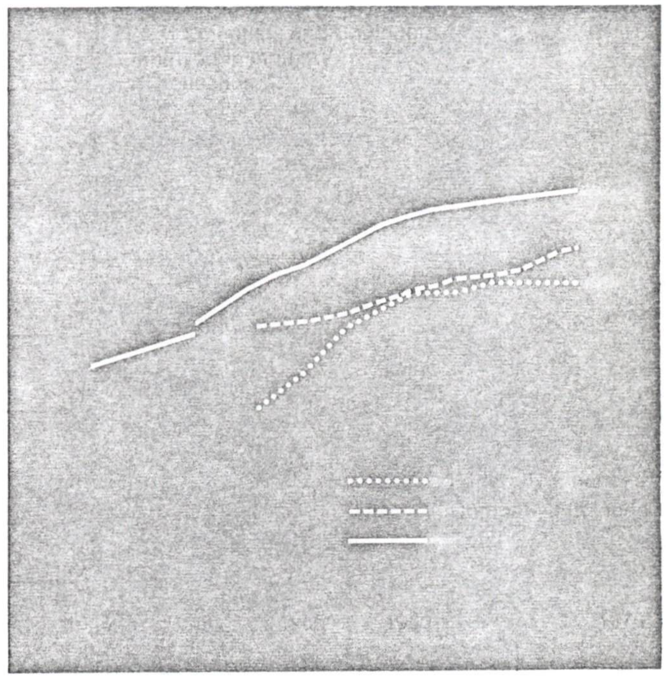


Figure 5. From the same data used in Figure 4, the year-to-year changes in total federal research and development support are shown. ("1958 dollars" were arrived at using the implicit G.N.P. deflator, since there is no specific R. and D. deflator available.)

Figure 6. Post-war growth of research and development in industry in terms of the number of scientists and engineers employed. The 1953-1961 company-federal estimates are by the authors, and 1962-1968 company-federal estimates are from the National Science Foundation. (Sources: 1945-1950 figures—Department of Defense, *The Growth of Scientific Research and Development*, Washington, 1953; 1950-1957—National Science Foundation (jointly with Bureau of Labor Statistics), *Employment of Scientists and Engineers in the United States, 1950-1965*, NSF 68-30, Washington, 1968; 1958-1968—National Science Foundation, *Research and Development in Industry—1968*, NSF 70-29, Washington, 1970.)



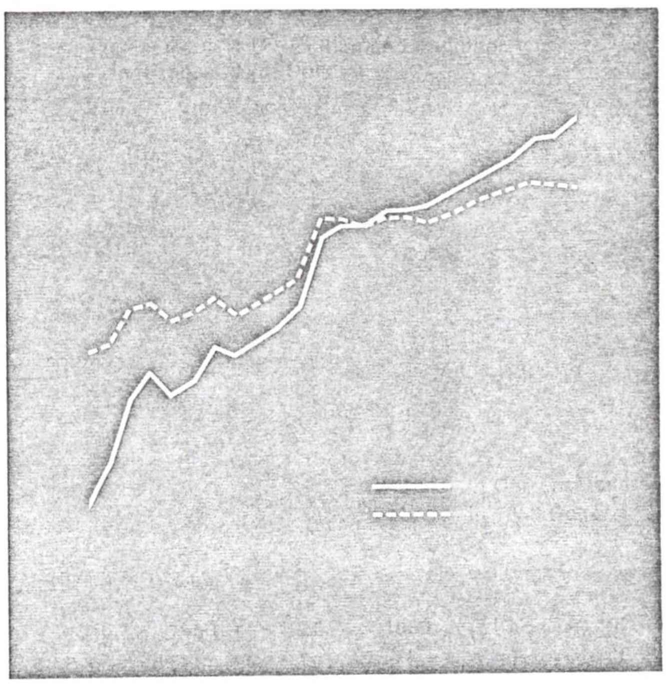
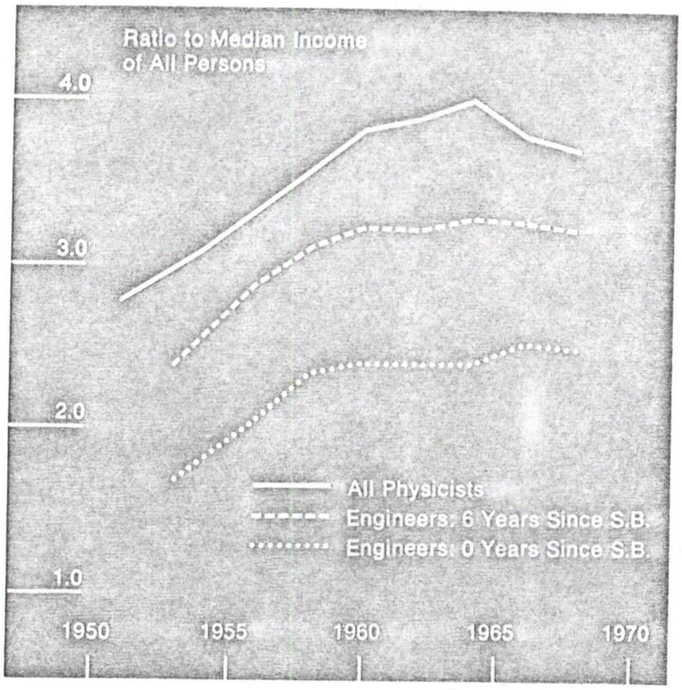


Figure 7. Increases in the cost of research and development per R. and D. scientist and engineer in industry coincide with the increases in federal support traced in Figure 5. (Sources: 1945-1952—Department of Defense; 1953-1956—National Science Foundation/Bureau of Labor Statistics; 1957-1968—National Science Foundation)

rates of inflation and of improvement in productivity. Indeed, the rapid growth of federal research and development has itself done much to raise the costs. The major increases illustrated in Figure 7 correspond to the increases in federal research and development support (Figure 5). A dominant source of the rise in costs was the increase in salaries of scientists and engineers relative to others (Figure 8).

Figure 8. Salaries of physicists and engineers as a ratio of the median income of all persons. The rapid rises of the 1950's were a dominant contribution to the cost increases shown in Figure 7 (Sources: median income—Census Bureau's yearly *Current Population Reports, Series P-60 (Consumer Income)*, 1951-1968; engineers—Engineering Manpower Commission, *Professional Income of Engineers, 1970*, New York: Engineers' Joint Council, 1970; physicists—American Institute of Physics, *Physics Manpower—1966* and *Physics Manpower—1969*, Publications R-196 and R-220, based on data from the National Science Foundation's National Register)



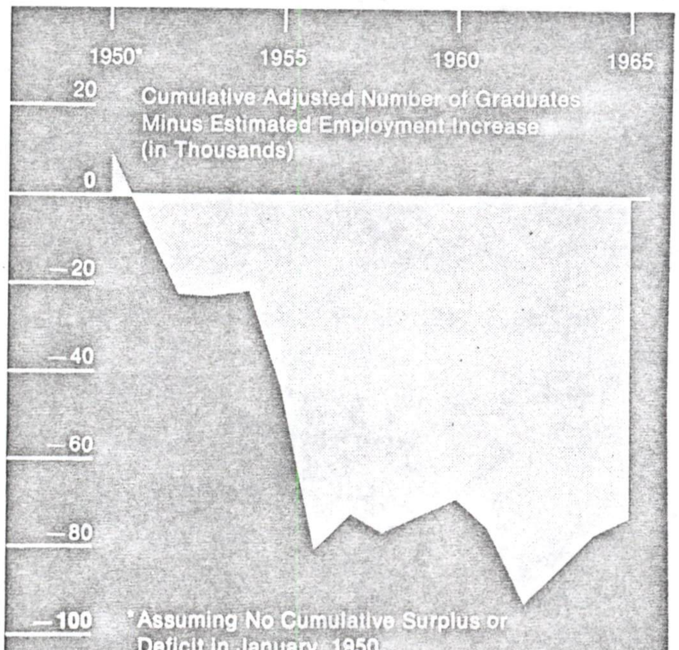


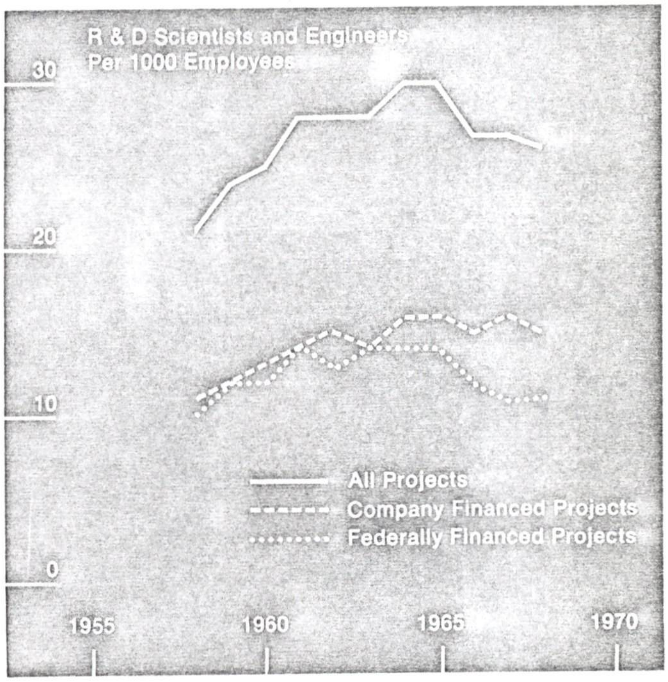
Figure 9. Between 1950 and 1965, nearly 100,000 more engineers were created (on the employment record) than became available as new graduates. This graph traces the cumulative progress of the appearance of "engineers" for whom no engineering degrees were awarded. (Sources: employment figures—National Science Foundation/Bureau of Labor Statistics; degrees—U.S. Office of Education *Digest of Educational Statistics*, OE-10024-70, Washington, 1970 edn.)

During the period 1950 to 1960, the rapid increase in space and defense research and development increased the demand for new technical people (4). Apparently there was, within industry, a transfer of technical people from industrial to governmental projects. Because of this competition and the great increase in research and development support, salaries rose, and the cost of research and development, and probably of other technological activities, rose significantly.

Figure 9 illustrates a dramatic effect of this extraordinary demand. Between 1950 and 1965, nearly 100,000 more engineers were created than were available as graduates with engineering degrees. During these years, the increase in the number of engineers reported to be employed was substantially greater than the number of new engineers entering the labor force from higher education. Thus, it appears that industry must have been upgrading technicians to take the place of trained people who were transferred to federal programs. A related consequence of the rapid growth of research and development must have been a decrease in the average level of training, if not skill, of the remaining industrial engineers.

Since 1950, there has been an increase in industrial funding for research and development. However, its impact has been limited by rising costs. Figure 10 illustrates the year-by-year change in the number of R. & D. scientists and engineers per 1,000 employees in those companies performing research and development. Even these figures are somewhat inflated, for some of these scientists and engineers were no doubt engaged in research and development related to products sold for defense and space purposes. The figure illustrates that research and development for industrial purposes has remained about constant for nearly ten years.

Figure 10. For those companies reporting research and development activity, these curves show the number of R. & D. scientists and engineers employed per thousand employees. (Sources: 1958-1961—authors' estimates; 1962-1968—National Science Foundation)



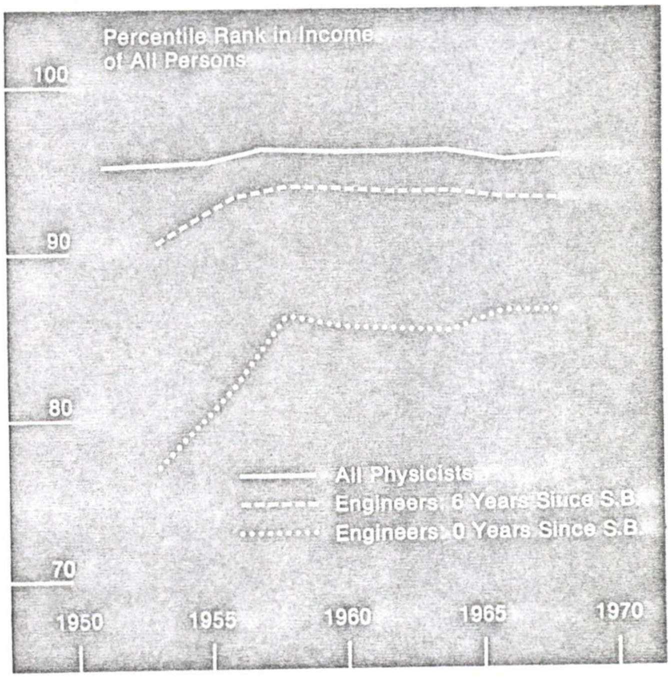


Figure 11. If incomes of all persons are arranged in a ranking order, any given income can be assigned a percentile position, indicating the percentage of the population having a lower income. Shown here are the percentile positions of median salaries earned by engineers and physicists. (Sources: as Figure 8)

Other factors have probably affected the industrial investment in technology. Interest rates have continually risen in the United States during this period, and, according to some economists at least, this has retarded capital investment. Not only is capital investment required in order to infuse new technology into the economy, but also large investment commitments in general tend to stimulate research and development. In addition, it is likely that the combination of high government demand and rapid obsolescence of technology in the space and defense fields attracted a disproportionate fraction of venture capital to these industries, and was an important contributing factor to the rising price of capital.

During the last several years, the decline of the federal effort has not been compensated for by the slight increase in industrial activity. The result has been unemployment of scientists and engineers, particularly those that were connected with space and defense. Crude estimates indicate the total unemployed to be of the order of 100,000.

To reiterate, the rapid and large growth of federally supported research and development, occurring particularly between 1953 and 1960, appears to have had several major effects on the technological activity of the United States and its industry. The most important effect of this growth was the rise in overall cost of research and development. This increase occurred not only in the costs of research and development to the government, but, very significantly, in the cost of this activity to industry. A major factor in this cost rise was the increased cost of the technical personnel engaged in it. The rise in the rank of starting engineers and scientists in the income distribution, relative to the rest of the population, dramatically illustrates this increase (Figure 11).

Starting salaries for engineers with bachelor degrees, for example, rose during the period of rapid research and development expansion from the 77th percentile in the rank of income of all people in the United States, to about the 86th percentile. During this same period, it is estimated by Freeman that about 20 to 30 per cent of the increased activity supported by the federal government was made possible by a transfer of people from industrially supported projects. The remaining increase was accomplished by absorbing the supply of new

Figure 12. Changes in salary within the engineering profession as a whole affect the number of students choosing engineering majors. This graph shows the success of a prediction of the proportion of all freshmen who choose engineering, made on the basis of engineering salaries, relative to other professional salaries, one year earlier. (Richard B. Freeman, *The Market for College-Trained Manpower*, Cambridge: Harvard University Press, 1971)

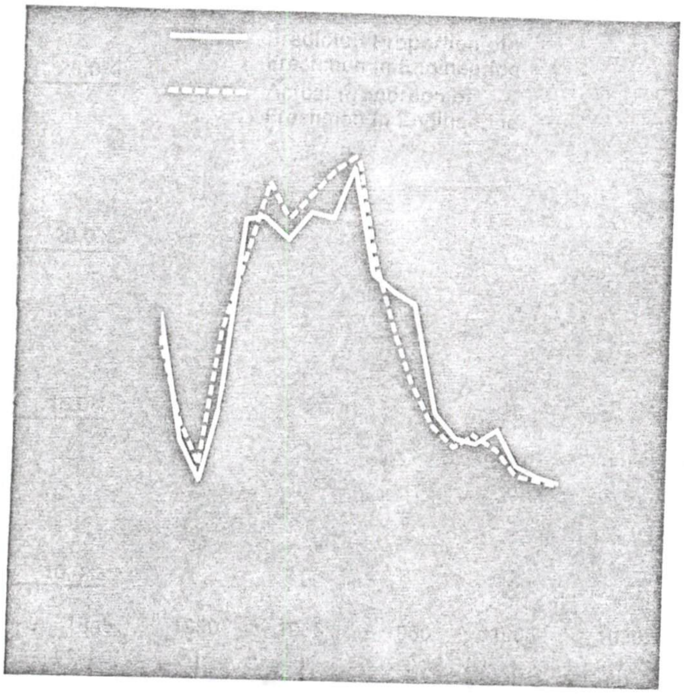


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Table I. The combined fraction of male college graduates choosing science, mathematics and engineering has changed little since World War II, although the relative proportions of these fields have changed somewhat. (Hugh Folk, *The Shortage of Scientists and Engineers*, Lexington, Heath Lexington, 1970)

technical people.

University as Supplier

The increase in demand generated by federal funds had a significant effect on the choice made among fields by those attending universities. The fraction of college graduates opting for science, mathematics, and engineering has changed very little since World War II (Table I). Hugh Folk has pointed out that the choice of a broad field by students does not appear to be affected by demand, which influences only the choice of lucrative activities *within* broad fields. Changes in salaries and stipends affect the choices between specialties, and determine in part whether or not students opt for graduate education in special fields. However, though those in science and engineering have been mostly supported by federal funds to universities, the proportion of scientists and engineers among all PhD's has not increased appreciably. Apparently, the federal funds merely permitted the universities to redistribute their resources to a rapidly rising social demand for graduate education proportionately in all fields of knowledge. Changes in salaries and stipends affected choices toward engineering and toward physics, for example. Figure 12 illustrates the relationship between the actual number of freshman enrollments in engineering, year-by-year, and the changed incentives predicted from salary changes.

There has been some shift between engineering and mathematics, but, in any event, the response of the new supply of technical people to economic factors is sluggish and cyclical. The yearly new supply of graduate scientists, mathematicians, and engineers has varied from 33,000 to a high of 61,000. In recent years, this new supply has been about equal to the reported increase in new employment of scientists and engineers, implying little upgrading of people who did not have a "certificate" as scientists or engineers.

There has been great growth in the support of research in universities by the federal government, with by far the largest share derived from the support of biomedical research in university medical schools and affiliated hospitals. However, for the physical sciences, and especially engineering, the largest share has derived from the Defense Department, AEC, and NASA. This support surely biased university activity away from industrially related research, especially that connected with the less glamorous industrial problems.

The Practical Loss

While it is probably impossible to assess all the effects of federal policy over the past several decades, there are several possibilities that appear reasonable. It seems reasonable to expect that, ten years or so after a relative decline in technical activity, its consequences should begin to be evident. For example, the rate of increase in productivity might begin to diminish. Although the dependence of productivity upon a wide range of other factors (the availability of capital, for example) is well recognized, eventually a reduction in investment in technical activity devoted to industrial purposes should be reflected in a decreased rate of im-

Table II. Approximate proportions of national resources, at market prices, devoted to research and development. For the U.S. and European countries selected, the figures are averages for 1959-1965; for Japan, the figures are for 1963. The data appear to indicate a significant U.S. advantage in defense and space research and a rather lesser advantage in civilian-oriented work. (Sources: Japan—*International Statistical Year for Research and Development, A Study of Resources Devoted to R. and D. in O.E.C.D. Member Countries in 1963/64*, Vol. 2, O.E.C.D., Paris, 1968; other countries—Boretsky, ref. 6.)

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Table III. The same information as in Table II, for civilian-oriented work only, translated into cost-equivalent terms and into full-time-equivalent technical man power. The last column expresses each national civilian research and development effort (in cost-equivalent terms) as a proportion of that nation's G.N.P., also converted into cost-equivalent terms. A number of nations, on this basis, have been making more intensive research efforts during the early '60's, for civilian purposes, than has the U.S. (after Boretsky)

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provement in productivity. And, indeed, in the last few years, productivity increases have declined (5).

There is another way in which we can deduce the effects of the post-war research and development policies. Boretsky (6) has compared the technical activity of Europe and Japan with that of the United States for the period 1959-65 (just following the rapid growth of the United States effort). Table II compares the total research and development efforts for these years as fractions of national G.N.P.'s at market prices, for the United States, Japan and the major European countries. The defense and space portion of the total effort and the civilian effort are also included for comparison. Superficially at least, this table would indicate a significant advantage of the United States for all research and development, and a somewhat lesser advantage in its "civilian-oriented" activity.

However, when research and development efforts are translated into cost-equivalent terms, and into the number of scientists, engineers, and technicians employed (Table III), the results are startling. The last column in Table III expresses cost-equivalent expenditures for research and development as fractions of the G.N.P.'s, the latter converted to equal-purchasing-power terms. When the comparison is thus made on the basis of cost-equivalent expenditures, the relative advantage of the United States investment in civilian research and development disappears. Even more significant, about 30 to 35 per cent more scientists, engineers, and technicians were engaged in civilian-oriented research and development in the eight European countries studied than in the United States. This group of countries has a slightly greater population than the United States, but a one-third smaller G.N.P. When compared on this basis, the relative effort in Europe was substantially greater than that in the United States—the reason being, basically, that the relative cost of research and development personnel is less in Europe than in the United States.

Furthermore, there was no substantial investment in defense and space research and development in any of the European countries except the United Kingdom; there was not a disproportionate rise in salaries, and there was no marked displacement of scientists and engineers from industrial to national projects. Although European data for more recent years are not readily available, it seems likely that—in view of the slow growth of research activity in the United States relative to other O.E.C.D. countries in these years—the disparity is now even greater. As early as 1955, the number of scientists and engineers engaged in non-space, non-defense activity in Europe must have been higher than in the United States.

A comparison between Japan and the United States is even more depressing. During the 1959-65 period, the Japanese spent a significantly larger portion of their G.N.P., on an equivalency basis, for civilian research and development than did the United States. With one-half the United States population and one-fifth the United States G.N.P., Japan employed 70 per cent as many professional research and development personnel in their civilian effort as did the United States.

Spin-Off?

Many would argue that the analysis thus far has neglected the indirect effects of the space and defense research and development efforts of the United States. It is clear that the research and development that has been supported by the government must have been beneficial to at least some industrial activities. Further, the government provided a market for sophisticated technical goods, which no doubt stimulated research and development activities which were transferable to civilian products. But, granted that this indirect effect of space and defense oriented work presumably exists, the question is, how significant is it?

Boretsky analyzes this matter in what seems to be an effective way. Consider the efforts of ten people engaged in federal research and development; how much effort aimed at a particular industrial objective, on the average, are these ten equivalent to? Boretsky argues that their absolute maximum equivalent is 3-1/3, and the minimum is perhaps one-half a civilian researcher. In other words, 5 to 33 per cent of a given amount of space and defense research and development might be considered to be the "direct" effect of that effort on the economy.

Assuming a "spin-off" as high as 20 per cent (for both Europe and the United States) a new measure of the effective number of scientists and engineers can be derived. It turns out that the United States still lags

behind Europe and Japan on a comparative population basis. In the specific field of nuclear technology not related to military applications, Boretsky makes a more startling comparison. He estimates that 50 per cent more scientists, engineers, and technicians are involved in this work in Europe than in the United States.

This disparity in technical effort, existing for more than ten years, may have begun to be reflected in our trade with Europe and with Japan. Consider the trade balance in the technologically intensive products of chemicals, machinery, electrical equipment, transportation equipment and instruments. In 1968, the United States had a favorable balance of trade of these products with Europe of $1.5 billion. From 1962 to 1968, however, the rate of growth of imports of these products from Europe averaged 20 per cent, and the rate of growth in their export from the United States averaged only 9 per cent. During this same period, the United State's trade balance with Japan in these products turned from a $300 million surplus to a $500 million deficit. While United States imports from Japan were growing at 32 per cent a year, United States exports to Japan were increasing at only 7 per cent a year.

If the trend continues, Boretsky estimates that by 1973, in technologically intensive products alone, there will be a trade deficit with Europe of almost $2 billion. The situation with respect to Japan is even more disturbing: he estimates that the United States "technological" trade deficit to Japan will be almost $5 billion by 1973.

It is clear, of course, that monetary factors and relative labor cost factors are also important to trade balance considerations. It is only in high-technology products with rapid potential for growth (and in agriculture, where the U.S. has long maintained a technological lead) that the United States has had much of a potential advantage—and it is here (*except* in agriculture) that we find the downturn.

Clearly, analysis of a matter as complicated as the relationship between technology, the economy, and social welfare can never be complete, nor can conclusions drawn from incomplete analysis ever be taken with assurance. Nevertheless, it appears that in the United States we have substantially under-invested in the kinds of technical effort that are necessary for the improvement of our industrial output and the quality of our life. In recent years this under-investment in technology for civilian pursuits has been made substantially greater as a result of the large commitment of the United States to activities related to defense and space. The natural working of the economic system which would in any case have led the industry to invest too little in technical activities has been further distorted because of the higher cost of research and development resulting from the federal effort. Even in the government sector of research and development, all the European countries and Japan spend more than 20 per cent of government research and development for civilian purposes, whereas the United States spends less than 6 per cent. Thus our competitors supplement the industrial investment in research and development for civilian purposes to a much greater degree than do we.

The Choice of Strategies

We are now faced with a dilemma. There are 100,000 scientists and engineers out of work; there are large unsatisfied social needs; we are suffering adverse effects from our past uses of technology; and our economic growth is faltering. At the same time, the costs of education and of research and development continue to rise, sustained apparently by the social and political structure that we have set up.

Direct research and development investments by the federal government—whether for defense, space or social welfare purposes—will, if they are too large, draw off technical activity which could be turned to industrial improvement, just as we experienced in the 1950's. Substantial increases in the availability of new scientist and engineer graduates would eventually lower their relative prices, but there would be a period of costly and inhumane readjustment. On the other hand, restrictive policies to discourage young people either from opting for technical education or from continuing at university for advanced graduate education are, of course, in the long term, self-defeating.

Like any complex public problem, this dilemma will not be resolved by any single public policy decision. Addressing the social tasks directly, perhaps the most important single action that is required is a substantial

increase in support for the improvement, both in quality and efficiency, of those public services in which private industry plays only a small role, such as education and the delivery of health care. Likewise, those socially desirable activities in which private incentives for technical work are small or non-existent, such as the improvement of living conditions in the cities and of the safety of our transport system, require significantly increased support.

To simply spend enough to re-employ unemployed scientists and engineers by immediate federal research and development funding in these social fields, is not the answer, for we do not know enough about the task; nor would such a move (which would in any case face great social obstacles) encourage industry to play its own part. For the present, in these fields we must not only invest in research and development, but we must devise ways of changing the structure of the delivery systems of social services and of the education of technical people, to facilitate the adoption and diffusion of new techniques. A major effort of direct government support to meet these social needs is required.

A second major effort would be the encouragement of university research related to improving industrial productivity, to reducing the waste and pollution of industry, and generally to problems associated with the productivity, products, and adverse effects of industrial production. This federal support to universities would redress the present academic bias, especially in engineering, toward the kinds of work that tend to improve our defense and space capabilities.

In some way, also, government must underwrite industrial research and development itself, since the economy has always tended to under-invest in it, and its present over-costliness results from past federal policies. This can be done either directly by subsidy or indirectly through tax rebates. The entire set of corporate and government policies that encourage potentially high-export industries needs to be reviewed.

Whether a society effectively uses technology for productive and beneficial purposes depends upon a large number of factors. The supply of technically trained people, the willingness to invest in them, the capital necessary to embody the technology in useful machines and processes, the level of general education, the skill of the potential labor force, the economic and political structure of the society, all play roles. The effective use of technology requires that a large number of appropriate conditions be met simultaneously; a single missing ingredient (for example, the absence of available capital, or the necessary management attitudes) may completely halt either technological innovation or the spread of technology within the society.

If we are to meet the social needs of our time and to continue to provide the material needs of our population, new policies and directions of our governmental, industrial and academic institutions are required.

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The U.S. government's pyramiding investment in research and development in the 1950's invoked the law of supply and demand, say Dr. Herbert Hollomon (seated in photograph) and Alan Harger. The loser was American industry—unable or unwilling to compete. Can we now restore to research its true value and to American industry its tradition of technological innovation?

J. Herbert Hollomon
Consultant to the President and Provost of M.I.T.

Alan E. Harger
Administrative Assistant to Dr. Hollomon

America's Technological Dilemma

During these times of rapid change, of the increasing awareness of social problems, of declining trade balances, of inflation, and of unemployed scientists and engineers, thoughtful attention must be directed to the science and technology policy of the U.S. One important aspect of this policy has to do with the way in which technology is used by society, particularly how it affects civilian or industrial activity.

Many people have struggled to quantify the influence that new technology has upon industrial development, economic growth, and social advance. Qualitatively, the dependence of a modern economy on the use of new technology is accepted: technology becomes embodied in more effective production machinery, in more skilled labor, and in products and services that better serve social needs. The direct connections between research and development, and the resultant particular practical benefits, are more difficult to specify. However, it is these connections which must be understood if science policy (national or corporate) is to be effective.

In any attempt to assess the direct consequences of investment in research and development, it must be clearly established that the particular investment has been directed toward the purposes which are being considered. For example, suppose we are looking for the sources of general economic health in the nation; we must recognize that the research and development which have been aimed toward space flight and defense are unlikely to have had as significant an influence as an equivalent research and development activity directed toward, let's say, improvement in productive efficiency in the automotive industry.

Clearly, the effects of research and development on a nation as a whole cannot be understood without distinguishing among the various economic sectors. In the United States, for example, where most workers are engaged in service activities and most research and development is devoted to manufacturing, the overall rate of change in productivity cannot be expected to correlate with the amount of national civilian-oriented research and development.

Other factors influence the consequences of research and development. Most important is the delay, of almost indeterminate length, between an investment in research and development and the appearance of its results in the world. Some recent studies have indicated that this time delay has shortened, but even so, any major new technological development does not diffuse throughout the society in less than five to ten years.

In a recent analysis, Harvard's Richard B. Freeman has found (after taking the time delay into account as best he could) a good correlation between the growth rates and profitabilities of different industrial sectors and the research and development that were performed in those sectors in prior years (1). Figures 1, 2, and 3 illustrate

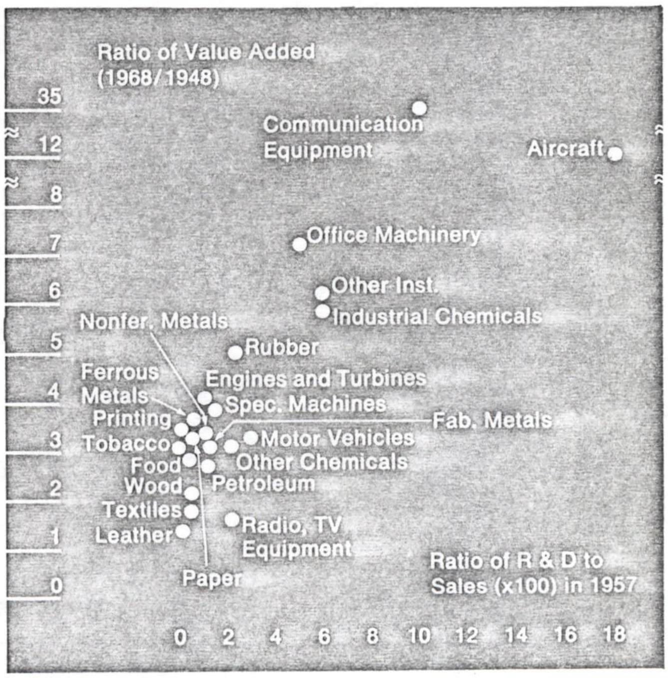
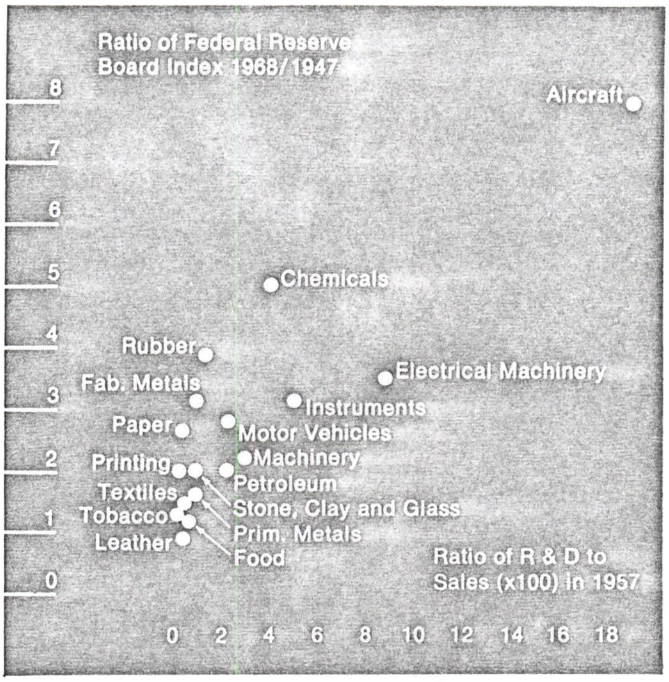


Figure 1. The gross association between research and development intensity and growth in output in various industries is shown here and in Figures 2 and 3 (on the following page). Research and development intensity is indexed by the ratio of R. and D. expenditures to sales. In Figure 1, increases in value added—a term denoting the difference between the value of a manufactured product and that of the starting materials—indicate output changes unadjusted for price increases.

Figure 2. The association between research and development intensity and growth in output in various industries (cont.): in this plot, output increases adjusted for price changes are measured by increases in the Federal Reserve Board Index of Production, and R. and D. intensity is indexed as in Figure 1.



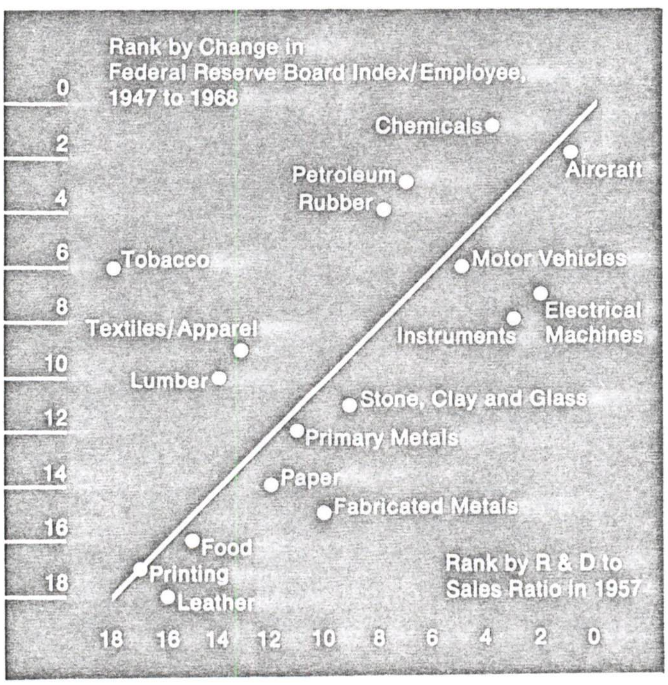


Figure 3. Changes in labor productivity are measured by the industries' indices of production (*see above*) divided by their number of employees. The rank-order relationship in this figure—like the relationships in Figures 1 and 2—indicates a positive and significant *correlation* between growth in industrial output and research and development intensity. (The three plots are after Freeman, ref. 1.)

the correlations. Professor William N. Leonard, of Hofstra, has shown that research and development spending by companies (excluding federal research and development) relates significantly to growth rate of sales, assets, and net income, in 16 industries which, combined, perform nearly all manufacturing activity (2).

Since World War II there have been many other analyses, both for particular industries and for the economy as a whole, that relate the effects of research and development to their economic consequences. It is clear that, for our type of national economy at least, industry under-invests in research and development relative to the total social return it generates in comparison with alternative investments. This under-investment arises because an individual firm cannot appropriate all of the benefits of any new technical development, but must bear most of the cost of that development. In other words, many of the results of a particular development are not of direct benefit to a firm, but indirectly affect other firms that use the results of the development. Furthermore, when a development is highly risky, a firm may forego investment in it because of the cost of failure, even though the rewards of the most probable outcome would fully justify the investment. Or to put the matter another way, individual firms will underinvest in order to minimize their risk, even though the expected rewards from investment in development, on an average basis for many firms, could be quite high. This situation becomes more serious the larger the initial development cost and the more radical the new technology. For instance, in the development of nuclear power the risk may be such that no firm exists with the capability of investing at the early stages of the technology. Only society as a whole can afford the risks or the uncertain costs resulting from technical uncertainty.

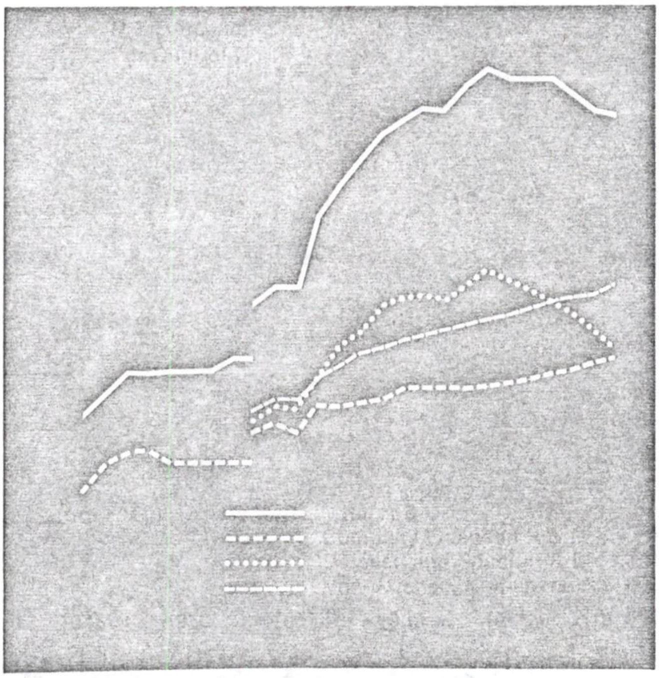
A summary of these studies of the effects of research and development, commissioned by the National Science Foundation (3) indicates that the contributions of research and development to economic growth and productivity, even with this under-investment, is positive, significant, and high.

Industry vs. Space and Defense

During and following World War II, the United States invested heavily in research and development, as illustrated in Figure 4. The most rapid increase occurred between 1953 and 1959, and resulted largely from increases in federal funding (Figure 5); since 1964 there has been a decrease in total effort relative to the G.N.P. It is clear that, as the federal government began to invest more and more in research and development, industry did not follow suit as rapidly; and that, conversely, as the federal government investment decreased, industrial investment in research and development tended to rise.

The recent growth of the U.S. research and development effort is less dramatic when measured, not in dollars, but in the number of the scientists and engineers involved (Figure 6). The costs of technical work have risen much more sharply than the general

Figure 4. Research and development spending in the U.S. since World War II. (Sources: 1945-1953 figures—Office of the Secretary of Defense, in the Census Bureau's *Statistical Abstract of the United States—1960,* Washington, 1960; 1953-1970 figures—National Science Foundation's *National Patterns of Research and Development Resources,* NSF 70-46, Washington, 1970)



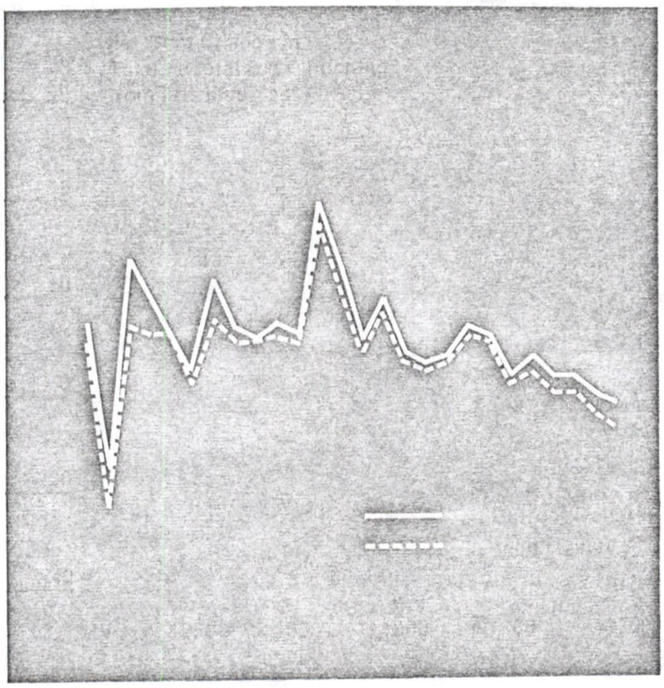
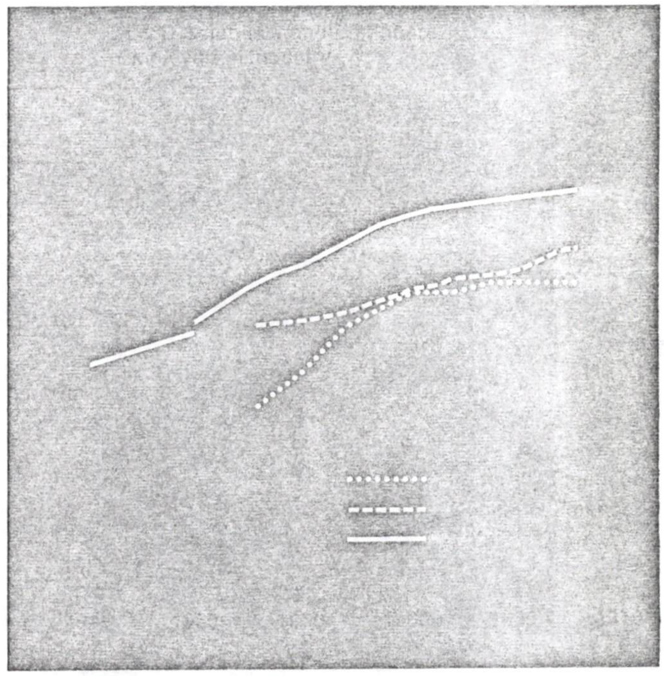


Figure 5. From the same data used in Figure 4, the year-to-year changes in total federal research and development support are shown. ("1958 dollars" were arrived at using the implicit G.N.P. deflator, since there is no specific R. and D. deflator available.)

Figure 6. Post-war growth of research and development in industry in terms of the number of scientists and engineers employed. The 1953-1961 company-federal estimates are by the authors, and 1962-1968 company-federal estimates are from the National Science Foundation. (Sources: 1945-1950 figures—Department of Defense, *The Growth of Scientific Research and Development,* Washington, 1953; 1950-1957—National Science Foundation (jointly with Bureau of Labor Statistics), *Employment of Scientists and Engineers in the United States, 1950-1965,* NSF 68-30, Washington, 1968; 1958-1968—National Science Foundation, *Research and Development in Industry—1968,* NSF 70-29, Washington, 1970.)



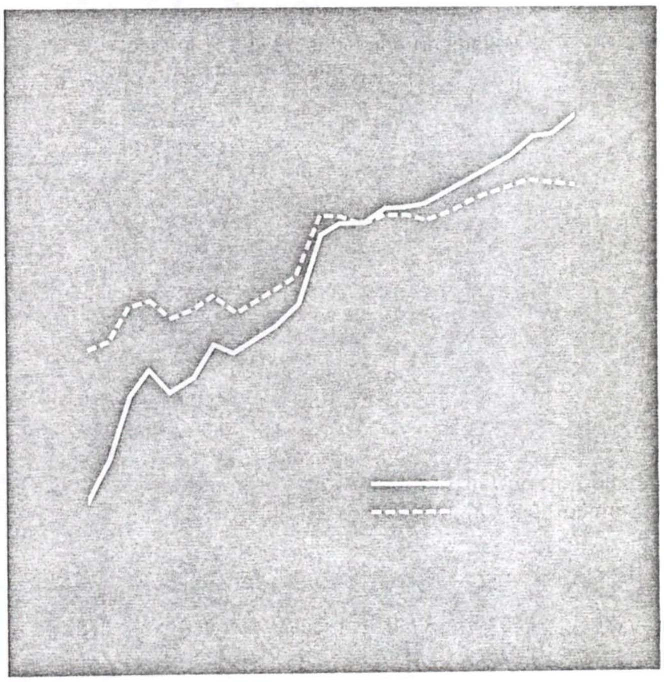
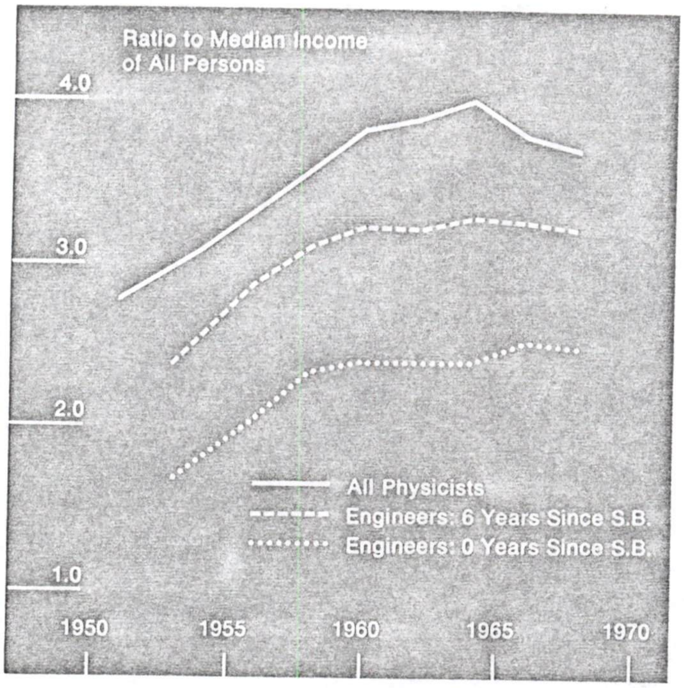


Figure 7. Increases in the cost of research and development per R. and D. scientist and engineer in industry coincide with the increases in federal support traced in Figure 5. (Sources: 1945-1952—Department of Defense; 1953-1956—National Science Foundation/Bureau of Labor Statistics; 1957-1968—National Science Foundation)

Figure 8. Salaries of physicists and engineers as a ratio of the median income of all persons. The rapid rises of the 1950's were a dominant contribution to the cost increases shown in Figure 7 (Sources: median income—Census Bureau's yearly *Current Population Reports, Series P-60 (Consumer Income)*, 1951-1968; engineers—Engineering Manpower Commission, *Professional Income of Engineers, 1970*, New York: Engineers' Joint Council, 1970; physicists—American Institute of Physics, *Physics Manpower—1966* and *Physics Manpower—1969*, Publications R-196 and R-220, based on data from the National Science Foundation's National Register)



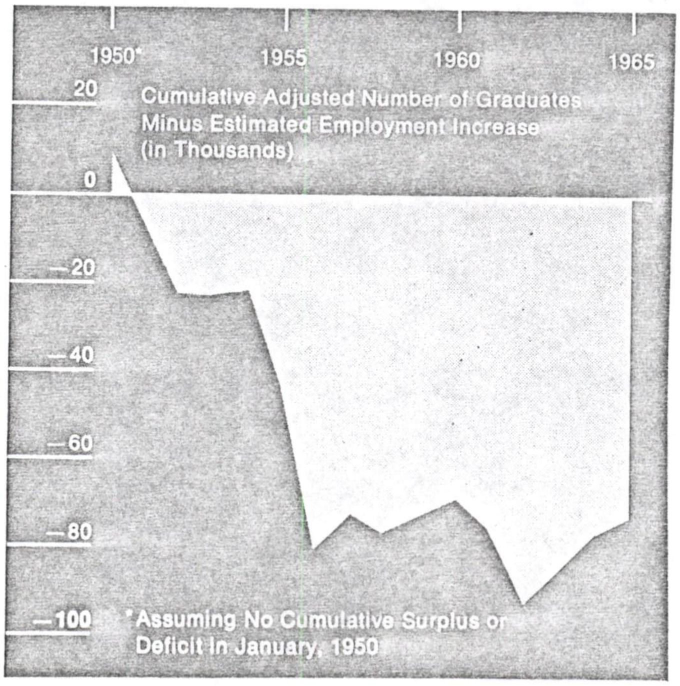


Figure 9. Between 1950 and 1965, nearly 100,000 more engineers were created (on the employment record) than became available as new graduates. This graph traces the cumulative progress of the appearance of "engineers" for whom no engineering degrees were awarded. (Sources: employment figures—National Science Foundation/Bureau of Labor Statistics; degrees—U.S. Office of Education *Digest of Educational Statistics*, OE-10024-70, Washington, 1970 edn.)

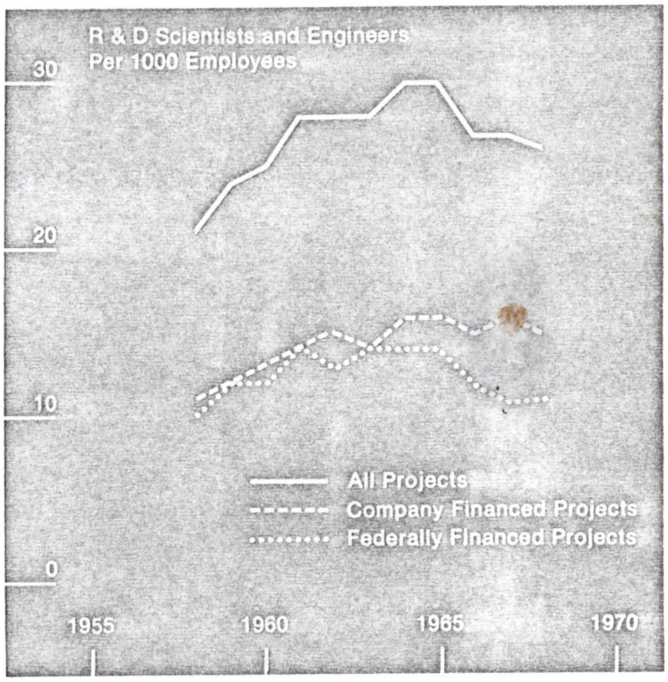
rates of inflation and of improvement in productivity. Indeed, the rapid growth of federal research and development has itself done much to raise the costs. The major increases illustrated in Figure 7 correspond to the increases in federal research and development support (Figure 5). A dominant source of the rise in costs was the increase in salaries of scientists and engineers relative to others (Figure 8).

During the period 1950 to 1960, the rapid increase in space and defense research and development increased the demand for new technical people (4). Apparently there was, within industry, a transfer of technical people from industrial to governmental projects. Because of this competition and the great increase in research and development support, salaries rose, and the cost of research and development, and probably of other technological activities, rose significantly.

Figure 9 illustrates a dramatic effect of this extraordinary demand. Between 1950 and 1965, nearly 100,000 more engineers were created than were available as graduates with engineering degrees. During these years, the increase in the number of engineers reported to be employed was substantially greater than the number of new engineers entering the labor force from higher education. Thus, it appears that industry must have been upgrading technicians to take the place of trained people who were transferred to federal programs. A related consequence of the rapid growth of research and development must have been a decrease in the average level of training, if not skill, of the remaining industrial engineers.

Since 1950, there has been an increase in industrial funding for research and development. However, its impact has been limited by rising costs. Figure 10 illustrates the year-by-year change in the number of R. & D. scientists and engineers per 1,000 employees in those companies performing research and development. Even these figures are somewhat inflated, for some of these scientists and engineers were no doubt engaged in research and development related to products sold for defense and space purposes. The figure illustrates that research and development for industrial purposes has remained about constant for nearly ten years.

Figure 10. For those companies reporting research and development activity, these curves show the number of R. & D. scientists and engineers employed per thousand employees. (Sources: 1958-1961—authors' estimates; 1962-1968—National Science Foundation)



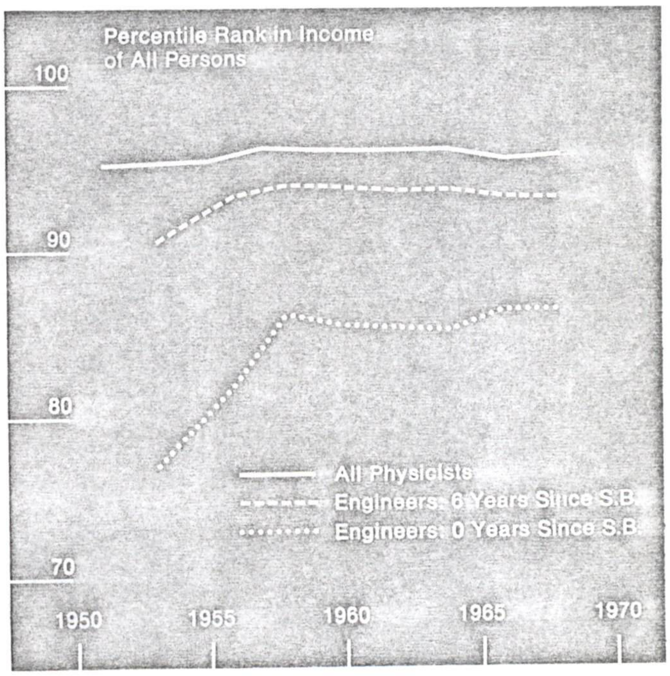


Figure 11. If incomes of all persons are arranged in a ranking order, any given income can be assigned a percentile position, indicating the percentage of the population having a lower income. Shown here are the percentile positions of median salaries earned by engineers and physicists. (Sources: as Figure 8)

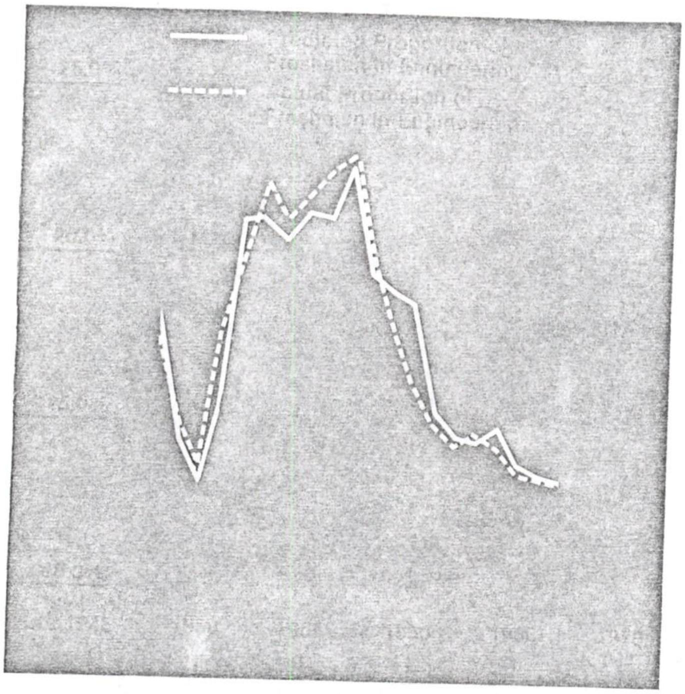
Other factors have probably affected the industrial investment in technology. Interest rates have continually risen in the United States during this period, and, according to some economists at least, this has retarded capital investment. Not only is capital investment required in order to infuse new technology into the economy, but also large investment commitments in general tend to stimulate research and development. In addition, it is likely that the combination of high government demand and rapid obsolescence of technology in the space and defense fields attracted a disproportionate fraction of venture capital to these industries, and was an important contributing factor to the rising price of capital.

During the last several years, the decline of the federal effort has not been compensated for by the slight increase in industrial activity. The result has been unemployment of scientists and engineers, particularly those that were connected with space and defense. Crude estimates indicate the total unemployed to be of the order of 100,000.

To reiterate, the rapid and large growth of federally supported research and development, occurring particularly between 1953 and 1960, appears to have had several major effects on the technological activity of the United States and its industry. The most important effect of this growth was the rise in overall cost of research and development. This increase occurred not only in the costs of research and development to the government, but, very significantly, in the cost of this activity to industry. A major factor in this cost rise was the increased cost of the technical personnel engaged in it. The rise in the rank of starting engineers and scientists in the income distribution, relative to the rest of the population, dramatically illustrates this increase (Figure 11).

Starting salaries for engineers with bachelor degrees, for example, rose during the period of rapid research and development expansion from the 77th percentile in the rank of income of all people in the United States, to about the 86th percentile. During this same period, it is estimated by Freeman that about 20 to 30 per cent of the increased activity supported by the federal government was made possible by a transfer of people from industrially supported projects. The remaining increase was accomplished by absorbing the supply of new

Figure 12. Changes in salary within the engineering profession as a whole affect the number of students choosing engineering majors. This graph shows the success of a prediction of the proportion of all freshmen who choose engineering, made on the basis of engineering salaries, relative to other professional salaries, one year earlier. (Richard B. Freeman, *The Market for College-Trained Manpower*, Cambridge: Harvard University Press, 1971)



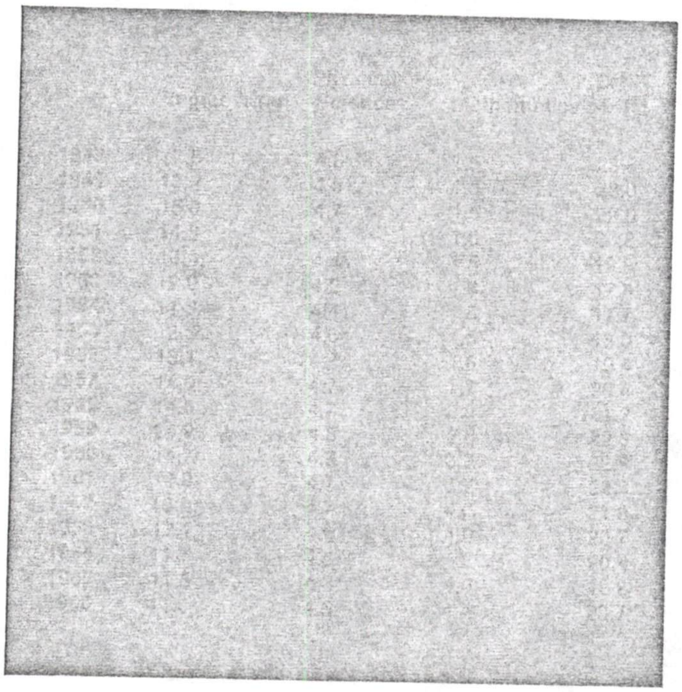


Table I. The combined fraction of male college graduates choosing science, mathematics and engineering has changed little since World War II, although the relative proportions of these fields have changed somewhat. (Hugh Folk, *The Shortage of Scientists and Engineers*, Lexington, Heath Lexington, 1970)

technical people.

University as Supplier

The increase in demand generated by federal funds had a significant effect on the choice made among fields by those attending universities. The fraction of college graduates opting for science, mathematics, and engineering has changed very little since World War II (Table I). Hugh Folk has pointed out that the choice of a broad field by students does not appear to be affected by demand, which influences only the choice of lucrative activities *within* broad fields. Changes in salaries and stipends affect the choices between specialties, and determine in part whether or not students opt for graduate education in special fields. However, though those in science and engineering have been mostly supported by federal funds to universities, the proportion of scientists and engineers among all PhD's has not increased appreciably. Apparently, the federal funds merely permitted the universities to redistribute their resources to a rapidly rising social demand for graduate education proportionately in all fields of knowledge. Changes in salaries and stipends affected choices toward engineering and toward physics, for example. Figure 12 illustrates the relationship between the actual number of freshman enrollments in engineering, year-by-year, and the changed incentives predicted from salary changes.

There has been some shift between engineering and mathematics, but, in any event, the response of the new supply of technical people to economic factors is sluggish and cyclical. The yearly new supply of graduate scientists, mathematicians, and engineers has varied from 33,000 to a high of 61,000. In recent years, this new supply has been about equal to the reported increase in new employment of scientists and engineers, implying little upgrading of people who did not have a "certificate" as scientists or engineers.

There has been great growth in the support of research in universities by the federal government, with by far the largest share derived from the support of biomedical research in university medical schools and affiliated hospitals. However, for the physical sciences, and especially engineering, the largest share has derived from the Defense Department, AEC, and NASA. This support surely biased university activity away from industrially related research, especially that connected with the less glamorous industrial problems.

The Practical Loss

While it is probably impossible to assess all the effects of federal policy over the past several decades, there are several possibilities that appear reasonable. It seems reasonable to expect that, ten years or so after a relative decline in technical activity, its consequences should begin to be evident. For example, the rate of increase in productivity might begin to diminish. Although the dependence of productivity upon a wide range of other factors (the availability of capital, for example) is well recognized, eventually a reduction in investment in technical activity devoted to industrial purposes should be reflected in a decreased rate of im-

Table II. Approximate proportions of national resources, at market prices, devoted to research and development. For the U.S. and European countries selected, the figures are averages for 1959-1965; for Japan, the figures are for 1963. The data appear to indicate a significant U.S. advantage in defense and space research and a rather lesser advantage in civilian-oriented work. (Sources: Japan—*International Statistical Year for Research and Development, A Study of Resources Devoted to R. and D. in O.E.C.D. Member Countries in 1963/64,* Vol. 2, O.E.C.D., Paris, 1968; other countries—Boretsky, ref. 6.)

Table III. The same information as in Table II, for civilian-oriented work only, translated into cost-equivalent terms and into full-time-equivalent technical man power. The last column expresses each national civilian research and development effort (in cost-equivalent terms) as a proportion of that nation's G.N.P., also converted into cost-equivalent terms. A number of nations, on this basis, have been making more intensive research efforts during the early '60's, for civilian purposes, than has the U.S. (after Boretsky)

provement in productivity. And, indeed, in the last few years, productivity increases have declined (5).

There is another way in which we can deduce the effects of the post-war research and development policies. Boretsky (6) has compared the technical activity of Europe and Japan with that of the United States for the period 1959-65 (just following the rapid growth of the United States effort). Table II compares the total research and development efforts for these years as fractions of national G.N.P.'s at market prices, for the United States, Japan and the major European countries. The defense and space portion of the total effort and the civilian effort are also included for comparison. Superficially at least, this table would indicate a significant advantage of the United States for all research and development, and a somewhat lesser advantage in its "civilian-oriented" activity.

However, when research and development efforts are translated into cost-equivalent terms, and into the number of scientists, engineers, and technicians employed (Table III), the results are startling. The last column in Table III expresses cost-equivalent expenditures for research and development as fractions of the G.N.P.'s, the latter converted to equal-purchasing-power terms. When the comparison is thus made on the basis of cost-equivalent expenditures, the relative advantage of the United States investment in civilian research and development disappears. Even more significant, about 30 to 35 per cent more scientists, engineers, and technicians were engaged in civilian-oriented research and development in the eight European countries studied than in the United States. This group of countries has a slightly greater population than the United States, but a one-third smaller G.N.P. When compared on this basis, the relative effort in Europe was substantially greater than that in the United States—the reason being, basically, that the relative cost of research and development personnel is less in Europe than in the United States.

Furthermore, there was no substantial investment in defense and space research and development in any of the European countries except the United Kingdom; there was not a disproportionate rise in salaries, and there was no marked displacement of scientists and engineers from industrial to national projects. Although European data for more recent years are not readily available, it seems likely that—in view of the slow growth of research activity in the United States relative to other O.E.C.D. countries in these years—the disparity is now even greater. As early as 1955, the number of scientists and engineers engaged in non-space, non-defense activity in Europe must have been higher than in the United States.

A comparison between Japan and the United States is even more depressing. During the 1959-65 period, the Japanese spent a significantly larger portion of their G.N.P., on an equivalency basis, for civilian research and development than did the United States. With one-half the United States population and one-fifth the United States G.N.P., Japan employed 70 per cent as many professional research and development personnel in their civilian effort as did the United States.

Spin-Off?

Many would argue that the analysis thus far has neglected the indirect effects of the space and defense research and development efforts of the United States. It is clear that the research and development that has been supported by the government must have been beneficial to at least some industrial activities. Further, the government provided a market for sophisticated technical goods, which no doubt stimulated research and development activities which were transferable to civilian products. But, granted that this indirect effect of space and defense oriented work presumably exists, the question is, how significant is it?

Boretsky analyzes this matter in what seems to be an effective way. Consider the efforts of ten people engaged in federal research and development; how much effort aimed at a particular industrial objective, on the average, are these ten equivalent to? Boretsky argues that their absolute maximum equivalent is 3-1/3, and the minimum is perhaps one-half a civilian researcher. In other words, 5 to 33 per cent of a given amount of space and defense research and development might be considered to be the "direct" effect of that effort on the economy.

Assuming a "spin-off" as high as 20 per cent (for both Europe and the United States) a new measure of the effective number of scientists and engineers can be derived. It turns out that the United States still lags

behind Europe and Japan on a comparative population basis. In the specific field of nuclear technology not related to military applications, Boretsky makes a more startling comparison. He estimates that 50 per cent more scientists, engineers, and technicians are involved in this work in Europe than in the United States.

This disparity in technical effort, existing for more than ten years, may have begun to be reflected in our trade with Europe and with Japan. Consider the trade balance in the technologically intensive products of chemicals, machinery, electrical equipment, transportation equipment and instruments. In 1968, the United States had a favorable balance of trade of these products with Europe of $1.5 billion. From 1962 to 1968, however, the rate of growth of imports of these products from Europe averaged 20 per cent, and the rate of growth in their export from the United States averaged only 9 per cent. During this same period, the United State's trade balance with Japan in these products turned from a $300 million surplus to a $500 million deficit. While United States imports from Japan were growing at 32 per cent a year, United States exports to Japan were increasing at only 7 per cent a year.

If the trend continues, Boretsky estimates that by 1973, in technologically intensive products alone, there will be a trade deficit with Europe of almost $2 billion. The situation with respect to Japan is even more disturbing: he estimates that the United States "technological" trade deficit to Japan will be almost $5 billion by 1973.

It is clear, of course, that monetary factors and relative labor cost factors are also important to trade balance considerations. It is only in high-technology products with rapid potential for growth (and in agriculture, where the U.S. has long maintained a technological lead) that the United States has had much of a potential advantage—and it is here (*except* in agriculture) that we find the downturn.

Clearly, analysis of a matter as complicated as the relationship between technology, the economy, and social welfare can never be complete, nor can conclusions drawn from incomplete analysis ever be taken with assurance. Nevertheless, it appears that in the United States we have substantially under-invested in the kinds of technical effort that are necessary for the improvement of our industrial output and the quality of our life. In recent years this under-investment in technology for civilian pursuits has been made substantially greater as a result of the large commitment of the United States to activities related to defense and space. The natural working of the economic system which would in any case have led the industry to invest too little in technical activities has been further distorted because of the higher cost of research and development resulting from the federal effort. Even in the government sector of research and development, all the European countries and Japan spend more than 20 per cent of government research and development for civilian purposes, whereas the United States spends less than 6 per cent. Thus our competitors supplement the industrial investment in research and development for civilian purposes to a much greater degree than do we.

The Choice of Strategies

We are now faced with a dilemma. There are 100,000 scientists and engineers out of work; there are large unsatisfied social needs; we are suffering adverse effects from our past uses of technology; and our economic growth is faltering. At the same time, the costs of education and of research and development continue to rise, sustained apparently by the social and political structure that we have set up.

Direct research and development investments by the federal government—whether for defense, space or social welfare purposes—will, if they are too large, draw off technical activity which could be turned to industrial improvement, just as we experienced in the 1950's. Substantial increases in the availability of new scientist and engineer graduates would eventually lower their relative prices, but there would be a period of costly and inhumane readjustment. On the other hand, restrictive policies to discourage young people either from opting for technical education or from continuing at university for advanced graduate education are, of course, in the long term, self-defeating.

Like any complex public problem, this dilemma will not be resolved by any single public policy decision. Addressing the social tasks directly, perhaps the most important single action that is required is a substantial

increase in support for the improvement, both in quality and efficiency, of those public services in which private industry plays only a small role, such as education and the delivery of health care. Likewise, those socially desirable activities in which private incentives for technical work are small or non-existent, such as the improvement of living conditions in the cities and of the safety of our transport system, require significantly increased support.

To simply spend enough to re-employ unemployed scientists and engineers by immediate federal research and development funding in these social fields, is not the answer, for we do not know enough about the task; nor would such a move (which would in any case face great social obstacles) encourage industry to play its own part. For the present, in these fields we must not only invest in research and development, but we must devise ways of changing the structure of the delivery systems of social services and of the education of technical people, to facilitate the adoption and diffusion of new techniques. A major effort of direct government support to meet these social needs is required.

A second major effort would be the encouragement of university research related to improving industrial productivity, to reducing the waste and pollution of industry, and generally to problems associated with the productivity, products, and adverse effects of industrial production. This federal support to universities would redress the present academic bias, especially in engineering, toward the kinds of work that tend to improve our defense and space capabilities.

In some way, also, government must underwrite industrial research and development itself, since the economy has always tended to under-invest in it, and its present over-costliness results from past federal policies. This can be done either directly by subsidy or indirectly through tax rebates. The entire set of corporate and government policies that encourage potentially high-export industries needs to be reviewed.

Whether a society effectively uses technology for productive and beneficial purposes depends upon a large number of factors. The supply of technically trained people, the willingness to invest in them, the capital necessary to embody the technology in useful machines and processes, the level of general education, the skill of the potential labor force, the economic and political structure of the society, all play roles. The effective use of technology requires that a large number of appropriate conditions be met simultaneously; a single missing ingredient (for example, the absence of available capital, or the necessary management attitudes) may completely halt either technological innovation or the spread of technology within the society.

If we are to meet the social needs of our time and to continue to provide the material needs of our population, new policies and directions of our governmental, industrial and academic institutions are required.

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The U.S. government's pyramiding investment in research and development in the 1950's invoked the law of supply and demand, say Dr. Herbert Hollomon (seated in photograph) and Alan Harger. The loser was American industry—unable or unwilling to compete. Can we now restore to research its true value and to American industry its tradition of technological innovation?

J. Herbert Hollomon
Consultant to the President and Provost of M.I.T.

Alan E. Harger
Administrative Assistant to Dr. Hollomon

America's Technological Dilemma

During these times of rapid change, of the increasing awareness of social problems, of declining trade balances, of inflation, and of unemployed scientists and engineers, thoughtful attention must be directed to the science and technology policy of the U.S. One important aspect of this policy has to do with the way in which technology is used by society, particularly how it affects civilian or industrial activity.

Many people have struggled to quantify the influence that new technology has upon industrial development, economic growth, and social advance. Qualitatively, the dependence of a modern economy on the use of new technology is accepted: technology becomes embodied in more effective production machinery, in more skilled labor, and in products and services that better serve social needs. The direct connections between research and development, and the resultant particular practical benefits, are more difficult to specify. However, it is these connections which must be understood if science policy (national or corporate) is to be effective.

In any attempt to assess the direct consequences of investment in research and development, it must be clearly established that the particular investment has been directed toward the purposes which are being considered. For example, suppose we are looking for the sources of general economic health in the nation; we must recognize that the research and development which have been aimed toward space flight and defense are unlikely to have had as significant an influence as an equivalent research and development activity directed toward, let's say, improvement in productive efficiency in the automotive industry.

Clearly, the effects of research and development on a nation as a whole cannot be understood without distinguishing among the various economic sectors. In the United States, for example, where most workers are engaged in service activities and most research and development is devoted to manufacturing, the overall rate of change in productivity cannot be expected to correlate with the amount of national civilian-oriented research and development.

Other factors influence the consequences of research and development. Most important is the delay, of almost indeterminate length, between an investment in research and development and the appearance of its results in the world. Some recent studies have indicated that this time delay has shortened, but even so, any major new technological development does not diffuse throughout the society in less than five to ten years.

In a recent analysis, Harvard's Richard B. Freeman has found (after taking the time delay into account as best he could) a good correlation between the growth rates and profitabilities of different industrial sectors and the research and development that were performed in those sectors in prior years (1). Figures 1, 2, and 3 illustrate

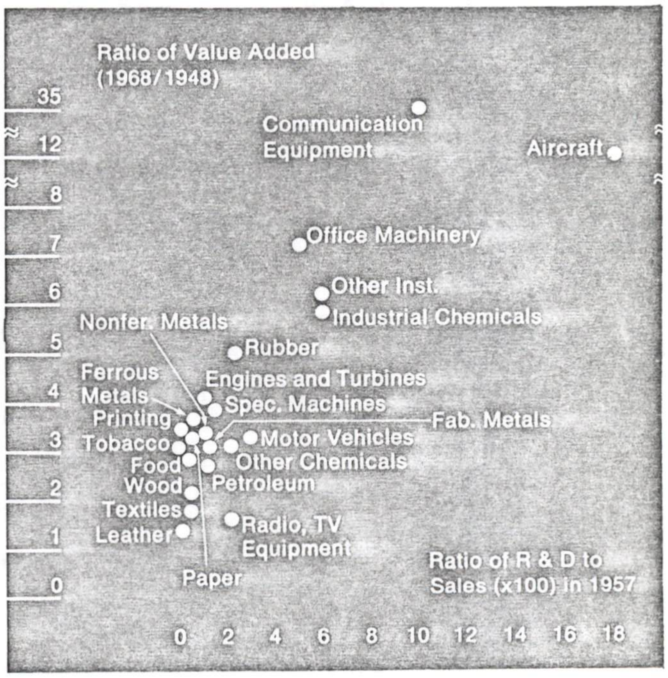
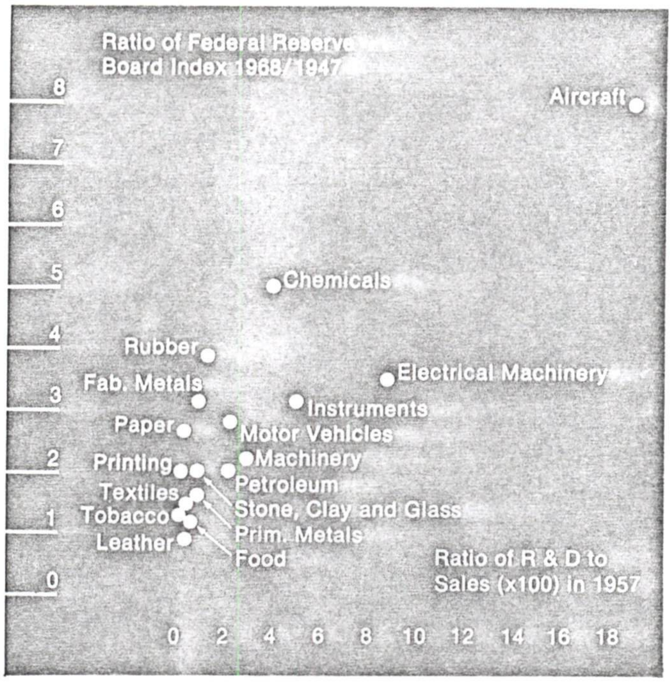


Figure 1. The gross association between research and development intensity and growth in output in various industries is shown here and in Figures 2 and 3 (on the following page). Research and development intensity is indexed by the ratio of R. and D. expenditures to sales. In Figure 1, increases in value added—a term denoting the difference between the value of a manufactured product and that of the starting materials—indicate output changes unadjusted for price increases.

Figure 2. The association between research and development intensity and growth in output in various industries (cont.): in this plot, output increases adjusted for price changes are measured by increases in the Federal Reserve Board Index of Production, and R. and D. intensity is indexed as in Figure 1.



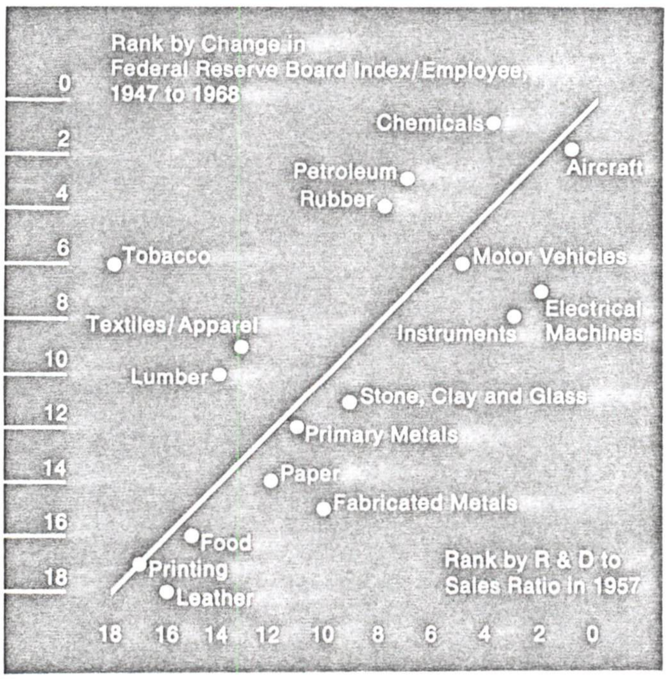


Figure 3. Changes in labor productivity are measured by the industries' indices of production (*see above*) divided by their number of employees. The rank-order relationship in this figure—like the relationships in Figures 1 and 2—indicates a positive and significant *correlation* between growth in industrial output and research and development intensity. (The three plots are after Freeman, ref. 1.)

the correlations. Professor William N. Leonard, of Hofstra, has shown that research and development spending by companies (excluding federal research and development) relates significantly to growth rate of sales, assets, and net income, in 16 industries which, combined, perform nearly all manufacturing activity (2).

Since World War II there have been many other analyses, both for particular industries and for the economy as a whole, that relate the effects of research and development to their economic consequences. It is clear that, for our type of national economy at least, industry under-invests in research and development relative to the total social return it generates in comparison with alternative investments. This under-investment arises because an individual firm cannot appropriate all of the benefits of any new technical development, but must bear most of the cost of that development. In other words, many of the results of a particular development are not of direct benefit to a firm, but indirectly affect other firms that use the results of the development. Furthermore, when a development is highly risky, a firm may forego investment in it because of the cost of failure, even though the rewards of the most probable outcome would fully justify the investment. Or to put the matter another way, individual firms will underinvest in order to minimize their risk, even though the expected rewards from investment in development, on an average basis for many firms, could be quite high. This situation becomes more serious the larger the initial development cost and the more radical the new technology. For instance, in the development of nuclear power the risk may be such that no firm exists with the capability of investing at the early stages of the technology. Only society as a whole can afford the risks or the uncertain costs resulting from technical uncertainty.

A summary of these studies of the effects of research and development, commissioned by the National Science Foundation (3) indicates that the contributions of research and development to economic growth and productivity, even with this under-investment, is positive, significant, and high.

Industry vs. Space and Defense

During and following World War II, the United States invested heavily in research and development, as illustrated in Figure 4. The most rapid increase occurred between 1953 and 1959, and resulted largely from increases in federal funding (Figure 5); since 1964 there has been a decrease in total effort relative to the G.N.P. It is clear that, as the federal government began to invest more and more in research and development, industry did not follow suit as rapidly; and that, conversely, as the federal government investment decreased, industrial investment in research and development tended to rise.

The recent growth of the U.S. research and development effort is less dramatic when measured, not in dollars, but in the number of the scientists and engineers involved (Figure 6). The costs of technical work have risen much more sharply than the general

Figure 4. Research and development spending in the U.S. since World War II. (Sources: 1945-1953 figures—Office of the Secretary of Defense, in the Census Bureau's *Statistical Abstract of the United States—1960,* Washington, 1960; 1953-1970 figures—National Science Foundation's *National Patterns of Research and Development Resources,* NSF 70-46, Washington, 1970)

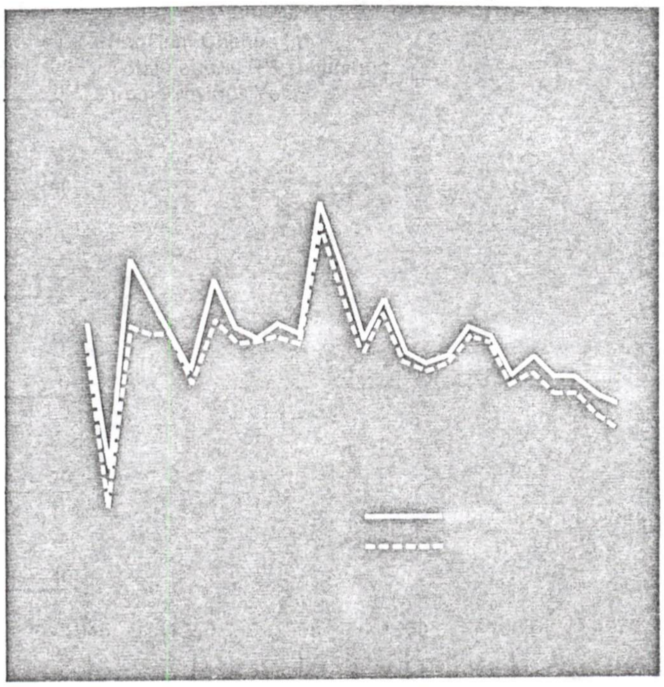
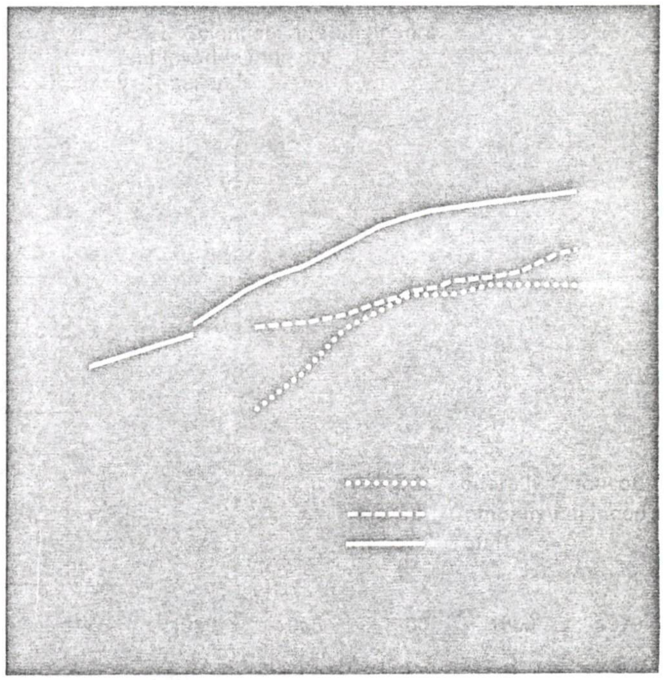


Figure 5. From the same data used in Figure 4, the year-to-year changes in total federal research and development support are shown. ("1958 dollars" were arrived at using the implicit G.N.P. deflator, since there is no specific R. and D. deflator available.)

Figure 6. Post-war growth of research and development in industry in terms of the number of scientists and engineers employed. The 1953-1961 company-federal estimates are by the authors, and 1962-1968 company-federal estimates are from the National Science Foundation. (Sources: 1945-1950 figures—Department of Defense, *The Growth of Scientific Research and Development,* Washington, 1953; 1950-1957—National Science Foundation (jointly with Bureau of Labor Statistics), *Employment of Scientists and Engineers in the United States, 1950-1965,* NSF 68-30, Washington, 1968; 1958-1968—National Science Foundation, *Research and Development in Industry—1968,* NSF 70-29, Washington, 1970.)



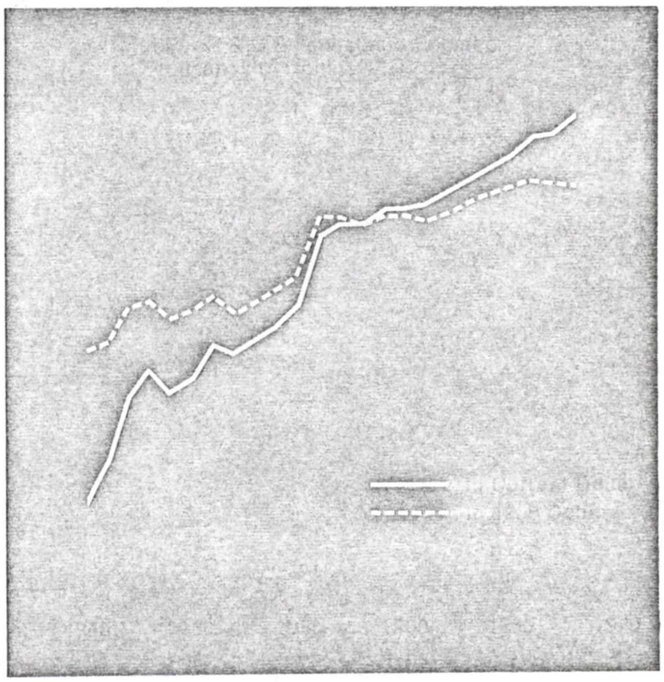
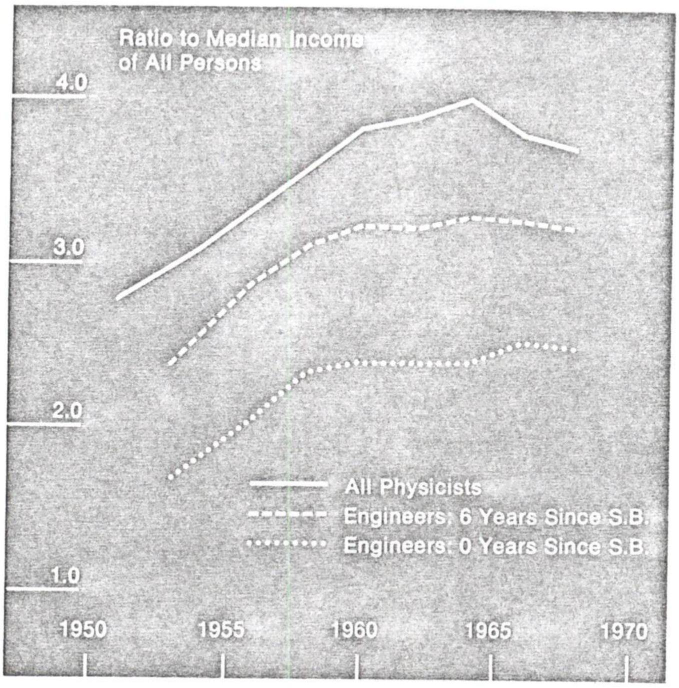


Figure 7. Increases in the cost of research and development per R. and D. scientist and engineer in industry coincide with the increases in federal support traced in Figure 5. (Sources: 1945-1952—Department of Defense; 1953-1956—National Science Foundation/Bureau of Labor Statistics; 1957-1968—National Science Foundation)

Figure 8. Salaries of physicists and engineers as a ratio of the median income of all persons. The rapid rises of the 1950's were a dominant contribution to the cost increases shown in Figure 7 (Sources: median income—Census Bureau's yearly *Current Population Reports, Series P-60 (Consumer Income)*, 1951-1968; engineers—Engineering Manpower Commission, *Professional Income of Engineers, 1970*, New York: Engineers' Joint Council, 1970; physicists—American Institute of Physics, *Physics Manpower—1966* and *Physics Manpower—1969*, Publications R-196 and R-220, based on data from the National Science Foundation's National Register)



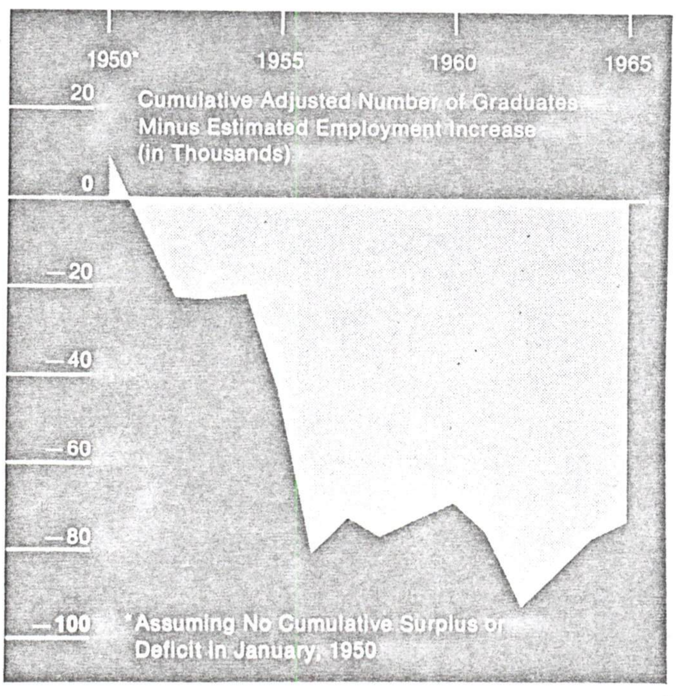


Figure 9. Between 1950 and 1965, nearly 100,000 more engineers were created (on the employment record) than became available as new graduates. This graph traces the cumulative progress of the appearance of "engineers" for whom no engineering degrees were awarded. (Sources: employment figures—National Science Foundation/Bureau of Labor Statistics; degrees—U.S. Office of Education *Digest of Educational Statistics*, OE-10024-70, Washington, 1970 edn.)

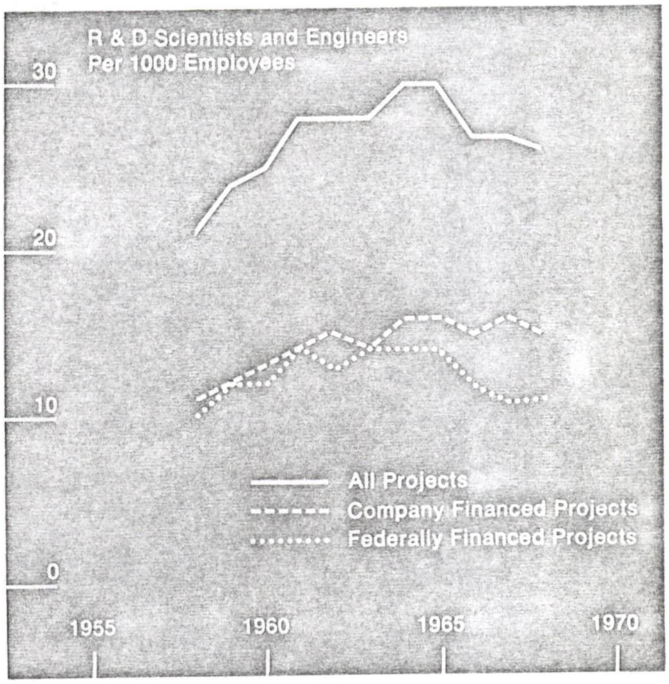
rates of inflation and of improvement in productivity. Indeed, the rapid growth of federal research and development has itself done much to raise the costs. The major increases illustrated in Figure 7 correspond to the increases in federal research and development support (Figure 5). A dominant source of the rise in costs was the increase in salaries of scientists and engineers relative to others (Figure 8).

During the period 1950 to 1960, the rapid increase in space and defense research and development increased the demand for new technical people (4). Apparently there was, within industry, a transfer of technical people from industrial to governmental projects. Because of this competition and the great increase in research and development support, salaries rose, and the cost of research and development, and probably of other technological activities, rose significantly.

Figure 9 illustrates a dramatic effect of this extraordinary demand. Between 1950 and 1965, nearly 100,000 more engineers were created than were available as graduates with engineering degrees. During these years, the increase in the number of engineers reported to be employed was substantially greater than the number of new engineers entering the labor force from higher education. Thus, it appears that industry must have been upgrading technicians to take the place of trained people who were transferred to federal programs. A related consequence of the rapid growth of research and development must have been a decrease in the average level of training, if not skill, of the remaining industrial engineers.

Since 1950, there has been an increase in industrial funding for research and development. However, its impact has been limited by rising costs. Figure 10 illustrates the year-by-year change in the number of R. & D. scientists and engineers per 1,000 employees in those companies performing research and development. Even these figures are somewhat inflated, for some of these scientists and engineers were no doubt engaged in research and development related to products sold for defense and space purposes. The figure illustrates that research and development for industrial purposes has remained about constant for nearly ten years.

Figure 10. For those companies reporting research and development activity, these curves show the number of R. & D. scientists and engineers employed per thousand employees. (Sources: 1958-1961—authors' estimates; 1962-1968—National Science Foundation)



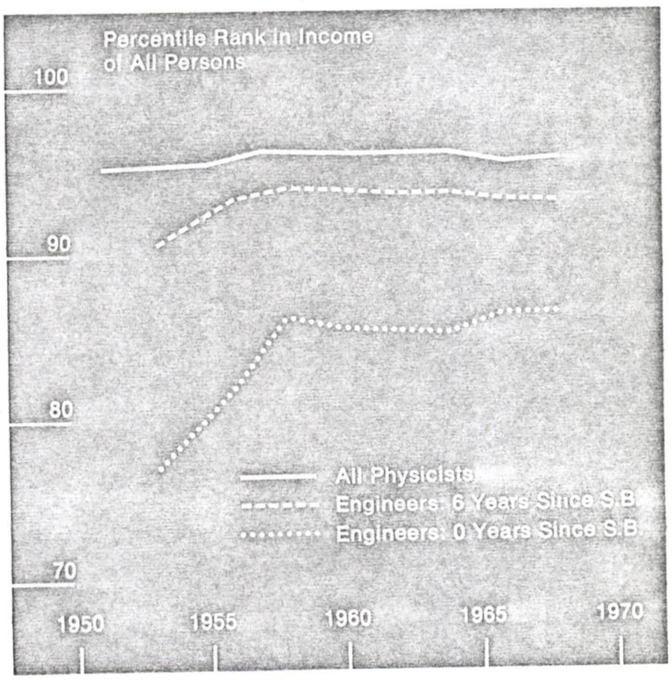


Figure 11. If incomes of all persons are arranged in a ranking order, any given income can be assigned a percentile position, indicating the percentage of the population having a lower income. Shown here are the percentile positions of median salaries earned by engineers and physicists. (Sources: as Figure 8)

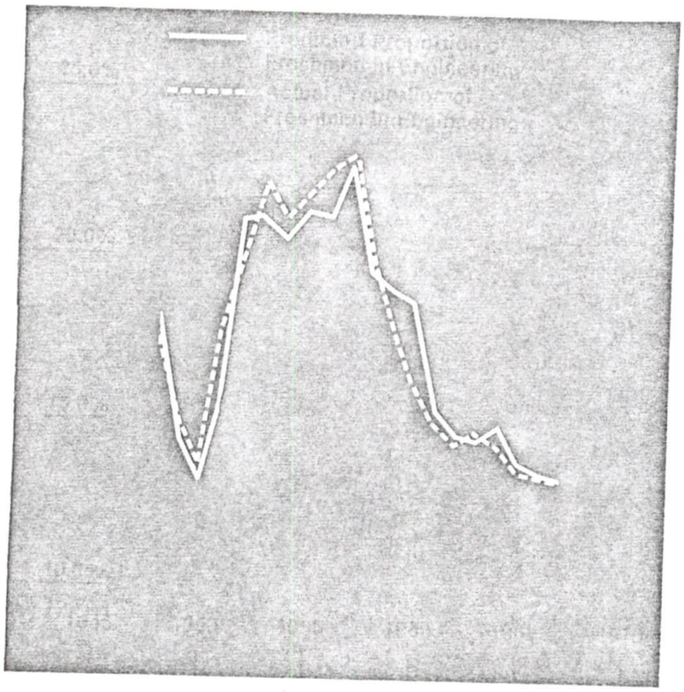
Other factors have probably affected the industrial investment in technology. Interest rates have continually risen in the United States during this period, and, according to some economists at least, this has retarded capital investment. Not only is capital investment required in order to infuse new technology into the economy, but also large investment commitments in general tend to stimulate research and development. In addition, it is likely that the combination of high government demand and rapid obsolescence of technology in the space and defense fields attracted a disproportionate fraction of venture capital to these industries, and was an important contributing factor to the rising price of capital.

During the last several years, the decline of the federal effort has not been compensated for by the slight increase in industrial activity. The result has been unemployment of scientists and engineers, particularly those that were connected with space and defense. Crude estimates indicate the total unemployed to be of the order of 100,000.

To reiterate, the rapid and large growth of federally supported research and development, occurring particularly between 1953 and 1960, appears to have had several major effects on the technological activity of the United States and its industry. The most important effect of this growth was the rise in overall cost of research and development. This increase occurred not only in the costs of research and development to the government, but, very significantly, in the cost of this activity to industry. A major factor in this cost rise was the increased cost of the technical personnel engaged in it. The rise in the rank of starting engineers and scientists in the income distribution, relative to the rest of the population, dramatically illustrates this increase (Figure 11).

Starting salaries for engineers with bachelor degrees, for example, rose during the period of rapid research and development expansion from the 77th percentile in the rank of income of all people in the United States, to about the 86th percentile. During this same period, it is estimated by Freeman that about 20 to 30 per cent of the increased activity supported by the federal government was made possible by a transfer of people from industrially supported projects. The remaining increase was accomplished by absorbing the supply of new

Figure 12. Changes in salary within the engineering profession as a whole affect the number of students choosing engineering majors. This graph shows the success of a prediction of the proportion of all freshmen who choose engineering, made on the basis of engineering salaries, relative to other professional salaries, one year earlier. (Richard B. Freeman, *The Market for College-Trained Manpower*, Cambridge: Harvard University Press, 1971)



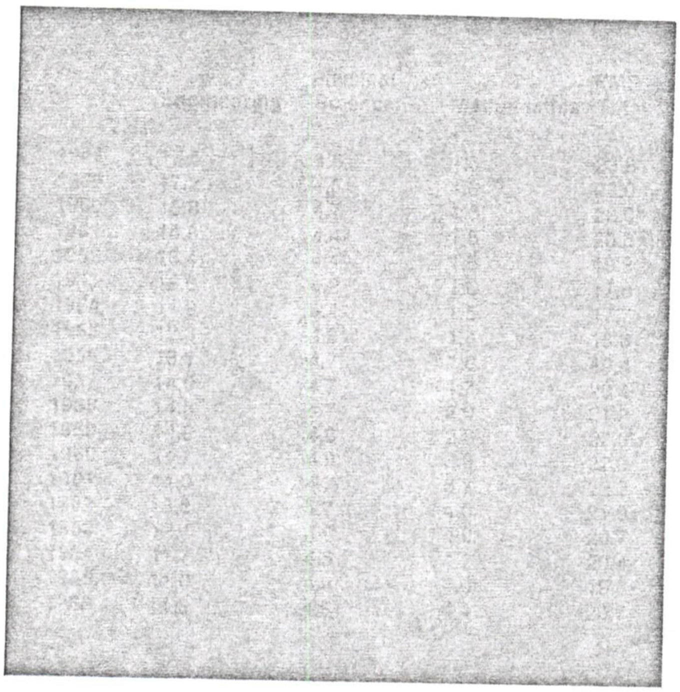


Table I. The combined fraction of male college graduates choosing science, mathematics and engineering has changed little since World War II, although the relative proportions of these fields have changed somewhat. (Hugh Folk, *The Shortage of Scientists and Engineers*, Lexington, Heath Lexington, 1970)

technical people.

University as Supplier

The increase in demand generated by federal funds had a significant effect on the choice made among fields by those attending universities. The fraction of college graduates opting for science, mathematics, and engineering has changed very little since World War II (Table I). Hugh Folk has pointed out that the choice of a broad field by students does not appear to be affected by demand, which influences only the choice of lucrative activities *within* broad fields. Changes in salaries and stipends affect the choices between specialties, and determine in part whether or not students opt for graduate education in special fields. However, though those in science and engineering have been mostly supported by federal funds to universities, the proportion of scientists and engineers among all PhD's has not increased appreciably. Apparently, the federal funds merely permitted the universities to redistribute their resources to a rapidly rising social demand for graduate education proportionately in all fields of knowledge. Changes in salaries and stipends affected choices toward engineering and toward physics, for example. Figure 12 illustrates the relationship between the actual number of freshman enrollments in engineering, year-by-year, and the changed incentives predicted from salary changes.

There has been some shift between engineering and mathematics, but, in any event, the response of the new supply of technical people to economic factors is sluggish and cyclical. The yearly new supply of graduate scientists, mathematicians, and engineers has varied from 33,000 to a high of 61,000. In recent years, this new supply has been about equal to the reported increase in new employment of scientists and engineers, implying little upgrading of people who did not have a "certificate" as scientists or engineers.

There has been great growth in the support of research in universities by the federal government, with by far the largest share derived from the support of biomedical research in university medical schools and affiliated hospitals. However, for the physical sciences, and especially engineering, the largest share has derived from the Defense Department, AEC, and NASA. This support surely biased university activity away from industrially related research, especially that connected with the less glamorous industrial problems.

The Practical Loss

While it is probably impossible to assess all the effects of federal policy over the past several decades, there are several possibilities that appear reasonable. It seems reasonable to expect that, ten years or so after a relative decline in technical activity, its consequences should begin to be evident. For example, the rate of increase in productivity might begin to diminish. Although the dependence of productivity upon a wide range of other factors (the availability of capital, for example) is well recognized, eventually a reduction in investment in technical activity devoted to industrial purposes should be reflected in a decreased rate of im-

Table II. Approximate proportions of national resources, at market prices, devoted to research and development. For the U.S. and European countries selected, the figures are averages for 1959-1965; for Japan, the figures are for 1963. The data appear to indicate a significant U.S. advantage in defense and space research and a rather lesser advantage in civilian-oriented work. (Sources: Japan—*International Statistical Year for Research and Development, A Study of Resources Devoted to R. and D. in O.E.C.D. Member Countries in 1963/64,* Vol. 2, O.E.C.D., Paris, 1968; other countries—Boretsky, ref. 6.)

[illegible]

Table III. The same information as in Table II, for civilian-oriented work only, translated into cost-equivalent terms and into full-time-equivalent technical man power. The last column expresses each national civilian research and development effort (in cost-equivalent terms) as a proportion of that nation's G.N.P., also converted into cost-equivalent terms. A number of nations, on this basis, have been making more intensive research efforts during the early '60's, for civilian purposes, than has the U.S. (after Boretsky)

[illegible]

provement in productivity. And, indeed, in the last few years, productivity increases have declined (5).

There is another way in which we can deduce the effects of the post-war research and development policies. Boretsky (6) has compared the technical activity of Europe and Japan with that of the United States for the period 1959-65 (just following the rapid growth of the United States effort). Table II compares the total research and development efforts for these years as fractions of national G.N.P.'s at market prices, for the United States, Japan and the major European countries. The defense and space portion of the total effort and the civilian effort are also included for comparison. Superficially at least, this table would indicate a significant advantage of the United States for all research and development, and a somewhat lesser advantage in its "civilian-oriented" activity.

However, when research and development efforts are translated into cost-equivalent terms, and into the number of scientists, engineers, and technicians employed (Table III), the results are startling. The last column in Table III expresses cost-equivalent expenditures for research and development as fractions of the G.N.P.'s, the latter converted to equal-purchasing-power terms. When the comparison is thus made on the basis of cost-equivalent expenditures, the relative advantage of the United States investment in civilian research and development disappears. Even more significant, about 30 to 35 per cent more scientists, engineers, and technicians were engaged in civilian-oriented research and development in the eight European countries studied than in the United States. This group of countries has a slightly greater population than the United States, but a one-third smaller G.N.P. When compared on this basis, the relative effort in Europe was substantially greater than that in the United States—the reason being, basically, that the relative cost of research and development personnel is less in Europe than in the United States.

Furthermore, there was no substantial investment in defense and space research and development in any of the European countries except the United Kingdom; there was not a disproportionate rise in salaries, and there was no marked displacement of scientists and engineers from industrial to national projects. Although European data for more recent years are not readily available, it seems likely that—in view of the slow growth of research activity in the United States relative to other O.E.C.D. countries in these years—the disparity is now even greater. As early as 1955, the number of scientists and engineers engaged in non-space, non-defense activity in Europe must have been higher than in the United States.

A comparison between Japan and the United States is even more depressing. During the 1959-65 period, the Japanese spent a significantly larger portion of their G.N.P., on an equivalency basis, for civilian research and development than did the United States. With one-half the United States population and one-fifth the United States G.N.P., Japan employed 70 per cent as many professional research and development personnel in their civilian effort as did the United States.

Spin-Off?

Many would argue that the analysis thus far has neglected the indirect effects of the space and defense research and development efforts of the United States. It is clear that the research and development that has been supported by the government must have been beneficial to at least some industrial activities. Further, the government provided a market for sophisticated technical goods, which no doubt stimulated research and development activities which were transferable to civilian products. But, granted that this indirect effect of space and defense oriented work presumably exists, the question is, how significant is it?

Boretsky analyzes this matter in what seems to be an effective way. Consider the efforts of ten people engaged in federal research and development; how much effort aimed at a particular industrial objective, on the average, are these ten equivalent to? Boretsky argues that their absolute maximum equivalent is 3-1/3, and the minimum is perhaps one-half a civilian researcher. In other words, 5 to 33 per cent of a given amount of space and defense research and development might be considered to be the "direct" effect of that effort on the economy.

Assuming a "spin-off" as high as 20 per cent (for both Europe and the United States) a new measure of the effective number of scientists and engineers can be derived. It turns out that the United States still lags

behind Europe and Japan on a comparative population basis. In the specific field of nuclear technology not related to military applications, Boretsky makes a more startling comparison. He estimates that 50 per cent more scientists, engineers, and technicians are involved in this work in Europe than in the United States.

This disparity in technical effort, existing for more than ten years, may have begun to be reflected in our trade with Europe and with Japan. Consider the trade balance in the technologically intensive products of chemicals, machinery, electrical equipment, transportation equipment and instruments. In 1968, the United States had a favorable balance of trade of these products with Europe of $1.5 billion. From 1962 to 1968, however, the rate of growth of imports of these products from Europe averaged 20 per cent, and the rate of growth in their export from the United States averaged only 9 per cent. During this same period, the United State's trade balance with Japan in these products turned from a $300 million surplus to a $500 million deficit. While United States imports from Japan were growing at 32 per cent a year, United States exports to Japan were increasing at only 7 per cent a year.

If the trend continues, Boretsky estimates that by 1973, in technologically intensive products alone, there will be a trade deficit with Europe of almost $2 billion. The situation with respect to Japan is even more disturbing: he estimates that the United States "technological" trade deficit to Japan will be almost $5 billion by 1973.

It is clear, of course, that monetary factors and relative labor cost factors are also important to trade balance considerations. It is only in high-technology products with rapid potential for growth (and in agriculture, where the U.S. has long maintained a technological lead) that the United States has had much of a potential advantage—and it is here (*except* in agriculture) that we find the downturn.

Clearly, analysis of a matter as complicated as the relationship between technology, the economy, and social welfare can never be complete, nor can conclusions drawn from incomplete analysis ever be taken with assurance. Nevertheless, it appears that in the United States we have substantially under-invested in the kinds of technical effort that are necessary for the improvement of our industrial output and the quality of our life. In recent years this under-investment in technology for civilian pursuits has been made substantially greater as a result of the large commitment of the United States to activities related to defense and space. The natural working of the economic system which would in any case have led the industry to invest too little in technical activities has been further distorted because of the higher cost of research and development resulting from the federal effort. Even in the government sector of research and development, all the European countries and Japan spend more than 20 per cent of government research and development for civilian purposes, whereas the United States spends less than 6 per cent. Thus our competitors supplement the industrial investment in research and development for civilian purposes to a much greater degree than do we.

The Choice of Strategies

We are now faced with a dilemma. There are 100,000 scientists and engineers out of work; there are large unsatisfied social needs; we are suffering adverse effects from our past uses of technology; and our economic growth is faltering. At the same time, the costs of education and of research and development continue to rise, sustained apparently by the social and political structure that we have set up.

Direct research and development investments by the federal government—whether for defense, space or social welfare purposes—will, if they are too large, draw off technical activity which could be turned to industrial improvement, just as we experienced in the 1950's. Substantial increases in the availability of new scientist and engineer graduates would eventually lower their relative prices, but there would be a period of costly and inhumane readjustment. On the other hand, restrictive policies to discourage young people either from opting for technical education or from continuing at university for advanced graduate education are, of course, in the long term, self-defeating.

Like any complex public problem, this dilemma will not be resolved by any single public policy decision. Addressing the social tasks directly, perhaps the most important single action that is required is a substantial

increase in support for the improvement, both in quality and efficiency, of those public services in which private industry plays only a small role, such as education and the delivery of health care. Likewise, those socially desirable activities in which private incentives for technical work are small or non-existent, such as the improvement of living conditions in the cities and of the safety of our transport system, require significantly increased support.

To simply spend enough to re-employ unemployed scientists and engineers by immediate federal research and development funding in these social fields, is not the answer, for we do not know enough about the task; nor would such a move (which would in any case face great social obstacles) encourage industry to play its own part. For the present, in these fields we must not only invest in research and development, but we must devise ways of changing the structure of the delivery systems of social services and of the education of technical people, to facilitate the adoption and diffusion of new techniques. A major effort of direct government support to meet these social needs is required.

A second major effort would be the encouragement of university research related to improving industrial productivity, to reducing the waste and pollution of industry, and generally to problems associated with the productivity, products, and adverse effects of industrial production. This federal support to universities would redress the present academic bias, especially in engineering, toward the kinds of work that tend to improve our defense and space capabilities.

In some way, also, government must underwrite industrial research and development itself, since the economy has always tended to under-invest in it, and its present over-costliness results from past federal policies. This can be done either directly by subsidy or indirectly through tax rebates. The entire set of corporate and government policies that encourage potentially high-export industries needs to be reviewed.

Whether a society effectively uses technology for productive and beneficial purposes depends upon a large number of factors. The supply of technically trained people, the willingness to invest in them, the capital necessary to embody the technology in useful machines and processes, the level of general education, the skill of the potential labor force, the economic and political structure of the society, all play roles. The effective use of technology requires that a large number of appropriate conditions be met simultaneously; a single missing ingredient (for example, the absence of available capital, or the necessary management attitudes) may completely halt either technological innovation or the spread of technology within the society.

If we are to meet the social needs of our time and to continue to provide the material needs of our population, new policies and directions of our governmental, industrial and academic institutions are required.

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J. Herbert Hollomon, currently serving as Consultant to the President and the Provost of M.I.T., was formerly President of the University of Oklahoma. Under President Kennedy he served as Assistant Secretary of Commerce for Science and Technology, and as Acting Undersecretary of Commerce under President Johnson, Dr. Hollomon is a graduate of M.I.T. (his doctorate is in metallurgy). He founded *Acta Metallurgica*, and co-authored, with L. Jaffee, *Ferrous Metallurgical Design*. He is a founding member of National Academy of Engineering, and is presently on the N.A.E.'s Committee for Transportation.

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The U.S. government's pyramiding investment in research and development in the 1950's invoked the law of supply and demand, say Dr. Herbert Hollomon (seated in photograph) and Alan Harger. The loser was American industry—unable or unwilling to compete. Can we now restore to research its true value and to American industry its tradition of technological innovation?

J. Herbert Hollomon
Consultant to the President and Provost of M.I.T.

Alan E. Harger
Administrative Assistant to Dr. Hollomon

America's Technological Dilemma

During these times of rapid change, of the increasing awareness of social problems, of declining trade balances, of inflation, and of unemployed scientists and engineers, thoughtful attention must be directed to the science and technology policy of the U.S. One important aspect of this policy has to do with the way in which technology is used by society, particularly how it affects civilian or industrial activity.

Many people have struggled to quantify the influence that new technology has upon industrial development, economic growth, and social advance. Qualitatively, the dependence of a modern economy on the use of new technology is accepted: technology becomes embodied in more effective production machinery, in more skilled labor, and in products and services that better serve social needs. The direct connections between research and development, and the resultant particular practical benefits, are more difficult to specify. However, it is these connections which must be understood if science policy (national or corporate) is to be effective.

In any attempt to assess the direct consequences of investment in research and development, it must be clearly established that the particular investment has been directed toward the purposes which are being considered. For example, suppose we are looking for the sources of general economic health in the nation; we must recognize that the research and development which have been aimed toward space flight and defense are unlikely to have had as significant an influence as an equivalent research and development activity directed toward, let's say, improvement in productive efficiency in the automotive industry.

Clearly, the effects of research and development on a nation as a whole cannot be understood without distinguishing among the various economic sectors. In the United States, for example, where most workers are engaged in service activities and most research and development is devoted to manufacturing, the overall rate of change in productivity cannot be expected to correlate with the amount of national civilian-oriented research and development.

Other factors influence the consequences of research and development. Most important is the delay, of almost indeterminate length, between an investment in research and development and the appearance of its results in the world. Some recent studies have indicated that this time delay has shortened, but even so, any major new technological development does not diffuse throughout the society in less than five to ten years.

In a recent analysis, Harvard's Richard B. Freeman has found (after taking the time delay into account as best he could) a good correlation between the growth rates and profitabilities of different industrial sectors and the research and development that were performed in those sectors in prior years (1). Figures 1, 2, and 3 illustrate

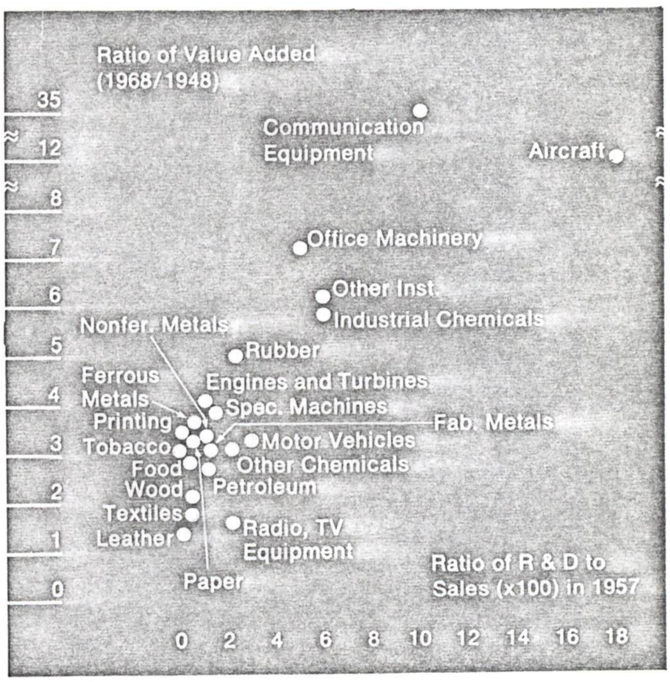
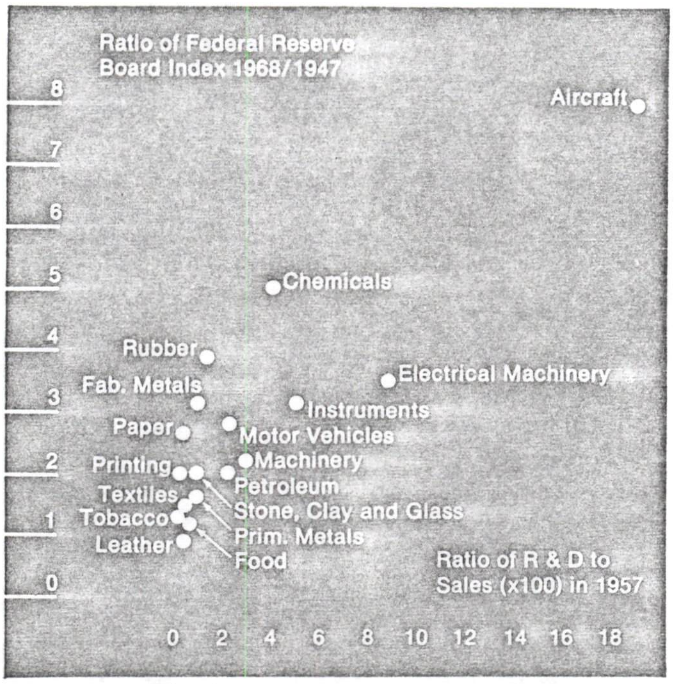


Figure 1. The gross association between research and development intensity and growth in output in various industries is shown here and in Figures 2 and 3 (on the following page). Research and development intensity is indexed by the ratio of R. and D. expenditures to sales. In Figure 1, increases in value added—a term denoting the difference between the value of a manufactured product and that of the starting materials—indicate output changes unadjusted for price increases.

Figure 2. The association between research and development intensity and growth in output in various industries (cont.): in this plot, output increases adjusted for price changes are measured by increases in the Federal Reserve Board Index of Production, and R. and D. intensity is indexed as in Figure 1.



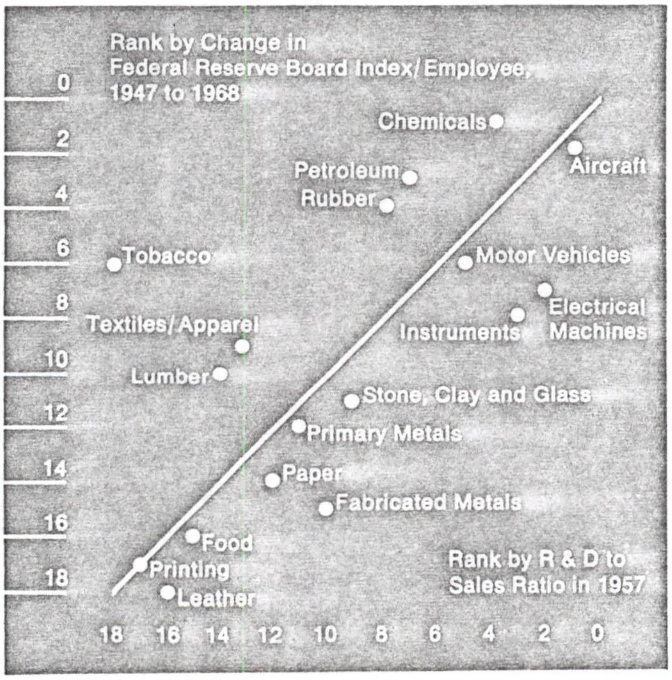


Figure 3. Changes in labor productivity are measured by the industries' indices of production (*see above*) divided by their number of employees. The rank-order relationship in this figure—like the relationships in Figures 1 and 2—indicates a positive and significant *correlation* between growth in industrial output and research and development intensity. (The three plots are after Freeman, ref. 1.)

the correlations. Professor William N. Leonard, of Hofstra, has shown that research and development spending by companies (excluding federal research and development) relates significantly to growth rate of sales, assets, and net income, in 16 industries which, combined, perform nearly all manufacturing activity (2).

Since World War II there have been many other analyses, both for particular industries and for the economy as a whole, that relate the effects of research and development to their economic consequences. It is clear that, for our type of national economy at least, industry under-invests in research and development relative to the total social return it generates in comparison with alternative investments. This under-investment arises because an individual firm cannot appropriate all of the benefits of any new technical development, but must bear most of the cost of that development. In other words, many of the results of a particular development are not of direct benefit to a firm, but indirectly affect other firms that use the results of the development. Furthermore, when a development is highly risky, a firm may forego investment in it because of the cost of failure, even though the rewards of the most probable outcome would fully justify the investment. Or to put the matter another way, individual firms will underinvest in order to minimize their risk, even though the expected rewards from investment in development, on an average basis for many firms, could be quite high. This situation becomes more serious the larger the initial development cost and the more radical the new technology. For instance, in the development of nuclear power the risk may be such that no firm exists with the capability of investing at the early stages of the technology. Only society as a whole can afford the risks or the uncertain costs resulting from technical uncertainty.

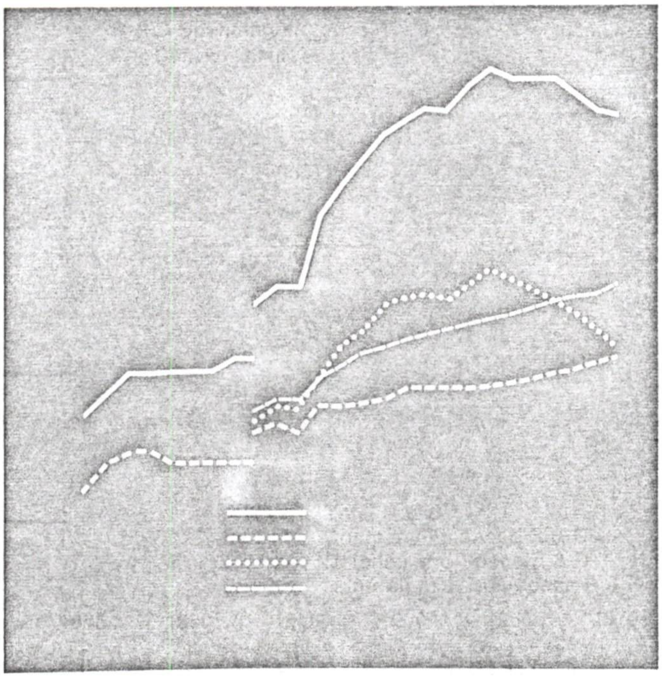
A summary of these studies of the effects of research and development, commissioned by the National Science Foundation (3) indicates that the contributions of research and development to economic growth and productivity, even with this under-investment, is positive, significant, and high.

Industry vs. Space and Defense

During and following World War II, the United States invested heavily in research and development, as illustrated in Figure 4. The most rapid increase occurred between 1953 and 1959, and resulted largely from increases in federal funding (Figure 5); since 1964 there has been a decrease in total effort relative to the G.N.P. It is clear that, as the federal government began to invest more and more in research and development, industry did not follow suit as rapidly; and that, conversely, as the federal government investment decreased, industrial investment in research and development tended to rise.

The recent growth of the U.S. research and development effort is less dramatic when measured, not in dollars, but in the number of the scientists and engineers involved (Figure 6). The costs of technical work have risen much more sharply than the general

Figure 4. Research and development spending in the U.S. since World War II. (Sources: 1945-1953 figures—Office of the Secretary of Defense, in the Census Bureau's *Statistical Abstract of the United States—1960,* Washington, 1960; 1953-1970 figures—National Science Foundation's *National Patterns of Research and Development Resources,* NSF 70-46, Washington, 1970)



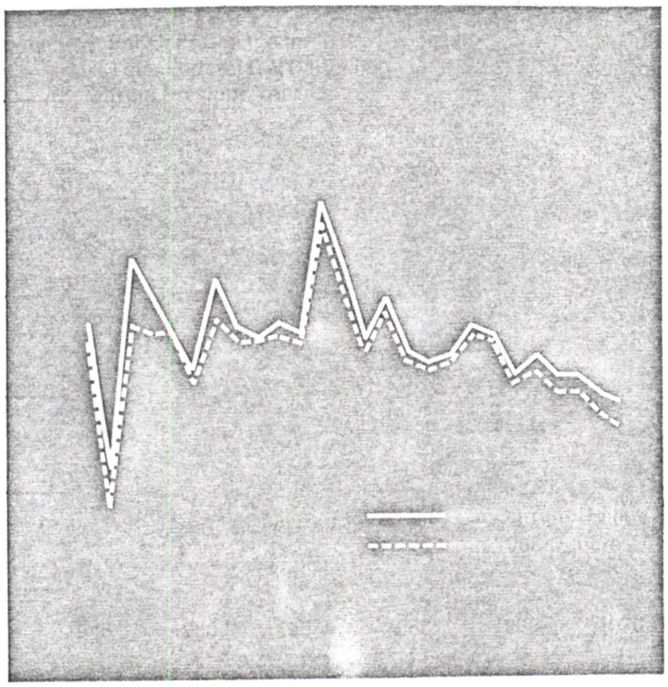
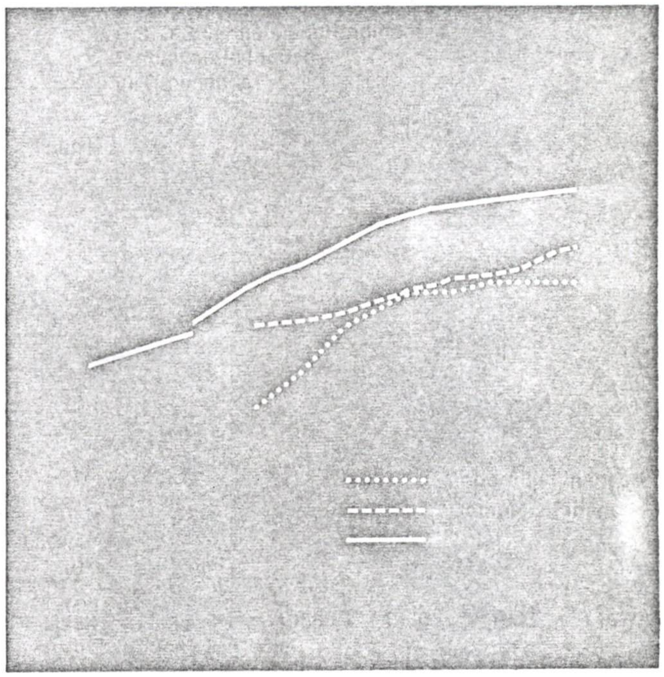


Figure 5. From the same data used in Figure 4, the year-to-year changes in total federal research and development support are shown. ("1958 dollars" were arrived at using the implicit G.N.P. deflator, since there is no specific R. and D. deflator available.)

Figure 6. Post-war growth of research and development in industry in terms of the number of scientists and engineers employed. The 1953-1961 company-federal estimates are by the authors, and 1962-1968 company-federal estimates are from the National Science Foundation. (Sources: 1945-1950 figures—Department of Defense, *The Growth of Scientific Research and Development,* Washington, 1953; 1950-1957—National Science Foundation (jointly with Bureau of Labor Statistics), *Employment of Scientists and Engineers in the United States, 1950-1965,* NSF 68-30, Washington, 1968; 1958-1968—National Science Foundation, *Research and Development in Industry—1968,* NSF 70-29, Washington, 1970.)



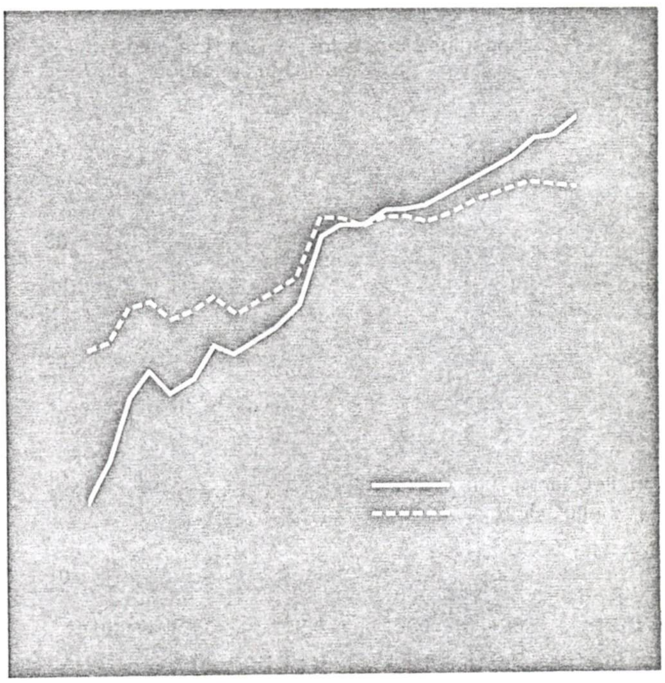
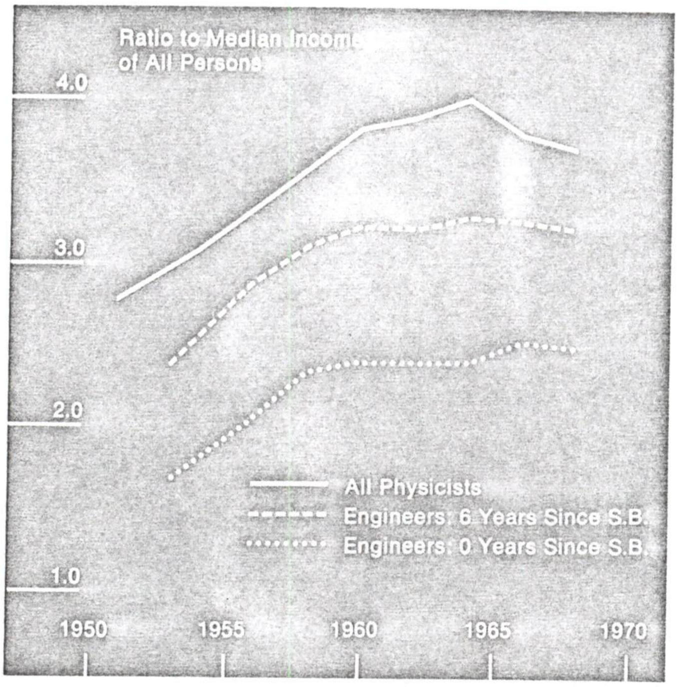


Figure 7. Increases in the cost of research and development per R. and D. scientist and engineer in industry coincide with the increases in federal support traced in Figure 5. (Sources: 1945-1952—Department of Defense; 1953-1956—National Science Foundation/Bureau of Labor Statistics; 1957-1968—National Science Foundation)

Figure 8. Salaries of physicists and engineers as a ratio of the median income of all persons. The rapid rises of the 1950's were a dominant contribution to the cost increases shown in Figure 7 (Sources: median income—Census Bureau's yearly *Current Population Reports, Series P-60 (Consumer Income)*, 1951-1968; engineers—Engineering Manpower Commission, *Professional Income of Engineers, 1970*, New York: Engineers' Joint Council, 1970; physicists—American Institute of Physics, *Physics Manpower—1966* and *Physics Manpower—1969*, Publications R-196 and R-220, based on data from the National Science Foundation's National Register)



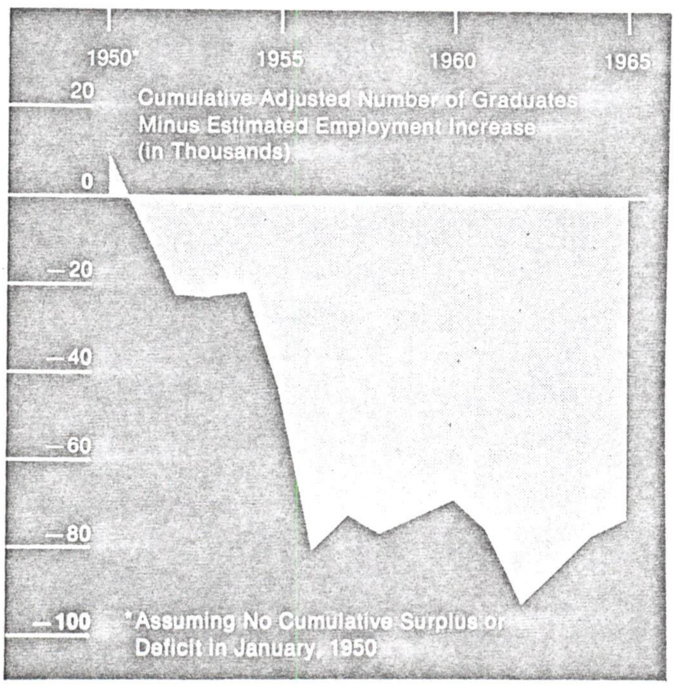


Figure 9. Between 1950 and 1965, nearly 100,000 more engineers were created (on the employment record) than became available as new graduates. This graph traces the cumulative progress of the appearance of "engineers" for whom no engineering degrees were awarded. (Sources: employment figures—National Science Foundation/Bureau of Labor Statistics; degrees—U.S. Office of Education *Digest of Educational Statistics*, OE-10024-70, Washington, 1970 edn.)

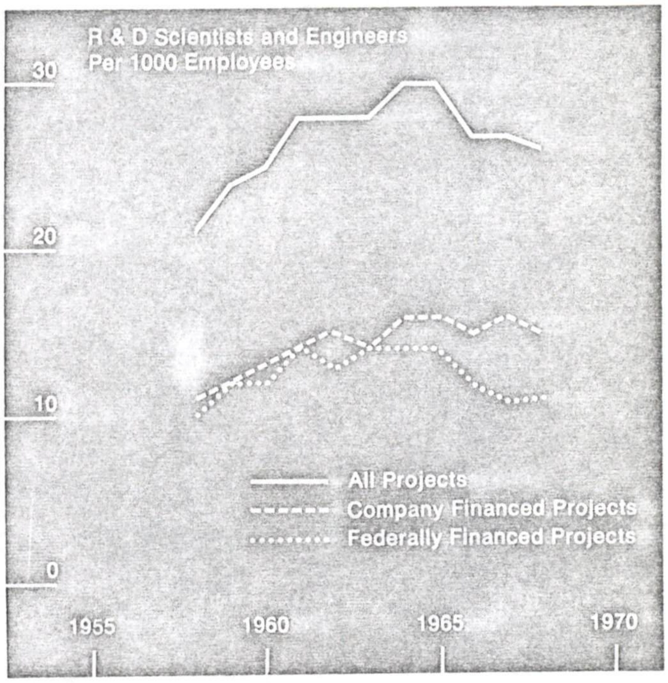
rates of inflation and of improvement in productivity. Indeed, the rapid growth of federal research and development has itself done much to raise the costs. The major increases illustrated in Figure 7 correspond to the increases in federal research and development support (Figure 5). A dominant source of the rise in costs was the increase in salaries of scientists and engineers relative to others (Figure 8).

During the period 1950 to 1960, the rapid increase in space and defense research and development increased the demand for new technical people (4). Apparently there was, within industry, a transfer of technical people from industrial to governmental projects. Because of this competition and the great increase in research and development support, salaries rose, and the cost of research and development, and probably of other technological activities, rose significantly.

Figure 9 illustrates a dramatic effect of this extraordinary demand. Between 1950 and 1965, nearly 100,000 more engineers were created than were available as graduates with engineering degrees. During these years, the increase in the number of engineers reported to be employed was substantially greater than the number of new engineers entering the labor force from higher education. Thus, it appears that industry must have been upgrading technicians to take the place of trained people who were transferred to federal programs. A related consequence of the rapid growth of research and development must have been a decrease in the average level of training, if not skill, of the remaining industrial engineers.

Since 1950, there has been an increase in industrial funding for research and development. However, its impact has been limited by rising costs. Figure 10 illustrates the year-by-year change in the number of R. & D. scientists and engineers per 1,000 employees in those companies performing research and development. Even these figures are somewhat inflated, for some of these scientists and engineers were no doubt engaged in research and development related to products sold for defense and space purposes. The figure illustrates that research and development for industrial purposes has remained about constant for nearly ten years.

Figure 10. For those companies reporting research and development activity, these curves show the number of R. & D. scientists and engineers employed per thousand employees. (Sources: 1958-1961—authors' estimates; 1962-1968—National Science Foundation)



Other factors have probably affected the industrial investment in technology. Interest rates have continually risen in the United States during this period, and, according to some economists at least, this has retarded capital investment. Not only is capital investment required in order to infuse new technology into the economy, but also large investment commitments in general tend to stimulate research and development. In addition, it is likely that the combination of high government demand and rapid obsolescence of technology in the space and defense fields attracted a disproportionate fraction of venture capital to these industries, and was an important contributing factor to the rising price of capital.

During the last several years, the decline of the federal effort has not been compensated for by the slight increase in industrial activity. The result has been unemployment of scientists and engineers, particularly those that were connected with space and defense. Crude estimates indicate the total unemployed to be of the order of 100,000.

To reiterate, the rapid and large growth of federally supported research and development, occurring particularly between 1953 and 1960, appears to have had several major effects on the technological activity of the United States and its industry. The most important effect of this growth was the rise in overall cost of research and development. This increase occurred not only in the costs of research and development to the government, but, very significantly, in the cost of this activity to industry. A major factor in this cost rise was the increased cost of the technical personnel engaged in it. The rise in the rank of starting engineers and scientists in the income distribution, relative to the rest of the population, dramatically illustrates this increase (Figure 11).

Starting salaries for engineers with bachelor degrees, for example, rose during the period of rapid research and development expansion from the 77th percentile in the rank of income of all people in the United States, to about the 86th percentile. During this same period, it is estimated by Freeman that about 20 to 30 per cent of the increased activity supported by the federal government was made possible by a transfer of people from industrially supported projects. The remaining increase was accomplished by absorbing the supply of new

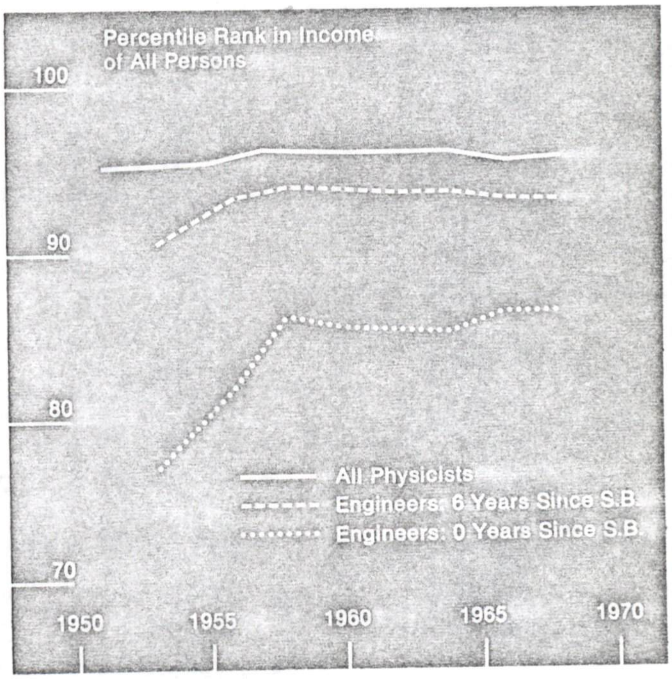


Figure 11. If incomes of all persons are arranged in a ranking order, any given income can be assigned a percentile position, indicating the percentage of the population having a lower income. Shown here are the percentile positions of median salaries earned by engineers and physicists. (Sources: as Figure 8)

Figure 12. Changes in salary within the engineering profession as a whole affect the number of students choosing engineering majors. This graph shows the success of a prediction of the proportion of all freshmen who choose engineering, made on the basis of engineering salaries, relative to other professional salaries, one year earlier. (Richard B. Freeman, *The Market for College-Trained Manpower,* Cambridge: Harvard University Press, 1971)

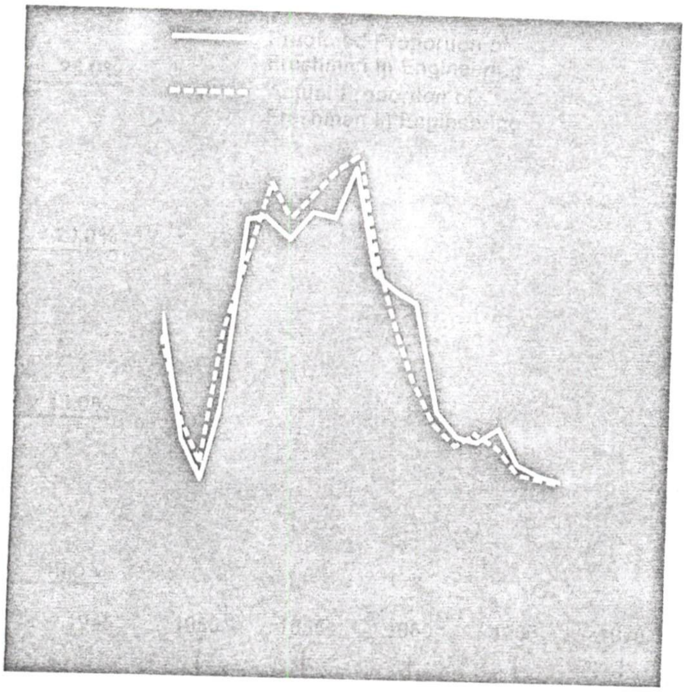


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Table I. The combined fraction of male college graduates choosing science, mathematics and engineering has changed little since World War II, although the relative proportions of these fields have changed somewhat. (Hugh Folk, *The Shortage of Scientists and Engineers,* Lexington, Heath Lexington, 1970)

technical people.

University as Supplier

The increase in demand generated by federal funds had a significant effect on the choice made among fields by those attending universities. The fraction of college graduates opting for science, mathematics, and engineering has changed very little since World War II (Table I). Hugh Folk has pointed out that the choice of a broad field by students does not appear to be affected by demand, which influences only the choice of lucrative activities *within* broad fields. Changes in salaries and stipends affect the choices between specialties, and determine in part whether or not students opt for graduate education in special fields. However, though those in science and engineering have been mostly supported by federal funds to universities, the proportion of scientists and engineers among all PhD's has not increased appreciably. Apparently, the federal funds merely permitted the universities to redistribute their resources to a rapidly rising social demand for graduate education proportionately in all fields of knowledge. Changes in salaries and stipends affected choices toward engineering and toward physics, for example. Figure 12 illustrates the relationship between the actual number of freshman enrollments in engineering, year-by-year, and the changed incentives predicted from salary changes.

There has been some shift between engineering and mathematics, but, in any event, the response of the new supply of technical people to economic factors is sluggish and cyclical. The yearly new supply of graduate scientists, mathematicians, and engineers has varied from 33,000 to a high of 61,000. In recent years, this new supply has been about equal to the reported increase in new employment of scientists and engineers, implying little upgrading of people who did not have a "certificate" as scientists or engineers.

There has been great growth in the support of research in universities by the federal government, with by far the largest share derived from the support of biomedical research in university medical schools and affiliated hospitals. However, for the physical sciences, and especially engineering, the largest share has derived from the Defense Department, AEC, and NASA. This support surely biased university activity away from industrially related research, especially that connected with the less glamorous industrial problems.

The Practical Loss

While it is probably impossible to assess all the effects of federal policy over the past several decades, there are several possibilities that appear reasonable. It seems reasonable to expect that, ten years or so after a relative decline in technical activity, its consequences should begin to be evident. For example, the rate of increase in productivity might begin to diminish. Although the dependence of productivity upon a wide range of other factors (the availability of capital, for example) is well recognized, eventually a reduction in investment in technical activity devoted to industrial purposes should be reflected in a decreased rate of im-

Table II. Approximate proportions of national resources, at market prices, devoted to research and development. For the U.S. and European countries selected, the figures are averages for 1959-1965; for Japan, the figures are for 1963. The data appear to indicate a significant U.S. advantage in defense and space research and a rather lesser advantage in civilian-oriented work. (Sources: Japan—*International Statistical Year for Research and Development, A Study of Resources Devoted to R. and D. in O.E.C.D. Member Countries in 1963/64*, Vol. 2, O.E.C.D., Paris, 1968; other countries—Boretsky, ref. 6.)

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Table III. The same information as in Table II, for civilian-oriented work only, translated into cost-equivalent terms and into full-time-equivalent technical man power. The last column expresses each national civilian research and development effort (in cost-equivalent terms) as a proportion of that nation's G.N.P., also converted into cost-equivalent terms. A number of nations, on this basis, have been making more intensive research efforts during the early '60's, for civilian purposes, than has the U.S. (after Boretsky)

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provement in productivity. And, indeed, in the last few years, productivity increases have declined (5).

There is another way in which we can deduce the effects of the post-war research and development policies. Boretsky (6) has compared the technical activity of Europe and Japan with that of the United States for the period 1959-65 (just following the rapid growth of the United States effort). Table II compares the total research and development efforts for these years as fractions of national G.N.P.'s at market prices, for the United States, Japan and the major European countries. The defense and space portion of the total effort and the civilian effort are also included for comparison. Superficially at least, this table would indicate a significant advantage of the United States for all research and development, and a somewhat lesser advantage in its "civilian-oriented" activity.

However, when research and development efforts are translated into cost-equivalent terms, and into the number of scientists, engineers, and technicians employed (Table III), the results are startling. The last column in Table III expresses cost-equivalent expenditures for research and development as fractions of the G.N.P.'s, the latter converted to equal-purchasing-power terms. When the comparison is thus made on the basis of cost-equivalent expenditures, the relative advantage of the United States investment in civilian research and development disappears. Even more significant, about 30 to 35 per cent more scientists, engineers, and technicians were engaged in civilian-oriented research and development in the eight European countries studied than in the United States. This group of countries has a slightly greater population than the United States, but a one-third smaller G.N.P. When compared on this basis, the relative effort in Europe was substantially greater than that in the United States—the reason being, basically, that the relative cost of research and development personnel is less in Europe than in the United States.

Furthermore, there was no substantial investment in defense and space research and development in any of the European countries except the United Kingdom; there was not a disproportionate rise in salaries, and there was no marked displacement of scientists and engineers from industrial to national projects. Although European data for more recent years are not readily available, it seems likely that—in view of the slow growth of research activity in the United States relative to other O.E.C.D. countries in these years—the disparity is now even greater. As early as 1955, the number of scientists and engineers engaged in non-space, non-defense activity in Europe must have been higher than in the United States.

A comparison between Japan and the United States is even more depressing. During the 1959-65 period, the Japanese spent a significantly larger portion of their G.N.P., on an equivalency basis, for civilian research and development than did the United States. With one-half the United States population and one-fifth the United States G.N.P., Japan employed 70 per cent as many professional research and development personnel in their civilian effort as did the United States.

Spin-Off?

Many would argue that the analysis thus far has neglected the indirect effects of the space and defense research and development efforts of the United States. It is clear that the research and development that has been supported by the government must have been beneficial to at least some industrial activities. Further, the government provided a market for sophisticated technical goods, which no doubt stimulated research and development activities which were transferable to civilian products. But, granted that this indirect effect of space and defense oriented work presumably exists, the question is, how significant is it?

Boretsky analyzes this matter in what seems to be an effective way. Consider the efforts of ten people engaged in federal research and development; how much effort aimed at a particular industrial objective, on the average, are these ten equivalent to? Boretsky argues that their absolute maximum equivalent is 3-1/3, and the minimum is perhaps one-half a civilian researcher. In other words, 5 to 33 per cent of a given amount of space and defense research and development might be considered to be the "direct" effect of that effort on the economy.

Assuming a "spin-off" as high as 20 per cent (for both Europe and the United States) a new measure of the effective number of scientists and engineers can be derived. It turns out that the United States still lags

behind Europe and Japan on a comparative population basis. In the specific field of nuclear technology not related to military applications, Boretsky makes a more startling comparison. He estimates that 50 per cent more scientists, engineers, and technicians are involved in this work in Europe than in the United States.

This disparity in technical effort, existing for more than ten years, may have begun to be reflected in our trade with Europe and with Japan. Consider the trade balance in the technologically intensive products of chemicals, machinery, electrical equipment, transportation equipment and instruments. In 1968, the United States had a favorable balance of trade of these products with Europe of $1.5 billion. From 1962 to 1968, however, the rate of growth of imports of these products from Europe averaged 20 per cent, and the rate of growth in their export from the United States averaged only 9 per cent. During this same period, the United State's trade balance with Japan in these products turned from a $300 million surplus to a $500 million deficit. While United States imports from Japan were growing at 32 per cent a year, United States exports to Japan were increasing at only 7 per cent a year.

If the trend continues, Boretsky estimates that by 1973, in technologically intensive products alone, there will be a trade deficit with Europe of almost $2 billion. The situation with respect to Japan is even more disturbing: he estimates that the United States "technological" trade deficit to Japan will be almost $5 billion by 1973.

It is clear, of course, that monetary factors and relative labor cost factors are also important to trade balance considerations. It is only in high-technology products with rapid potential for growth (and in agriculture, where the U.S. has long maintained a technological lead) that the United States has had much of a potential advantage—and it is here (*except* in agriculture) that we find the downturn.

Clearly, analysis of a matter as complicated as the relationship between technology, the economy, and social welfare can never be complete, nor can conclusions drawn from incomplete analysis ever be taken with assurance. Nevertheless, it appears that in the United States we have substantially under-invested in the kinds of technical effort that are necessary for the improvement of our industrial output and the quality of our life. In recent years this under-investment in technology for civilian pursuits has been made substantially greater as a result of the large commitment of the United States to activities related to defense and space. The natural working of the economic system which would in any case have led the industry to invest too little in technical activities has been further distorted because of the higher cost of research and development resulting from the federal effort. Even in the government sector of research and development, all the European countries and Japan spend more than 20 per cent of government research and development for civilian purposes, whereas the United States spends less than 6 per cent. Thus our competitors supplement the industrial investment in research and development for civilian purposes to a much greater degree than do we.

The Choice of Strategies

We are now faced with a dilemma. There are 100,000 scientists and engineers out of work; there are large unsatisfied social needs; we are suffering adverse effects from our past uses of technology; and our economic growth is faltering. At the same time, the costs of education and of research and development continue to rise, sustained apparently by the social and political structure that we have set up.

Direct research and development investments by the federal government—whether for defense, space or social welfare purposes—will, if they are too large, draw off technical activity which could be turned to industrial improvement, just as we experienced in the 1950's. Substantial increases in the availability of new scientist and engineer graduates would eventually lower their relative prices, but there would be a period of costly and inhumane readjustment. On the other hand, restrictive policies to discourage young people either from opting for technical education or from continuing at university for advanced graduate education are, of course, in the long term, self-defeating.

Like any complex public problem, this dilemma will not be resolved by any single public policy decision. Addressing the social tasks directly, perhaps the most important single action that is required is a substantial

increase in support for the improvement, both in quality and efficiency, of those public services in which private industry plays only a small role, such as education and the delivery of health care. Likewise, those socially desirable activities in which private incentives for technical work are small or non-existent, such as the improvement of living conditions in the cities and of the safety of our transport system, require significantly increased support.

To simply spend enough to re-employ unemployed scientists and engineers by immediate federal research and development funding in these social fields, is not the answer, for we do not know enough about the task; nor would such a move (which would in any case face great social obstacles) encourage industry to play its own part. For the present, in these fields we must not only invest in research and development, but we must devise ways of changing the structure of the delivery systems of social services and of the education of technical people, to facilitate the adoption and diffusion of new techniques. A major effort of direct government support to meet these social needs is required.

A second major effort would be the encouragement of university research related to improving industrial productivity, to reducing the waste and pollution of industry, and generally to problems associated with the productivity, products, and adverse effects of industrial production. This federal support to universities would redress the present academic bias, especially in engineering, toward the kinds of work that tend to improve our defense and space capabilities.

In some way, also, government must underwrite industrial research and development itself, since the economy has always tended to under-invest in it, and its present over-costliness results from past federal policies. This can be done either directly by subsidy or indirectly through tax rebates. The entire set of corporate and government policies that encourage potentially high-export industries needs to be reviewed.

Whether a society effectively uses technology for productive and beneficial purposes depends upon a large number of factors. The supply of technically trained people, the willingness to invest in them, the capital necessary to embody the technology in useful machines and processes, the level of general education, the skill of the potential labor force, the economic and political structure of the society, all play roles. The effective use of technology requires that a large number of appropriate conditions be met simultaneously; a single missing ingredient (for example, the absence of available capital, or the necessary management attitudes) may completely halt either technological innovation or the spread of technology within the society.

If we are to meet the social needs of our time and to continue to provide the material needs of our population, new policies and directions of our governmental, industrial and academic institutions are required.

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The U.S. government's pyramiding investment in research and development in the 1950's invoked the law of supply and demand, say Dr. Herbert Hollomon (seated in photograph) and Alan Harger. The loser was American industry—unable or unwilling to compete. Can we now restore to research its true value and to American industry its tradition of technological innovation?

J. Herbert Hollomon
Consultant to the President and Provost of M.I.T.

Alan E. Harger
Administrative Assistant to Dr. Hollomon

America's Technological Dilemma

During these times of rapid change, of the increasing awareness of social problems, of declining trade balances, of inflation, and of unemployed scientists and engineers, thoughtful attention must be directed to the science and technology policy of the U.S. One important aspect of this policy has to do with the way in which technology is used by society, particularly how it affects civilian or industrial activity.

Many people have struggled to quantify the influence that new technology has upon industrial development, economic growth, and social advance. Qualitatively, the dependence of a modern economy on the use of new technology is accepted: technology becomes embodied in more effective production machinery, in more skilled labor, and in products and services that better serve social needs. The direct connections between research and development, and the resultant particular practical benefits, are more difficult to specify. However, it is these connections which must be understood if science policy (national or corporate) is to be effective.

In any attempt to assess the direct consequences of investment in research and development, it must be clearly established that the particular investment has been directed toward the purposes which are being considered. For example, suppose we are looking for the sources of general economic health in the nation; we must recognize that the research and development which have been aimed toward space flight and defense are unlikely to have had as significant an influence as an equivalent research and development activity directed toward, let's say, improvement in productive efficiency in the automotive industry.

Clearly, the effects of research and development on a nation as a whole cannot be understood without distinguishing among the various economic sectors. In the United States, for example, where most workers are engaged in service activities and most research and development is devoted to manufacturing, the overall rate of change in productivity cannot be expected to correlate with the amount of national civilian-oriented research and development.

Other factors influence the consequences of research and development. Most important is the delay, of almost indeterminate length, between an investment in research and development and the appearance of its results in the world. Some recent studies have indicated that this time delay has shortened, but even so, any major new technological development does not diffuse throughout the society in less than five to ten years.

In a recent analysis, Harvard's Richard B. Freeman has found (after taking the time delay into account as best he could) a good correlation between the growth rates and profitabilities of different industrial sectors and the research and development that were performed in those sectors in prior years (1). Figures 1, 2, and 3 illustrate

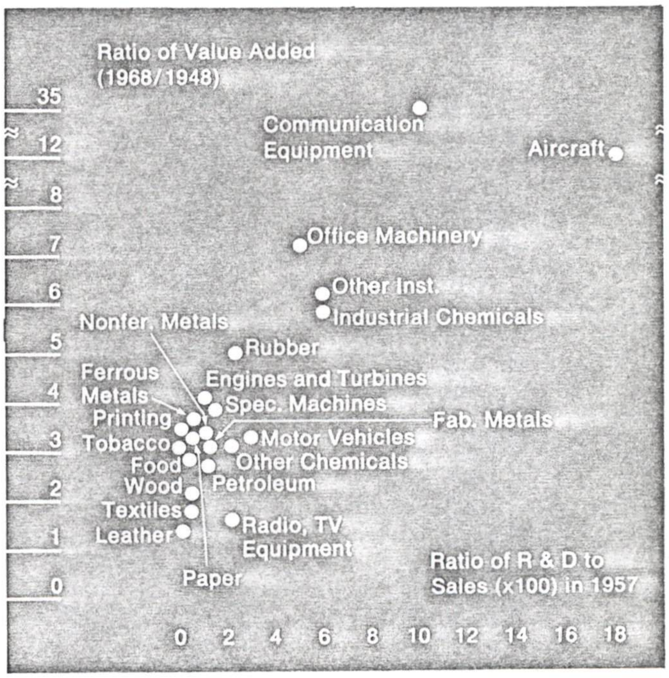
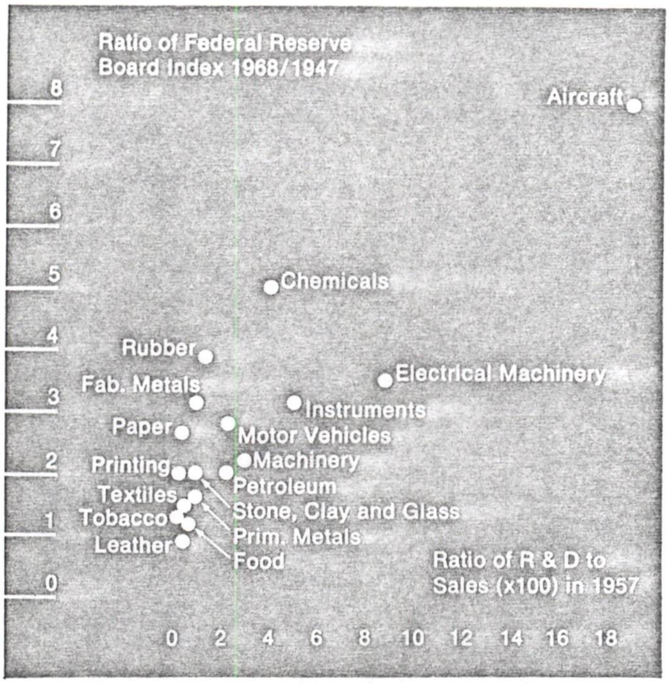


Figure 1. The gross association between research and development intensity and growth in output in various industries is shown here and in Figures 2 and 3 (on the following page). Research and development intensity is indexed by the ratio of R. and D. expenditures to sales. In Figure 1, increases in value added—a term denoting the difference between the value of a manufactured product and that of the starting materials—indicate output changes unadjusted for price increases.

Figure 2. The association between research and development intensity and growth in output in various industries (cont.): in this plot, output increases adjusted for price changes are measured by increases in the Federal Reserve Board Index of Production, and R. and D. intensity is indexed as in Figure 1.



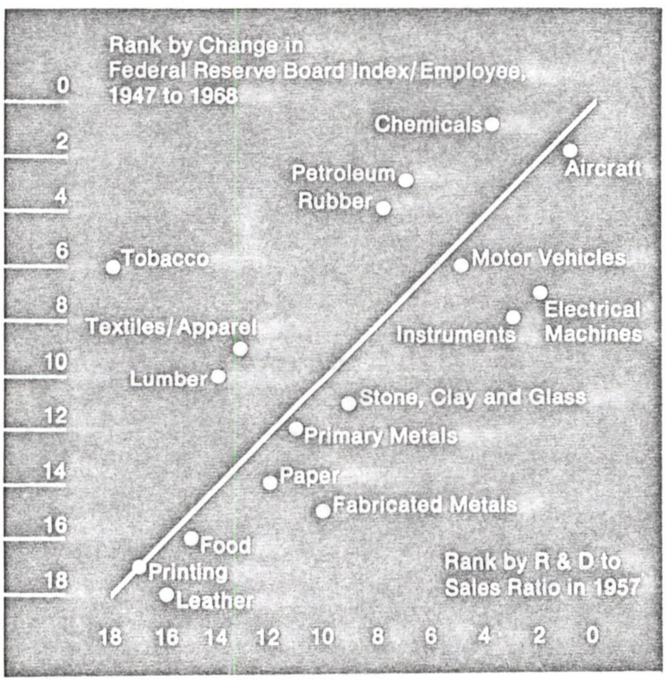


Figure 3. Changes in labor productivity are measured by the industries' indices of production (*see above*) divided by their number of employees. The rank-order relationship in this figure—like the relationships in Figures 1 and 2—indicates a positive and significant *correlation* between growth in industrial output and research and development intensity. (The three plots are after Freeman, ref. 1.)

the correlations. Professor William N. Leonard, of Hofstra, has shown that research and development spending by companies (excluding federal research and development) relates significantly to growth rate of sales, assets, and net income, in 16 industries which, combined, perform nearly all manufacturing activity (2).

Since World War II there have been many other analyses, both for particular industries and for the economy as a whole, that relate the effects of research and development to their economic consequences. It is clear that, for our type of national economy at least, industry under-invests in research and development relative to the total social return it generates in comparison with alternative investments. This under-investment arises because an individual firm cannot appropriate all of the benefits of any new technical development, but must bear most of the cost of that development. In other words, many of the results of a particular development are not of direct benefit to a firm, but indirectly affect other firms that use the results of the development. Furthermore, when a development is highly risky, a firm may forego investment in it because of the cost of failure, even though the rewards of the most probable outcome would fully justify the investment. Or to put the matter another way, individual firms will underinvest in order to minimize their risk, even though the expected rewards from investment in development, on an average basis for many firms, could be quite high. This situation becomes more serious the larger the initial development cost and the more radical the new technology. For instance, in the development of nuclear power the risk may be such that no firm exists with the capability of investing at the early stages of the technology. Only society as a whole can afford the risks or the uncertain costs resulting from technical uncertainty.

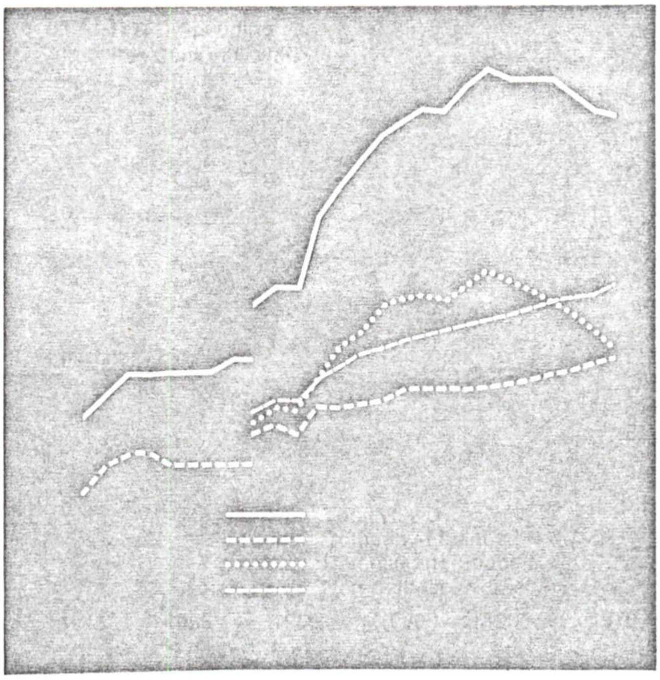
A summary of these studies of the effects of research and development, commissioned by the National Science Foundation (3) indicates that the contributions of research and development to economic growth and productivity, even with this under-investment, is positive, significant, and high.

Industry vs. Space and Defense

During and following World War II, the United States invested heavily in research and development, as illustrated in Figure 4. The most rapid increase occurred between 1953 and 1959, and resulted largely from increases in federal funding (Figure 5); since 1964 there has been a decrease in total effort relative to the G.N.P. It is clear that, as the federal government began to invest more and more in research and development, industry did not follow suit as rapidly; and that, conversely, as the federal government investment decreased, industrial investment in research and development tended to rise.

The recent growth of the U.S. research and development effort is less dramatic when measured, not in dollars, but in the number of the scientists and engineers involved (Figure 6). The costs of technical work have risen much more sharply than the general

Figure 4. Research and development spending in the U.S. since World War II. (Sources: 1945-1953 figures—Office of the Secretary of Defense, in the Census Bureau's *Statistical Abstract of the United States—1960*, Washington, 1960; 1953-1970 figures—National Science Foundation's *National Patterns of Research and Development Resources*, NSF 70-46, Washington, 1970)



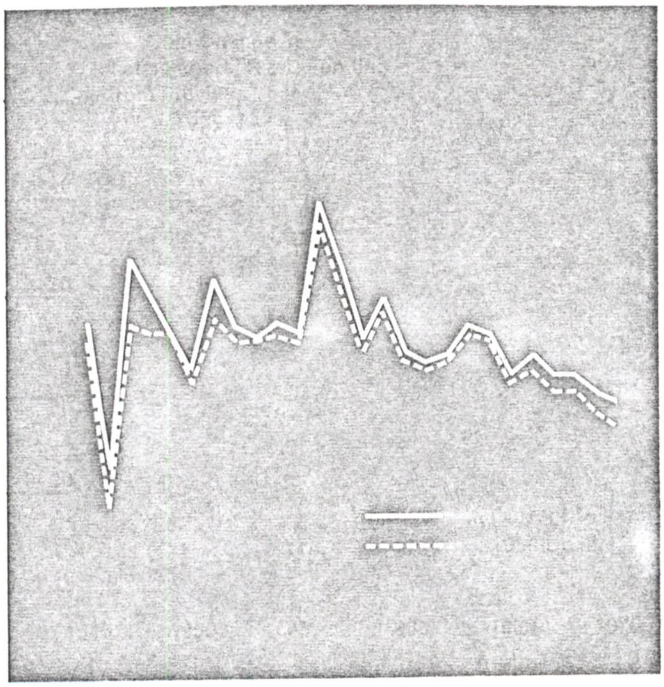
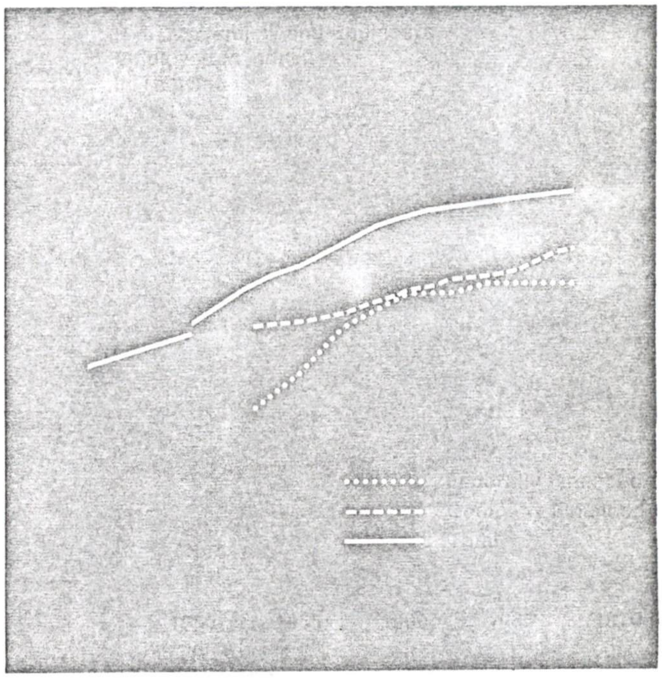


Figure 5. From the same data used in Figure 4, the year-to-year changes in total federal research and development support are shown. ("1958 dollars" were arrived at using the implicit G.N.P. deflator, since there is no specific R. and D. deflator available.)

Figure 6. Post-war growth of research and development in industry in terms of the number of scientists and engineers employed. The 1953-1961 company-federal estimates are by the authors, and 1962-1968 company-federal estimates are from the National Science Foundation. (Sources: 1945-1950 figures—Department of Defense, *The Growth of Scientific Research and Development*, Washington, 1953; 1950-1957—National Science Foundation (jointly with Bureau of Labor Statistics), *Employment of Scientists and Engineers in the United States, 1950-1965*, NSF 68-30, Washington, 1968; 1958-1968—National Science Foundation, *Research and Development in Industry—1968*, NSF 70-29, Washington, 1970.)



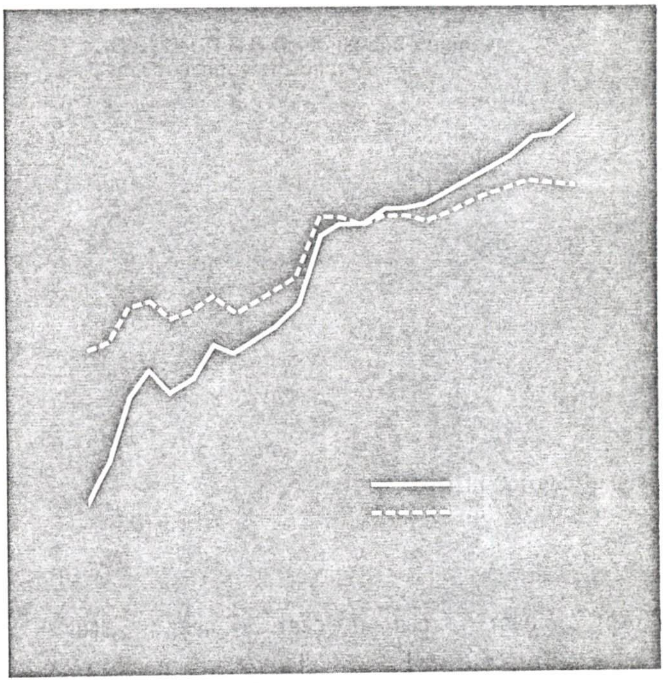
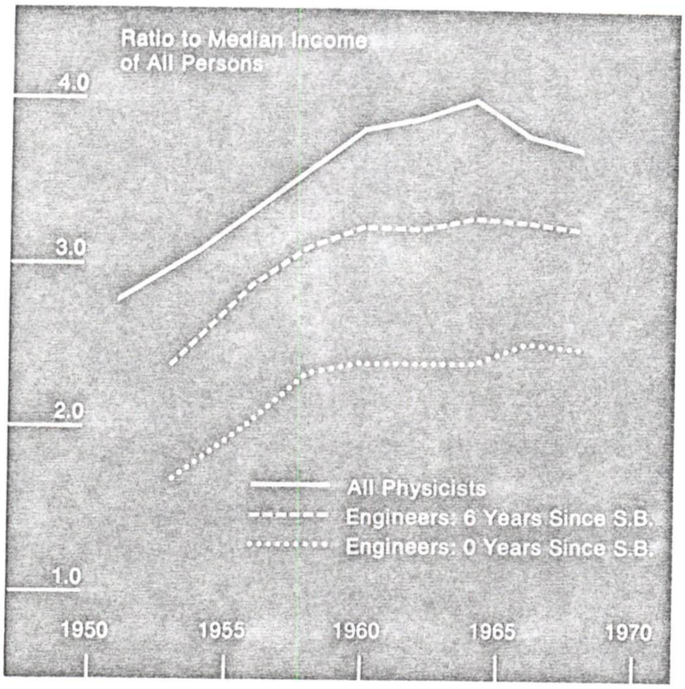


Figure 7. Increases in the cost of research and development per R. and D. scientist and engineer in industry coincide with the increases in federal support traced in Figure 5. (Sources: 1945-1952—Department of Defense; 1953-1956—National Science Foundation/Bureau of Labor Statistics; 1957-1968—National Science Foundation)

Figure 8. Salaries of physicists and engineers as a ratio of the median income of all persons. The rapid rises of the 1950's were a dominant contribution to the cost increases shown in Figure 7 (Sources: median income—Census Bureau's yearly *Current Population Reports, Series P-60 (Consumer Income)*, 1951-1968; engineers—Engineering Manpower Commission, *Professional Income of Engineers, 1970*, New York: Engineers' Joint Council, 1970; physicists—American Institute of Physics, *Physics Manpower—1966* and *Physics Manpower—1969*, Publications R-196 and R-220, based on data from the National Science Foundation's National Register)



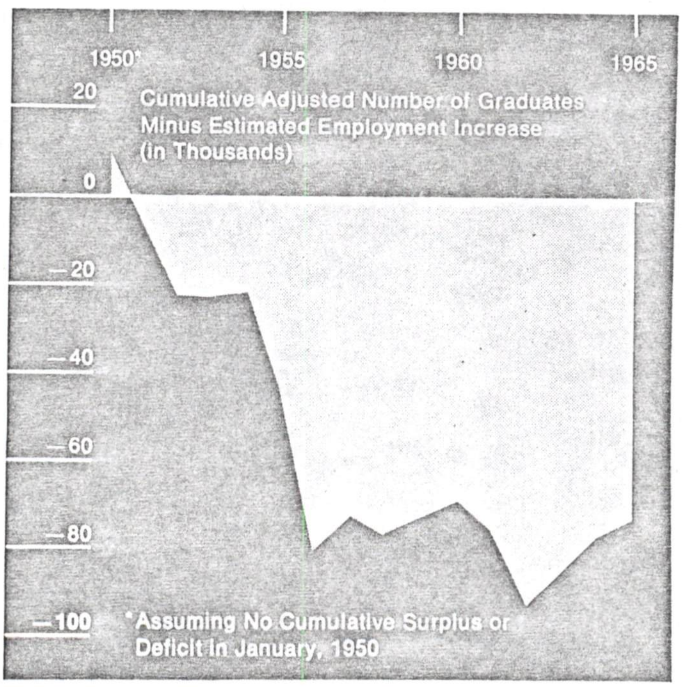


Figure 9. Between 1950 and 1965, nearly 100,000 more engineers were created (on the employment record) than became available as new graduates. This graph traces the cumulative progress of the appearance of "engineers" for whom no engineering degrees were awarded. (Sources: employment figures—National Science Foundation/Bureau of Labor Statistics; degrees—U.S. Office of Education *Digest of Educational Statistics*, OE-10024-70, Washington, 1970 edn.)

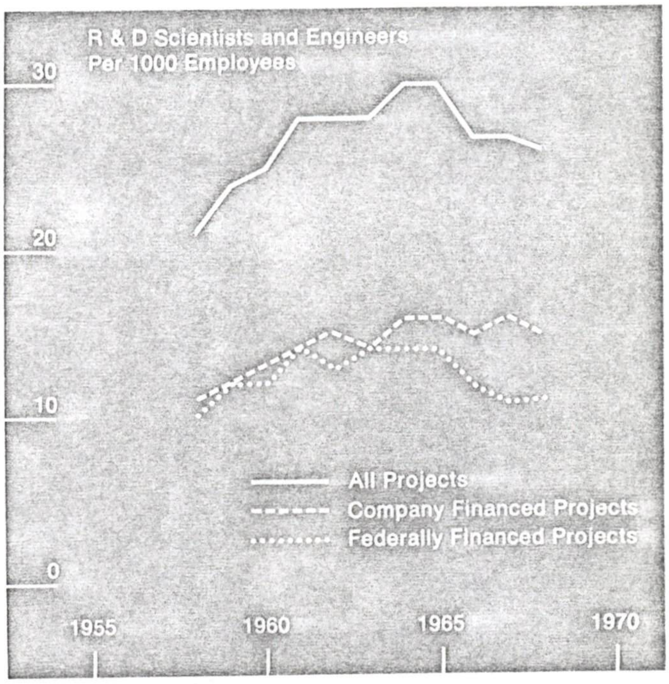
rates of inflation and of improvement in productivity. Indeed, the rapid growth of federal research and development has itself done much to raise the costs. The major increases illustrated in Figure 7 correspond to the increases in federal research and development support (Figure 5). A dominant source of the rise in costs was the increase in salaries of scientists and engineers relative to others (Figure 8).

During the period 1950 to 1960, the rapid increase in space and defense research and development increased the demand for new technical people (4). Apparently there was, within industry, a transfer of technical people from industrial to governmental projects. Because of this competition and the great increase in research and development support, salaries rose, and the cost of research and development, and probably of other technological activities, rose significantly.

Figure 9 illustrates a dramatic effect of this extraordinary demand. Between 1950 and 1965, nearly 100,000 more engineers were created than were available as graduates with engineering degrees. During these years, the increase in the number of engineers reported to be employed was substantially greater than the number of new engineers entering the labor force from higher education. Thus, it appears that industry must have been upgrading technicians to take the place of trained people who were transferred to federal programs. A related consequence of the rapid growth of research and development must have been a decrease in the average level of training, if not skill, of the remaining industrial engineers.

Since 1950, there has been an increase in industrial funding for research and development. However, its impact has been limited by rising costs. Figure 10 illustrates the year-by-year change in the number of R. & D. scientists and engineers per 1,000 employees in those companies performing research and development. Even these figures are somewhat inflated, for some of these scientists and engineers were no doubt engaged in research and development related to products sold for defense and space purposes. The figure illustrates that research and development for industrial purposes has remained about constant for nearly ten years.

Figure 10. For those companies reporting research and development activity, these curves show the number of R. & D. scientists and engineers employed per thousand employees. (Sources: 1958-1961—authors' estimates; 1962-1968—National Science Foundation)



Other factors have probably affected the industrial investment in technology. Interest rates have continually risen in the United States during this period, and, according to some economists at least, this has retarded capital investment. Not only is capital investment required in order to infuse new technology into the economy, but also large investment commitments in general tend to stimulate research and development. In addition, it is likely that the combination of high government demand and rapid obsolescence of technology in the space and defense fields attracted a disproportionate fraction of venture capital to these industries, and was an important contributing factor to the rising price of capital.

During the last several years, the decline of the federal effort has not been compensated for by the slight increase in industrial activity. The result has been unemployment of scientists and engineers, particularly those that were connected with space and defense. Crude estimates indicate the total unemployed to be of the order of 100,000.

To reiterate, the rapid and large growth of federally supported research and development, occurring particularly between 1953 and 1960, appears to have had several major effects on the technological activity of the United States and its industry. The most important effect of this growth was the rise in overall cost of research and development. This increase occurred not only in the costs of research and development to the government, but, very significantly, in the cost of this activity to industry. A major factor in this cost rise was the increased cost of the technical personnel engaged in it. The rise in the rank of starting engineers and scientists in the income distribution, relative to the rest of the population, dramatically illustrates this increase (Figure 11).

Starting salaries for engineers with bachelor degrees, for example, rose during the period of rapid research and development expansion from the 77th percentile in the rank of income of all people in the United States, to about the 86th percentile. During this same period, it is estimated by Freeman that about 20 to 30 per cent of the increased activity supported by the federal government was made possible by a transfer of people from industrially supported projects. The remaining increase was accomplished by absorbing the supply of new

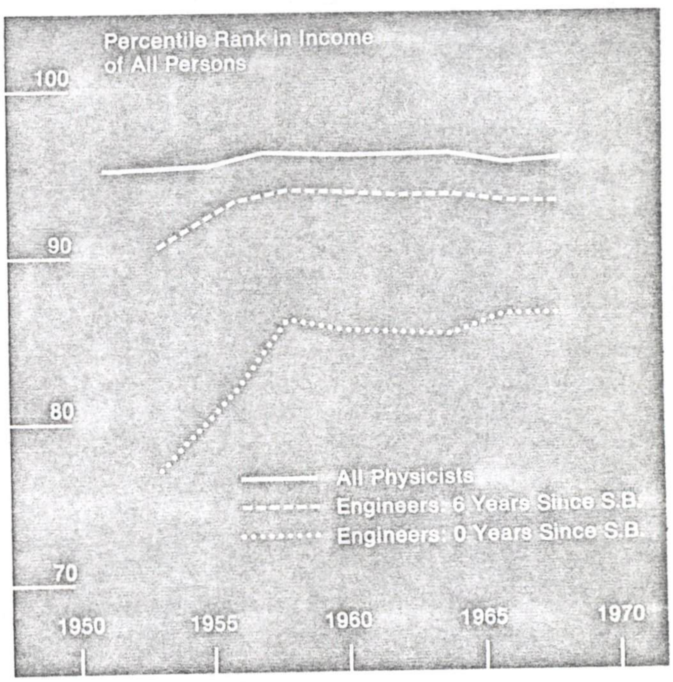


Figure 11. If incomes of all persons are arranged in a ranking order, any given income can be assigned a percentile position, indicating the percentage of the population having a lower income. Shown here are the percentile positions of median salaries earned by engineers and physicists. (Sources: as Figure 8)

Figure 12. Changes in salary within the engineering profession as a whole affect the number of students choosing engineering majors. This graph shows the success of a prediction of the proportion of all freshmen who choose engineering, made on the basis of engineering salaries, relative to other professional salaries, one year earlier. (Richard B. Freeman, *The Market for College-Trained Manpower,* Cambridge: Harvard University Press, 1971)

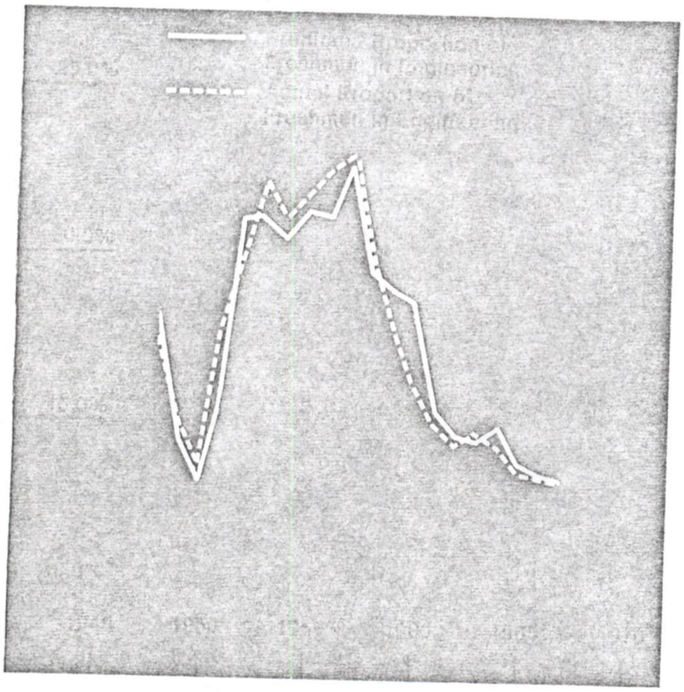


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Table I. The combined fraction of male college graduates choosing science, mathematics and engineering has changed little since World War II, although the relative proportions of these fields have changed somewhat. (Hugh Folk, *The Shortage of Scientists and Engineers,* Lexington, Heath Lexington, 1970)

technical people.

University as Supplier

The increase in demand generated by federal funds had a significant effect on the choice made among fields by those attending universities. The fraction of college graduates opting for science, mathematics, and engineering has changed very little since World War II (Table I). Hugh Folk has pointed out that the choice of a broad field by students does not appear to be affected by demand, which influences only the choice of lucrative activities *within* broad fields. Changes in salaries and stipends affect the choices between specialties, and determine in part whether or not students opt for graduate education in special fields. However, though those in science and engineering have been mostly supported by federal funds to universities, the proportion of scientists and engineers among all PhD's has not increased appreciably. Apparently, the federal funds merely permitted the universities to redistribute their resources to a rapidly rising social demand for graduate education proportionately in all fields of knowledge. Changes in salaries and stipends affected choices toward engineering and toward physics, for example. Figure 12 illustrates the relationship between the actual number of freshman enrollments in engineering, year-by-year, and the changed incentives predicted from salary changes.

There has been some shift between engineering and mathematics, but, in any event, the response of the new supply of technical people to economic factors is sluggish and cyclical. The yearly new supply of graduate scientists, mathematicians, and engineers has varied from 33,000 to a high of 61,000. In recent years, this new supply has been about equal to the reported increase in new employment of scientists and engineers, implying little upgrading of people who did not have a "certificate" as scientists or engineers.

There has been great growth in the support of research in universities by the federal government, with by far the largest share derived from the support of biomedical research in university medical schools and affiliated hospitals. However, for the physical sciences, and especially engineering, the largest share has derived from the Defense Department, AEC, and NASA. This support surely biased university activity away from industrially related research, especially that connected with the less glamorous industrial problems.

The Practical Loss

While it is probably impossible to assess all the effects of federal policy over the past several decades, there are several possibilities that appear reasonable. It seems reasonable to expect that, ten years or so after a relative decline in technical activity, its consequences should begin to be evident. For example, the rate of increase in productivity might begin to diminish. Although the dependence of productivity upon a wide range of other factors (the availability of capital, for example) is well recognized, eventually a reduction in investment in technical activity devoted to industrial purposes should be reflected in a decreased rate of im-

Table II. Approximate proportions of national resources, at market prices, devoted to research and development. For the U.S. and European countries selected, the figures are averages for 1959-1965; for Japan, the figures are for 1963. The data appear to indicate a significant U.S. advantage in defense and space research and a rather lesser advantage in civilian-oriented work. (Sources: Japan—*International Statistical Year for Research and Development, A Study of Resources Devoted to R. and D. in O.E.C.D. Member Countries in 1963/64*, Vol. 2, O.E.C.D., Paris, 1968; other countries—Boretsky, ref. 6.)

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Table III. The same information as in Table II, for civilian-oriented work only, translated into cost-equivalent terms and into full-time-equivalent technical man power. The last column expresses each national civilian research and development effort (in cost-equivalent terms) as a proportion of that nation's G.N.P., also converted into cost-equivalent terms. A number of nations, on this basis, have been making more intensive research efforts during the early '60's, for civilian purposes, than has the U.S. (after Boretsky)

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provement in productivity. And, indeed, in the last few years, productivity increases have declined (5).

There is another way in which we can deduce the effects of the post-war research and development policies. Boretsky (6) has compared the technical activity of Europe and Japan with that of the United States for the period 1959-65 (just following the rapid growth of the United States effort). Table II compares the total research and development efforts for these years as fractions of national G.N.P.'s at market prices, for the United States, Japan and the major European countries. The defense and space portion of the total effort and the civilian effort are also included for comparison. Superficially at least, this table would indicate a significant advantage of the United States for all research and development, and a somewhat lesser advantage in its "civilian-oriented" activity.

However, when research and development efforts are translated into cost-equivalent terms, and into the number of scientists, engineers, and technicians employed (Table III), the results are startling. The last column in Table III expresses cost-equivalent expenditures for research and development as fractions of the G.N.P.'s, the latter converted to equal-purchasing-power terms. When the comparison is thus made on the basis of cost-equivalent expenditures, the relative advantage of the United States investment in civilian research and development disappears. Even more significant, about 30 to 35 per cent more scientists, engineers, and technicians were engaged in civilian-oriented research and development in the eight European countries studied than in the United States. This group of countries has a slightly greater population than the United States, but a one-third smaller G.N.P. When compared on this basis, the relative effort in Europe was substantially greater than that in the United States—the reason being, basically, that the relative cost of research and development personnel is less in Europe than in the United States.

Furthermore, there was no substantial investment in defense and space research and development in any of the European countries except the United Kingdom; there was not a disproportionate rise in salaries, and there was no marked displacement of scientists and engineers from industrial to national projects. Although European data for more recent years are not readily available, it seems likely that—in view of the slow growth of research activity in the United States relative to other O.E.C.D. countries in these years—the disparity is now even greater. As early as 1955, the number of scientists and engineers engaged in non-space, non-defense activity in Europe must have been higher than in the United States.

A comparison between Japan and the United States is even more depressing. During the 1959-65 period, the Japanese spent a significantly larger portion of their G.N.P., on an equivalency basis, for civilian research and development than did the United States. With one-half the United States population and one-fifth the United States G.N.P., Japan employed 70 per cent as many professional research and development personnel in their civilian effort as did the United States.

Spin-Off?

Many would argue that the analysis thus far has neglected the indirect effects of the space and defense research and development efforts of the United States. It is clear that the research and development that has been supported by the government must have been beneficial to at least some industrial activities. Further, the government provided a market for sophisticated technical goods, which no doubt stimulated research and development activities which were transferable to civilian products. But, granted that this indirect effect of space and defense oriented work presumably exists, the question is, how significant is it?

Boretsky analyzes this matter in what seems to be an effective way. Consider the efforts of ten people engaged in federal research and development; how much effort aimed at a particular industrial objective, on the average, are these ten equivalent to? Boretsky argues that their absolute maximum equivalent is 3-1/3, and the minimum is perhaps one-half a civilian researcher. In other words, 5 to 33 per cent of a given amount of space and defense research and development might be considered to be the "direct" effect of that effort on the economy.

Assuming a "spin-off" as high as 20 per cent (for both Europe and the United States) a new measure of the effective number of scientists and engineers can be derived. It turns out that the United States still lags

behind Europe and Japan on a comparative population basis. In the specific field of nuclear technology not related to military applications, Boretsky makes a more startling comparison. He estimates that 50 per cent more scientists, engineers, and technicians are involved in this work in Europe than in the United States.

This disparity in technical effort, existing for more than ten years, may have begun to be reflected in our trade with Europe and with Japan. Consider the trade balance in the technologically intensive products of chemicals, machinery, electrical equipment, transportation equipment and instruments. In 1968, the United States had a favorable balance of trade of these products with Europe of $1.5 billion. From 1962 to 1968, however, the rate of growth of imports of these products from Europe averaged 20 per cent, and the rate of growth in their export from the United States averaged only 9 per cent. During this same period, the United State's trade balance with Japan in these products turned from a $300 million surplus to a $500 million deficit. While United States imports from Japan were growing at 32 per cent a year, United States exports to Japan were increasing at only 7 per cent a year.

If the trend continues, Boretsky estimates that by 1973, in technologically intensive products alone, there will be a trade deficit with Europe of almost $2 billion. The situation with respect to Japan is even more disturbing: he estimates that the United States "technological" trade deficit to Japan will be almost $5 billion by 1973.

It is clear, of course, that monetary factors and relative labor cost factors are also important to trade balance considerations. It is only in high-technology products with rapid potential for growth (and in agriculture, where the U.S. has long maintained a technological lead) that the United States has had much of a potential advantage—and it is here (*except* in agriculture) that we find the downturn.

Clearly, analysis of a matter as complicated as the relationship between technology, the economy, and social welfare can never be complete, nor can conclusions drawn from incomplete analysis ever be taken with assurance. Nevertheless, it appears that in the United States we have substantially under-invested in the kinds of technical effort that are necessary for the improvement of our industrial output and the quality of our life. In recent years this under-investment in technology for civilian pursuits has been made substantially greater as a result of the large commitment of the United States to activities related to defense and space. The natural working of the economic system which would in any case have led the industry to invest too little in technical activities has been further distorted because of the higher cost of research and development resulting from the federal effort. Even in the government sector of research and development, all the European countries and Japan spend more than 20 per cent of government research and development for civilian purposes, whereas the United States spends less than 6 per cent. Thus our competitors supplement the industrial investment in research and development for civilian purposes to a much greater degree than do we.

The Choice of Strategies

We are now faced with a dilemma. There are 100,000 scientists and engineers out of work; there are large unsatisfied social needs; we are suffering adverse effects from our past uses of technology; and our economic growth is faltering. At the same time, the costs of education and of research and development continue to rise, sustained apparently by the social and political structure that we have set up.

Direct research and development investments by the federal government—whether for defense, space or social welfare purposes—will, if they are too large, draw off technical activity which could be turned to industrial improvement, just as we experienced in the 1950's. Substantial increases in the availability of new scientist and engineer graduates would eventually lower their relative prices, but there would be a period of costly and inhumane readjustment. On the other hand, restrictive policies to discourage young people either from opting for technical education or from continuing at university for advanced graduate education are, of course, in the long term, self-defeating.

Like any complex public problem, this dilemma will not be resolved by any single public policy decision. Addressing the social tasks directly, perhaps the most important single action that is required is a substantial

increase in support for the improvement, both in quality and efficiency, of those public services in which private industry plays only a small role, such as education and the delivery of health care. Likewise, those socially desirable activities in which private incentives for technical work are small or non-existent, such as the improvement of living conditions in the cities and of the safety of our transport system, require significantly increased support.

To simply spend enough to re-employ unemployed scientists and engineers by immediate federal research and development funding in these social fields, is not the answer, for we do not know enough about the task; nor would such a move (which would in any case face great social obstacles) encourage industry to play its own part. For the present, in these fields we must not only invest in research and development, but we must devise ways of changing the structure of the delivery systems of social services and of the education of technical people, to facilitate the adoption and diffusion of new techniques. A major effort of direct government support to meet these social needs is required.

A second major effort would be the encouragement of university research related to improving industrial productivity, to reducing the waste and pollution of industry, and generally to problems associated with the productivity, products, and adverse effects of industrial production. This federal support to universities would redress the present academic bias, especially in engineering, toward the kinds of work that tend to improve our defense and space capabilities.

In some way, also, government must underwrite industrial research and development itself, since the economy has always tended to under-invest in it, and its present over-costliness results from past federal policies. This can be done either directly by subsidy or indirectly through tax rebates. The entire set of corporate and government policies that encourage potentially high-export industries needs to be reviewed.

Whether a society effectively uses technology for productive and beneficial purposes depends upon a large number of factors. The supply of technically trained people, the willingness to invest in them, the capital necessary to embody the technology in useful machines and processes, the level of general education, the skill of the potential labor force, the economic and political structure of the society, all play roles. The effective use of technology requires that a large number of appropriate conditions be met simultaneously; a single missing ingredient (for example, the absence of available capital, or the necessary management attitudes) may completely halt either technological innovation or the spread of technology within the society.

If we are to meet the social needs of our time and to continue to provide the material needs of our population, new policies and directions of our governmental, industrial and academic institutions are required.

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The U.S. government's pyramiding investment in research and development in the 1950's invoked the law of supply and demand, say Dr. Herbert Hollomon (seated in photograph) and Alan Harger. The loser was American industry—unable or unwilling to compete. Can we now restore to research its true value and to American industry its tradition of technological innovation?

J. Herbert Hollomon
Consultant to the President and Provost of M.I.T.

Alan E. Harger
Administrative Assistant to Dr. Hollomon

America's Technological Dilemma

During these times of rapid change, of the increasing awareness of social problems, of declining trade balances, of inflation, and of unemployed scientists and engineers, thoughtful attention must be directed to the science and technology policy of the U.S. One important aspect of this policy has to do with the way in which technology is used by society, particularly how it affects civilian or industrial activity.

Many people have struggled to quantify the influence that new technology has upon industrial development, economic growth, and social advance. Qualitatively, the dependence of a modern economy on the use of new technology is accepted: technology becomes embodied in more effective production machinery, in more skilled labor, and in products and services that better serve social needs. The direct connections between research and development, and the resultant particular practical benefits, are more difficult to specify. However, it is these connections which must be understood if science policy (national or corporate) is to be effective.

In any attempt to assess the direct consequences of investment in research and development, it must be clearly established that the particular investment has been directed toward the purposes which are being considered. For example, suppose we are looking for the sources of general economic health in the nation; we must recognize that the research and development which have been aimed toward space flight and defense are unlikely to have had as significant an influence as an equivalent research and development activity directed toward, let's say, improvement in productive efficiency in the automotive industry.

Clearly, the effects of research and development on a nation as a whole cannot be understood without distinguishing among the various economic sectors. In the United States, for example, where most workers are engaged in service activities and most research and development is devoted to manufacturing, the overall rate of change in productivity cannot be expected to correlate with the amount of national civilian-oriented research and development.

Other factors influence the consequences of research and development. Most important is the delay, of almost indeterminate length, between an investment in research and development and the appearance of its results in the world. Some recent studies have indicated that this time delay has shortened, but even so, any major new technological development does not diffuse throughout the society in less than five to ten years.

In a recent analysis, Harvard's Richard B. Freeman has found (after taking the time delay into account as best he could) a good correlation between the growth rates and profitabilities of different industrial sectors and the research and development that were performed in those sectors in prior years (1). Figures 1, 2, and 3 illustrate

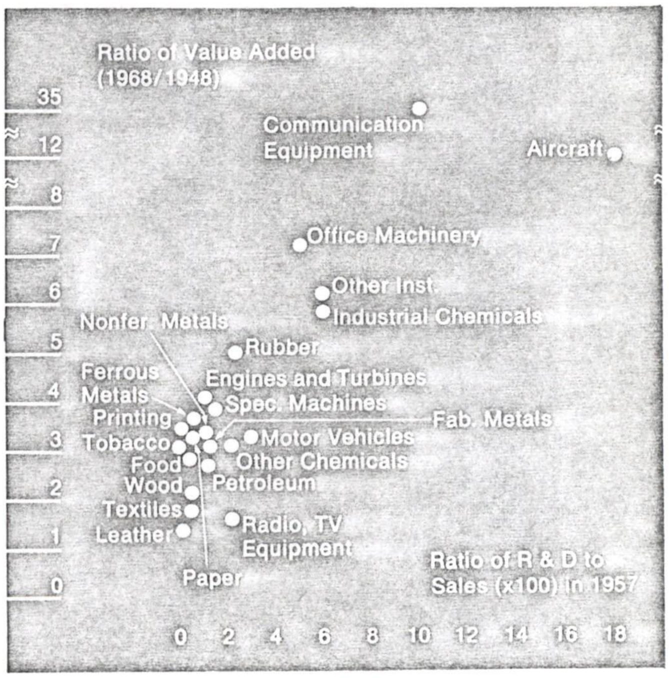
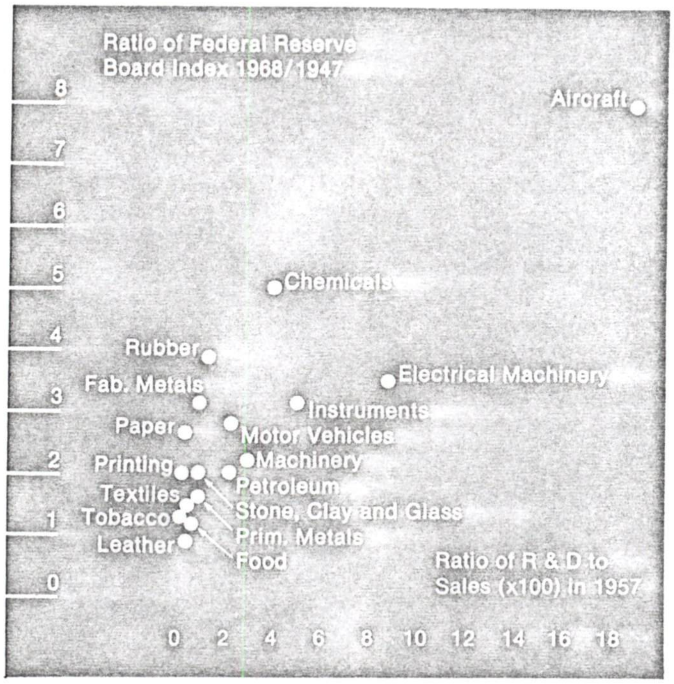


Figure 1. The gross association between research and development intensity and growth in output in various industries is shown here and in Figures 2 and 3 (on the following page). Research and development intensity is indexed by the ratio of R. and D. expenditures to sales. In Figure 1, increases in value added—a term denoting the difference between the value of a manufactured product and that of the starting materials—indicate output changes unadjusted for price increases.

Figure 2. The association between research and development intensity and growth in output in various industries (cont.): in this plot, output increases adjusted for price changes are measured by increases in the Federal Reserve Board Index of Production, and R. and D. intensity is indexed as in Figure 1.



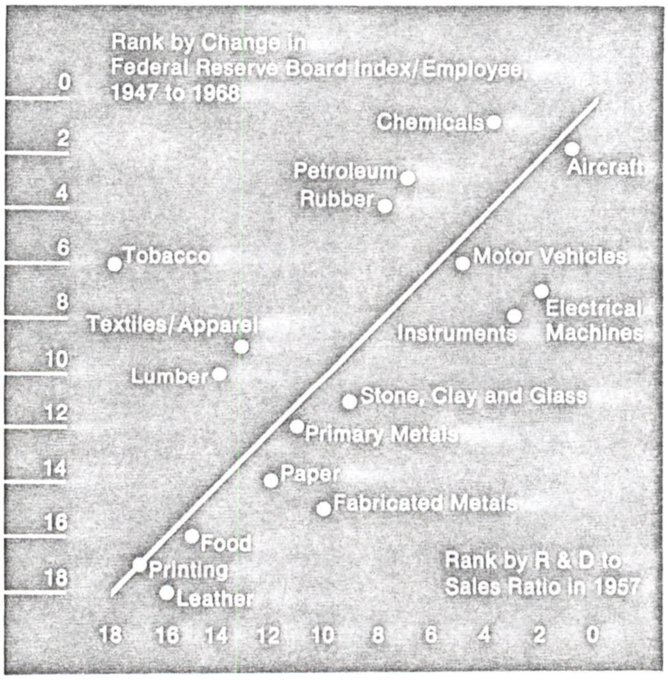


Figure 3. Changes in labor productivity are measured by the industries' indices of production (*see above*) divided by their number of employees. The rank-order relationship in this figure—like the relationships in Figures 1 and 2—indicates a positive and significant *correlation* between growth in industrial output and research and development intensity. (The three plots are after Freeman, ref. 1.)

the correlations. Professor William N. Leonard, of Hofstra, has shown that research and development spending by companies (excluding federal research and development) relates significantly to growth rate of sales, assets, and net income, in 16 industries which, combined, perform nearly all manufacturing activity (2).

Since World War II there have been many other analyses, both for particular industries and for the economy as a whole, that relate the effects of research and development to their economic consequences. It is clear that, for our type of national economy at least, industry under-invests in research and development relative to the total social return it generates in comparison with alternative investments. This under-investment arises because an individual firm cannot appropriate all of the benefits of any new technical development, but must bear most of the cost of that development. In other words, many of the results of a particular development are not of direct benefit to a firm, but indirectly affect other firms that use the results of the development. Furthermore, when a development is highly risky, a firm may forego investment in it because of the cost of failure, even though the rewards of the most probable outcome would fully justify the investment. Or to put the matter another way, individual firms will underinvest in order to minimize their risk, even though the expected rewards from investment in development, on an average basis for many firms, could be quite high. This situation becomes more serious the larger the initial development cost and the more radical the new technology. For instance, in the development of nuclear power the risk may be such that no firm exists with the capability of investing at the early stages of the technology. Only society as a whole can afford the risks or the uncertain costs resulting from technical uncertainty.

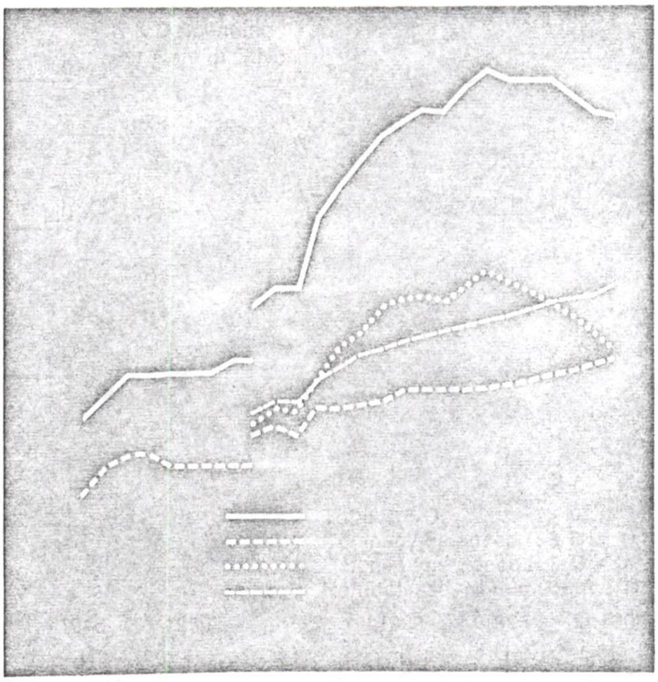
A summary of these studies of the effects of research and development, commissioned by the National Science Foundation (3) indicates that the contributions of research and development to economic growth and productivity, even with this under-investment, is positive, significant, and high.

Industry vs. Space and Defense

During and following World War II, the United States invested heavily in research and development, as illustrated in Figure 4. The most rapid increase occurred between 1953 and 1959, and resulted largely from increases in federal funding (Figure 5); since 1964 there has been a decrease in total effort relative to the G.N.P. It is clear that, as the federal government began to invest more and more in research and development, industry did not follow suit as rapidly; and that, conversely, as the federal government investment decreased, industrial investment in research and development tended to rise.

The recent growth of the U.S. research and development effort is less dramatic when measured, not in dollars, but in the number of the scientists and engineers involved (Figure 6). The costs of technical work have risen much more sharply than the general

Figure 4. Research and development spending in the U.S. since World War II. (Sources: 1945-1953 figures—Office of the Secretary of Defense, in the Census Bureau's *Statistical Abstract of the United States—1960,* Washington, 1960; 1953-1970 figures—National Science Foundation's *National Patterns of Research and Development Resources,* NSF 70-46, Washington, 1970)



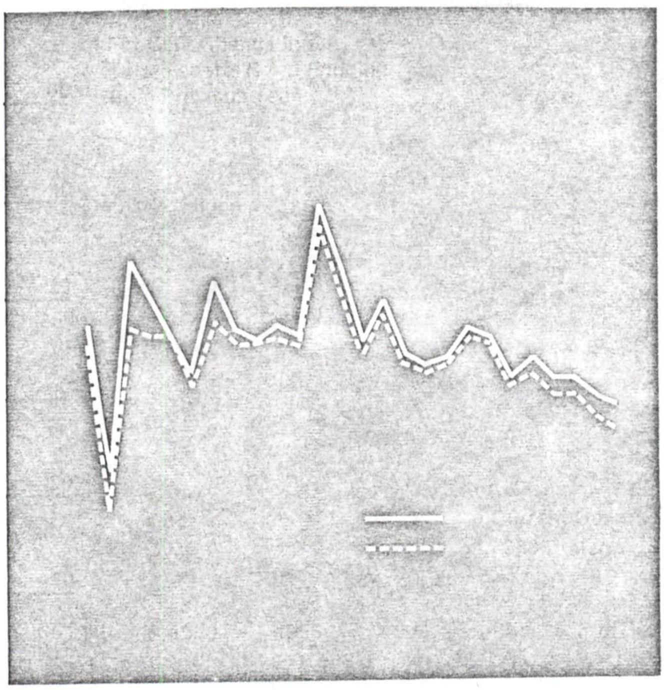
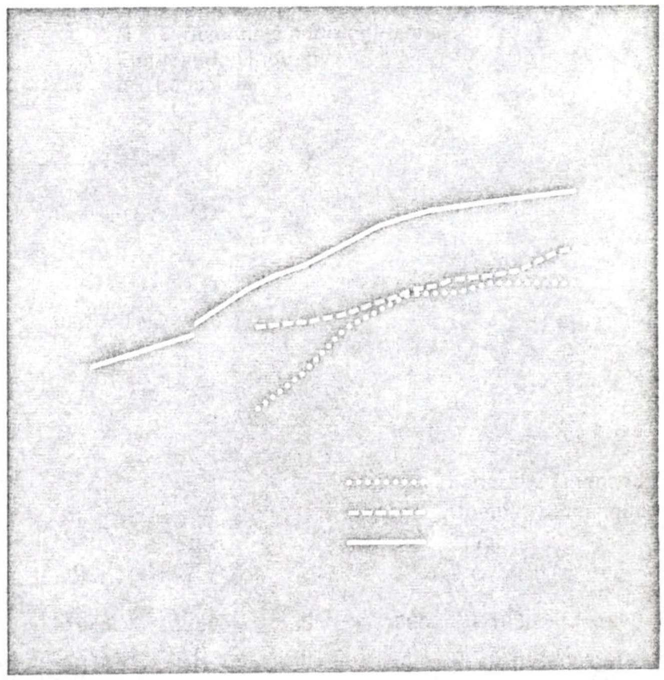


Figure 5. From the same data used in Figure 4, the year-to-year changes in total federal research and development support are shown. ("1958 dollars" were arrived at using the implicit G.N.P. deflator, since there is no specific R. and D. deflator available.)

Figure 6. Post-war growth of research and development in industry in terms of the number of scientists and engineers employed. The 1953-1961 company-federal estimates are by the authors, and 1962-1968 company-federal estimates are from the National Science Foundation. (Sources: 1945-1950 figures—Department of Defense, *The Growth of Scientific Research and Development,* Washington, 1953; 1950-1957—National Science Foundation (jointly with Bureau of Labor Statistics), *Employment of Scientists and Engineers in the United States, 1950-1965,* NSF 68-30, Washington, 1968; 1958-1968—National Science Foundation, *Research and Development in Industry—1968,* NSF 70-29, Washington, 1970.)



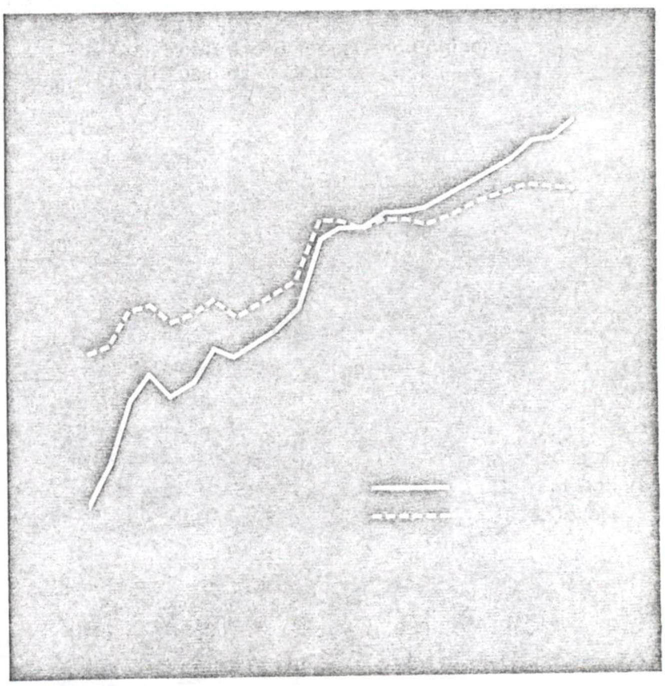
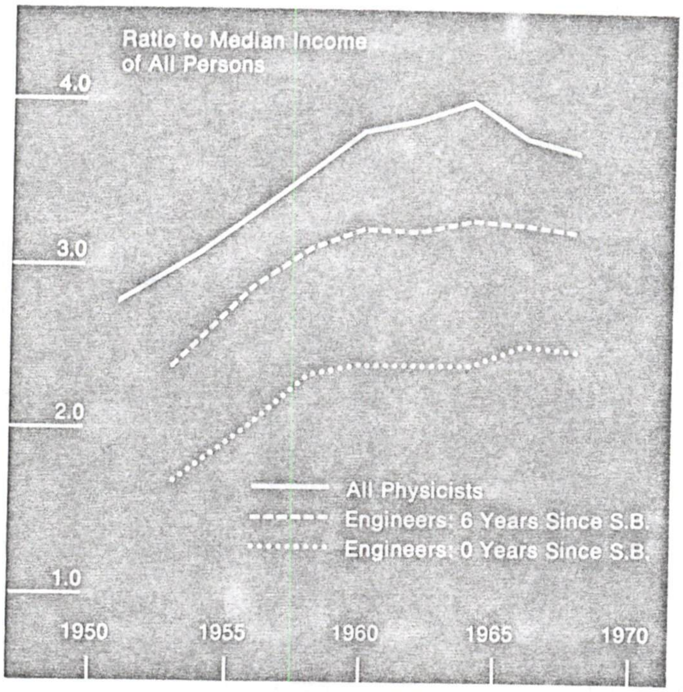


Figure 7. Increases in the cost of research and development per R. and D. scientist and engineer in industry coincide with the increases in federal support traced in Figure 5. (Sources: 1945-1952—Department of Defense; 1953-1956—National Science Foundation/Bureau of Labor Statistics; 1957-1968—National Science Foundation)

Figure 8. Salaries of physicists and engineers as a ratio of the median income of all persons. The rapid rises of the 1950's were a dominant contribution to the cost increases shown in Figure 7 (Sources: median income—Census Bureau's yearly *Current Population Reports, Series P-60* (*Consumer Income*), 1951-1968; engineers—Engineering Manpower Commission, *Professional Income of Engineers, 1970*, New York: Engineers' Joint Council, 1970; physicists—American Institute of Physics, *Physics Manpower—1966* and *Physics Manpower—1969*, Publications R-196 and R-220, based on data from the National Science Foundation's National Register)



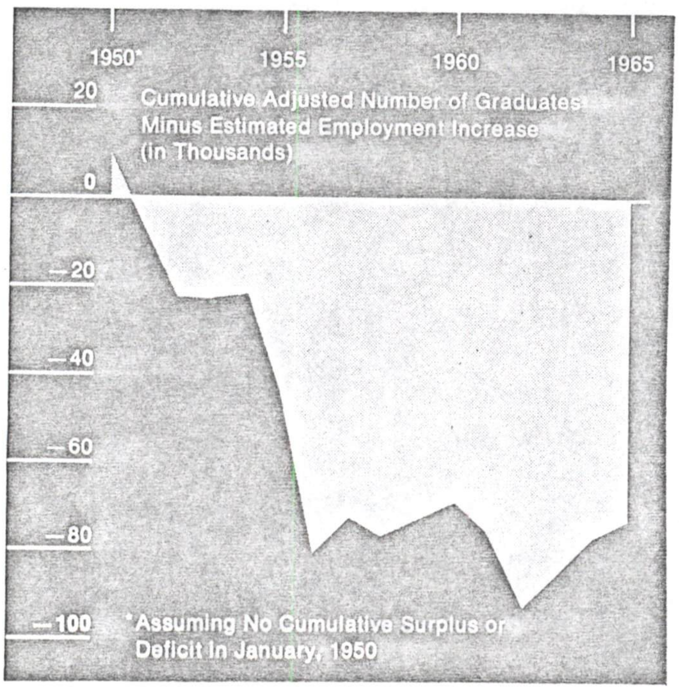


Figure 9. Between 1950 and 1965, nearly 100,000 more engineers were created (on the employment record) than became available as new graduates. This graph traces the cumulative progress of the appearance of "engineers" for whom no engineering degrees were awarded. (Sources: employment figures—National Science Foundation/Bureau of Labor Statistics; degrees—U.S. Office of Education *Digest of Educational Statistics*, OE-10024-70, Washington, 1970 edn.)

rates of inflation and of improvement in productivity. Indeed, the rapid growth of federal research and development has itself done much to raise the costs. The major increases illustrated in Figure 7 correspond to the increases in federal research and development support (Figure 5). A dominant source of the rise in costs was the increase in salaries of scientists and engineers relative to others (Figure 8).

During the period 1950 to 1960, the rapid increase in space and defense research and development increased the demand for new technical people (4). Apparently there was, within industry, a transfer of technical people from industrial to governmental projects. Because of this competition and the great increase in research and development support, salaries rose, and the cost of research and development, and probably of other technological activities, rose significantly.

Figure 9 illustrates a dramatic effect of this extraordinary demand. Between 1950 and 1965, nearly 100,000 more engineers were created than were available as graduates with engineering degrees. During these years, the increase in the number of engineers reported to be employed was substantially greater than the number of new engineers entering the labor force from higher education. Thus, it appears that industry must have been upgrading technicians to take the place of trained people who were transferred to federal programs. A related consequence of the rapid growth of research and development must have been a decrease in the average level of training, if not skill, of the remaining industrial engineers.

Since 1950, there has been an increase in industrial funding for research and development. However, its impact has been limited by rising costs. Figure 10 illustrates the year-by-year change in the number of R. & D. scientists and engineers per 1,000 employees in those companies performing research and development. Even these figures are somewhat inflated, for some of these scientists and engineers were no doubt engaged in research and development related to products sold for defense and space purposes. The figure illustrates that research and development for industrial purposes has remained about constant for nearly ten years.

Other factors have probably affected the industrial investment in technology. Interest rates have continually risen in the United States during this period, and, according to some economists at least, this has retarded capital investment. Not only is capital investment required in order to infuse new technology into the economy, but also large investment commitments in general tend to stimulate research and development. In addition, it is likely that the combination of high government demand and rapid obsolescence of technology in the space and defense fields attracted a disproportionate fraction of venture capital to these industries, and was an important contributing factor to the rising price of capital.

During the last several years, the decline of the federal effort has not been compensated for by the slight increase in industrial activity. The result has been unemployment of scientists and engineers, particularly those that were connected with space and defense. Crude estimates indicate the total unemployed to be of the order of 100,000.

To reiterate, the rapid and large growth of federally supported research and development, occurring particularly between 1953 and 1960, appears to have had several major effects on the technological activity of the United States and its industry. The most important effect of this growth was the rise in overall cost of research and development. This increase occurred not only in the costs of research and development to the government, but, very significantly, in the cost of this activity to industry. A major factor in this cost rise was the increased cost of the technical personnel engaged in it. The rise in the rank of starting engineers and scientists in the income distribution, relative to the rest of the population, dramatically illustrates this increase (Figure 11).

Starting salaries for engineers with bachelor degrees, for example, rose during the period of rapid research and development expansion from the 77th percentile in the rank of income of all people in the United States, to about the 86th percentile. During this same period, it is estimated by Freeman that about 20 to 30 per cent of the increased activity supported by the federal government was made possible by a transfer of people from industrially supported projects. The remaining increase was accomplished by absorbing the supply of new

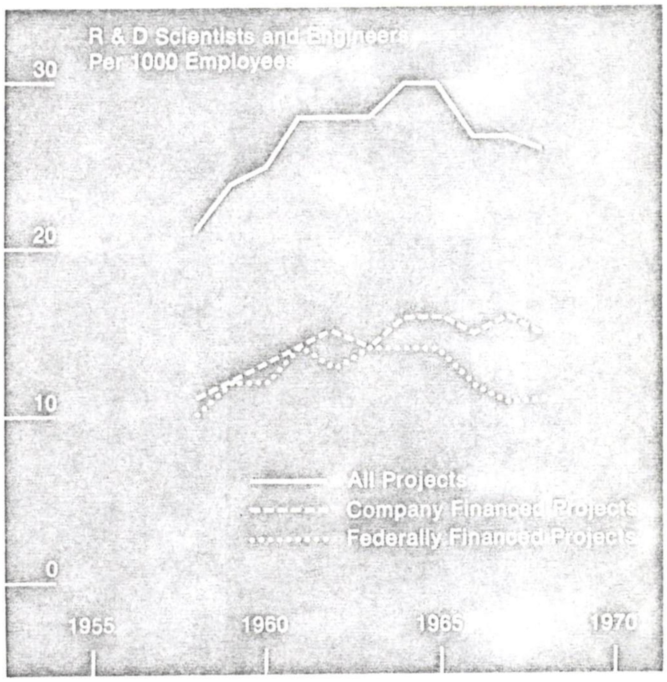


Figure 10. For those companies reporting research and development activity, these curves show the number of R. & D. scientists and engineers employed per thousand employees. (Sources: 1958-1961—authors' estimates; 1962-1968—National Science Foundation)

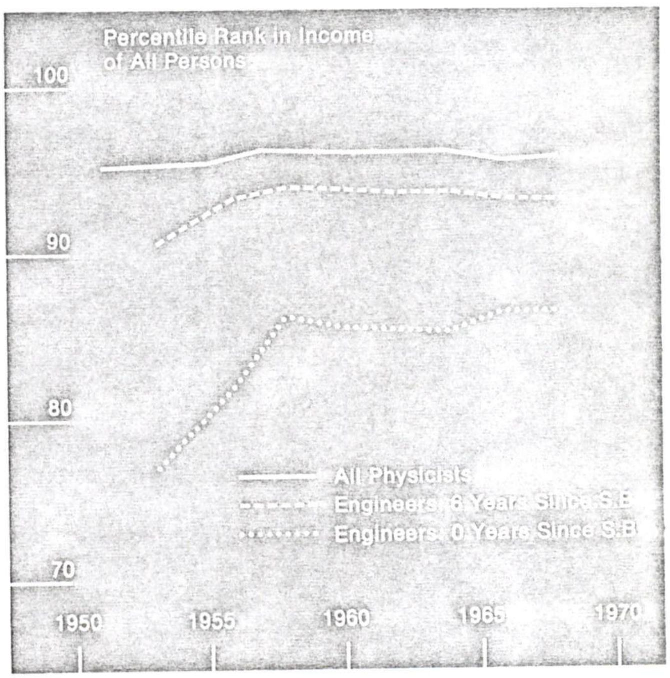
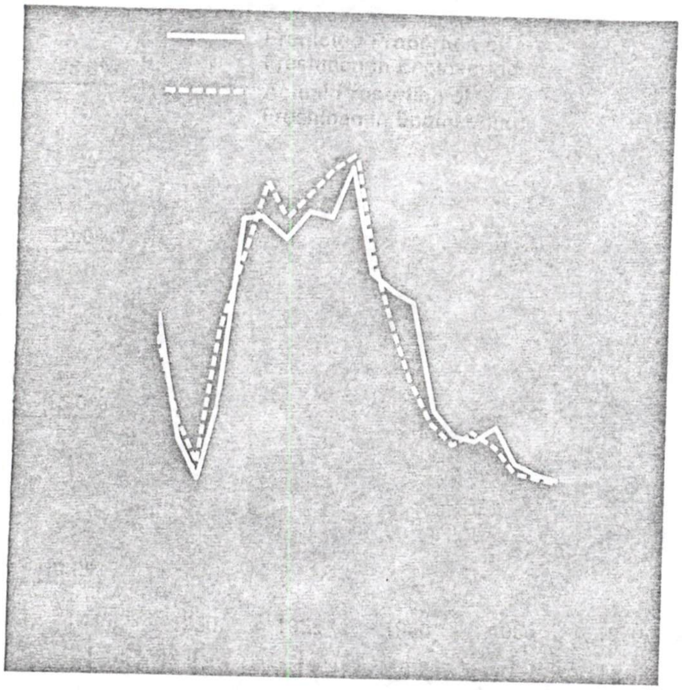


Figure 11. If incomes of all persons are arranged in a ranking order, any given income can be assigned a percentile position, indicating the percentage of the population having a lower income. Shown here are the percentile positions of median salaries earned by engineers and physicists. (Sources: as Figure 8)

Figure 12. Changes in salary within the engineering profession as a whole affect the number of students choosing engineering majors. This graph shows the success of a prediction of the proportion of all freshmen who choose engineering, made on the basis of engineering salaries, relative to other professional salaries, one year earlier. (Richard B. Freeman, *The Market for College-Trained Manpower*, Cambridge: Harvard University Press, 1971)



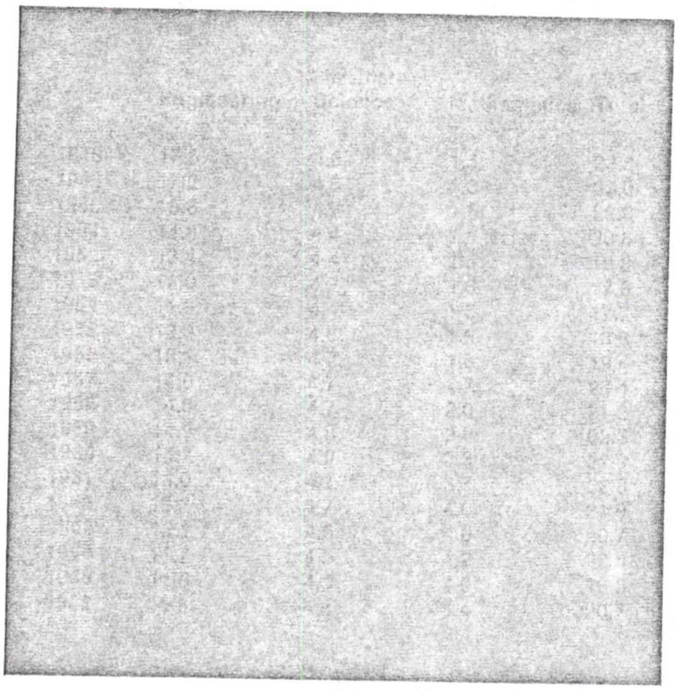


Table I. The combined fraction of male college graduates choosing science, mathematics and engineering has changed little since World War II, although the relative proportions of these fields have changed somewhat. (Hugh Folk, *The Shortage of Scientists and Engineers*, Lexington, Heath Lexington, 1970)

technical people.

University as Supplier

The increase in demand generated by federal funds had a significant effect on the choice made among fields by those attending universities. The fraction of college graduates opting for science, mathematics, and engineering has changed very little since World War II (Table I). Hugh Folk has pointed out that the choice of a broad field by students does not appear to be affected by demand, which influences only the choice of lucrative activities *within* broad fields. Changes in salaries and stipends affect the choices between specialties, and determine in part whether or not students opt for graduate education in special fields. However, though those in science and engineering have been mostly supported by federal funds to universities, the proportion of scientists and engineers among all PhD's has not increased appreciably. Apparently, the federal funds merely permitted the universities to redistribute their resources to a rapidly rising social demand for graduate education proportionately in all fields of knowledge. Changes in salaries and stipends affected choices toward engineering and toward physics, for example. Figure 12 illustrates the relationship between the actual number of freshman enrollments in engineering, year-by-year, and the changed incentives predicted from salary changes.

There has been some shift between engineering and mathematics, but, in any event, the response of the new supply of technical people to economic factors is sluggish and cyclical. The yearly new supply of graduate scientists, mathematicians, and engineers has varied from 33,000 to a high of 61,000. In recent years, this new supply has been about equal to the reported increase in new employment of scientists and engineers, implying little upgrading of people who did not have a "certificate" as scientists or engineers.

There has been great growth in the support of research in universities by the federal government, with by far the largest share derived from the support of biomedical research in university medical schools and affiliated hospitals. However, for the physical sciences, and especially engineering, the largest share has derived from the Defense Department, AEC, and NASA. This support surely biased university activity away from industrially related research, especially that connected with the less glamorous industrial problems.

The Practical Loss

While it is probably impossible to assess all the effects of federal policy over the past several decades, there are several possibilities that appear reasonable. It seems reasonable to expect that, ten years or so after a relative decline in technical activity, its consequences should begin to be evident. For example, the rate of increase in productivity might begin to diminish. Although the dependence of productivity upon a wide range of other factors (the availability of capital, for example) is well recognized, eventually a reduction in investment in technical activity devoted to industrial purposes should be reflected in a decreased rate of im-

Table II. Approximate proportions of national resources, at market prices, devoted to research and development. For the U.S. and European countries selected, the figures are averages for 1959-1965; for Japan, the figures are for 1963. The data appear to indicate a significant U.S. advantage in defense and space research and a rather lesser advantage in civilian-oriented work. (Sources: Japan—*International Statistical Year for Research and Development, A Study of Resources Devoted to R. and D. in O.E.C.D. Member Countries in 1963/64*, Vol. 2, O.E.C.D., Paris, 1968; other countries—Boretsky, ref. 6.)

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Table III. The same information as in Table II, for civilian-oriented work only, translated into cost-equivalent terms and into full-time-equivalent technical man power. The last column expresses each national civilian research and development effort (in cost-equivalent terms) as a proportion of that nation's G.N.P., also converted into cost-equivalent terms. A number of nations, on this basis, have been making more intensive research efforts during the early '60's, for civilian purposes, than has the U.S. (after Boretsky)

[illegible]

provement in productivity. And, indeed, in the last few years, productivity increases have declined (5).

There is another way in which we can deduce the effects of the post-war research and development policies. Boretsky (6) has compared the technical activity of Europe and Japan with that of the United States for the period 1959-65 (just following the rapid growth of the United States effort). Table II compares the total research and development efforts for these years as fractions of national G.N.P.'s at market prices, for the United States, Japan and the major European countries. The defense and space portion of the total effort and the civilian effort are also included for comparison. Superficially at least, this table would indicate a significant advantage of the United States for all research and development, and a somewhat lesser advantage in its "civilian-oriented" activity.

However, when research and development efforts are translated into cost-equivalent terms, and into the number of scientists, engineers, and technicians employed (Table III), the results are startling. The last column in Table III expresses cost-equivalent expenditures for research and development as fractions of the G.N.P.'s, the latter converted to equal-purchasing-power terms. When the comparison is thus made on the basis of cost-equivalent expenditures, the relative advantage of the United States investment in civilian research and development disappears. Even more significant, about 30 to 35 per cent more scientists, engineers, and technicians were engaged in civilian-oriented research and development in the eight European countries studied than in the United States. This group of countries has a slightly greater population than the United States, but a one-third smaller G.N.P. When compared on this basis, the relative effort in Europe was substantially greater than that in the United States—the reason being, basically, that the relative cost of research and development personnel is less in Europe than in the United States.

Furthermore, there was no substantial investment in defense and space research and development in any of the European countries except the United Kingdom; there was not a disproportionate rise in salaries, and there was no marked displacement of scientists and engineers from industrial to national projects. Although European data for more recent years are not readily available, it seems likely that—in view of the slow growth of research activity in the United States relative to other O.E.C.D. countries in these years—the disparity is now even greater. As early as 1955, the number of scientists and engineers engaged in non-space, non-defense activity in Europe must have been higher than in the United States.

A comparison between Japan and the United States is even more depressing. During the 1959-65 period, the Japanese spent a significantly larger portion of their G.N.P., on an equivalency basis, for civilian research and development than did the United States. With one-half the United States population and one-fifth the United States G.N.P., Japan employed 70 per cent as many professional research and development personnel in their civilian effort as did the United States.

Spin-Off?

Many would argue that the analysis thus far has neglected the indirect effects of the space and defense research and development efforts of the United States. It is clear that the research and development that has been supported by the government must have been beneficial to at least some industrial activities. Further, the government provided a market for sophisticated technical goods, which no doubt stimulated research and development activities which were transferable to civilian products. But, granted that this indirect effect of space and defense oriented work presumably exists, the question is, how significant is it?

Boretsky analyzes this matter in what seems to be an effective way. Consider the efforts of ten people engaged in federal research and development; how much effort aimed at a particular industrial objective, on the average, are these ten equivalent to? Boretsky argues that their absolute maximum equivalent is 3-1/3, and the minimum is perhaps one-half a civilian researcher. In other words, 5 to 33 per cent of a given amount of space and defense research and development might be considered to be the "direct" effect of that effort on the economy.

Assuming a "spin-off" as high as 20 per cent (for both Europe and the United States) a new measure of the effective number of scientists and engineers can be derived. It turns out that the United States still lags

behind Europe and Japan on a comparative population basis. In the specific field of nuclear technology not related to military applications, Boretsky makes a more startling comparison. He estimates that 50 per cent more scientists, engineers, and technicians are involved in this work in Europe than in the United States.

This disparity in technical effort, existing for more than ten years, may have begun to be reflected in our trade with Europe and with Japan. Consider the trade balance in the technologically intensive products of chemicals, machinery, electrical equipment, transportation equipment and instruments. In 1968, the United States had a favorable balance of trade of these products with Europe of $1.5 billion. From 1962 to 1968, however, the rate of growth of imports of these products from Europe averaged 20 per cent, and the rate of growth in their export from the United States averaged only 9 per cent. During this same period, the United State's trade balance with Japan in these products turned from a $300 million surplus to a $500 million deficit. While United States imports from Japan were growing at 32 per cent a year, United States exports to Japan were increasing at only 7 per cent a year.

If the trend continues, Boretsky estimates that by 1973, in technologically intensive products alone, there will be a trade deficit with Europe of almost $2 billion. The situation with respect to Japan is even more disturbing: he estimates that the United States "technological" trade deficit to Japan will be almost $5 billion by 1973.

It is clear, of course, that monetary factors and relative labor cost factors are also important to trade balance considerations. It is only in high-technology products with rapid potential for growth (and in agriculture, where the U.S. has long maintained a technological lead) that the United States has had much of a potential advantage—and it is here (*except* in agriculture) that we find the downturn.

Clearly, analysis of a matter as complicated as the relationship between technology, the economy, and social welfare can never be complete, nor can conclusions drawn from incomplete analysis ever be taken with assurance. Nevertheless, it appears that in the United States we have substantially under-invested in the kinds of technical effort that are necessary for the improvement of our industrial output and the quality of our life. In recent years this under-investment in technology for civilian pursuits has been made substantially greater as a result of the large commitment of the United States to activities related to defense and space. The natural working of the economic system which would in any case have led the industry to invest too little in technical activities has been further distorted because of the higher cost of research and development resulting from the federal effort. Even in the government sector of research and development, all the European countries and Japan spend more than 20 per cent of government research and development for civilian purposes, whereas the United States spends less than 6 per cent. Thus our competitors supplement the industrial investment in research and development for civilian purposes to a much greater degree than do we.

The Choice of Strategies

We are now faced with a dilemma. There are 100,000 scientists and engineers out of work; there are large unsatisfied social needs; we are suffering adverse effects from our past uses of technology; and our economic growth is faltering. At the same time, the costs of education and of research and development continue to rise, sustained apparently by the social and political structure that we have set up.

Direct research and development investments by the federal government—whether for defense, space or social welfare purposes—will, if they are too large, draw off technical activity which could be turned to industrial improvement, just as we experienced in the 1950's. Substantial increases in the availability of new scientist and engineer graduates would eventually lower their relative prices, but there would be a period of costly and inhumane readjustment. On the other hand, restrictive policies to discourage young people either from opting for technical education or from continuing at university for advanced graduate education are, of course, in the long term, self-defeating.

Like any complex public problem, this dilemma will not be resolved by any single public policy decision. Addressing the social tasks directly, perhaps the most important single action that is required is a substantial

increase in support for the improvement, both in quality and efficiency, of those public services in which private industry plays only a small role, such as education and the delivery of health care. Likewise, those socially desirable activities in which private incentives for technical work are small or non-existent, such as the improvement of living conditions in the cities and of the safety of our transport system, require significantly increased support.

To simply spend enough to re-employ unemployed scientists and engineers by immediate federal research and development funding in these social fields, is not the answer, for we do not know enough about the task; nor would such a move (which would in any case face great social obstacles) encourage industry to play its own part. For the present, in these fields we must not only invest in research and development, but we must devise ways of changing the structure of the delivery systems of social services and of the education of technical people, to facilitate the adoption and diffusion of new techniques. A major effort of direct government support to meet these social needs is required.

A second major effort would be the encouragement of university research related to improving industrial productivity, to reducing the waste and pollution of industry, and generally to problems associated with the productivity, products, and adverse effects of industrial production. This federal support to universities would redress the present academic bias, especially in engineering, toward the kinds of work that tend to improve our defense and space capabilities.

In some way, also, government must underwrite industrial research and development itself, since the economy has always tended to under-invest in it, and its present over-costliness results from past federal policies. This can be done either directly by subsidy or indirectly through tax rebates. The entire set of corporate and government policies that encourage potentially high-export industries needs to be reviewed.

Whether a society effectively uses technology for productive and beneficial purposes depends upon a large number of factors. The supply of technically trained people, the willingness to invest in them, the capital necessary to embody the technology in useful machines and processes, the level of general education, the skill of the potential labor force, the economic and political structure of the society, all play roles. The effective use of technology requires that a large number of appropriate conditions be met simultaneously; a single missing ingredient (for example, the absence of available capital, or the necessary management attitudes) may completely halt either technological innovation or the spread of technology within the society.

If we are to meet the social needs of our time and to continue to provide the material needs of our population, new policies and directions of our governmental, industrial and academic institutions are required.

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J. Herbert Hollomon, currently serving as Consultant to the President and the Provost of M.I.T., was formerly President of the University of Oklahoma. Under President Kennedy he served as Assistant Secretary of Commerce for Science and Technology, and as Acting Undersecretary of Commerce under President Johnson, Dr. Hollomon is a graduate of M.I.T. (his doctorate is in metallurgy). He founded *Acta Metallurgica*, and co-authored, with L. Jaffee, *Ferrous Metallurgical Design*. He is a founding member of National Academy of Engineering, and is presently on the N.A.E.'s Committee for Transportation.

Alan E Harger, Administrative Assistant to Dr. Hollomon, was formerly Assistant to the Director of the Division of Sponsored Research at M.I.T. He is an M.I.T. chemistry graduate whose Route-128 industrial experience includes consultancy work for the High Voltage Engineering Corporation.

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20506

August 20, 1971

Dear Mr. Olsen:

For your information, enclosed is a six volume report plus a Summary on Technology Assessment Methodologies.

OST contracted for this effort with the Mitre Corporation last year, with the objective to uncover the generic nature of the technology assessment process, by using carefully selected complex problems to serve as case studies, and by attempting to carry out an assessment in each area.

The case studies (pilot assessments) were the following: (1) Automotive Emissions; (2) Industrial Enzymes; (3) Mariculture (sea farming), and (4) Water-Domestic Wastes. The Mitre Corporation supplemented this effort with a fifth study at their expense, covering the area of (5) Computers.

The solution or resolution of the obvious practical problems that these pilot studies themselves posed was not the objective of the contract.

It is our hope that you will find the enclosed material useful.

Sincerely,

Gabor Strasser

Gabor Strasser
Technical Assistant to the Director
Project Officer, Technology Assessment Contract

Enclosures

Mr. Kenneth H. Olsen, President
Digital Equipment Corporation
Maynard, Massachusetts 01754

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EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20506

PRIVILEGED

18 September 1971

MEMORANDUM FOR DR. EDWARD E. DAVID, Jr.

From: Dr. Lawrence A. Goldmuntz

Subject: Domestic Council Study on New Technology

The Domestic Council study on new technology is defining opportunities in eight broad areas. These are listed briefly below with a description of the most important technological thrusts in each area to the extent they have been identified as of this date.

1. Transportation

Chairman: Dr. Robert Cannon
Deputy: Mr. Alfonso Linhares

The transportation study has identified three transportation goals and the long- and short-term development programs that can achieve these objectives.

(a) A short-term (achievable in five years) reduction in urban congestion accomplished by demand-actuated traffic control in addition to bus preference systems and coupled with a longer term program whose feasibility should be apparent by 1976, to provide low cost widely distributed automatic personal transportation for urban densities beyond the reach of conventional mass transit.

(b) A concerted approach to provide a cleaner, quieter, safer transportation. An expansion of the quiet engine and airport noise reduction programs; some development, training and implementation of technology that will reduce truck noise levels by 10 db; an expansion in the high specific energy and specific power battery development program; a technology development program to reduce the cost of tunnel construction; an improvement in emergency health services and highway safety programs to further reduce deaths, injuries and economic losses from auto traffic accidents; a program to reduce rail grade crossings; and finally, harbor traffic control systems to reduce maritime accidents.

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(c) An effort to increase the efficiency and productivity of the movement of people and goods. A major development and implementation program to improve passenger and rail transportation on the Eastern Seaboard in time for the 1976 bicentennial celebration and the planning for extending these capabilities to a national rail system; relief of impending congestion in the Northeast Corridor intercity highway system by real time information systems and by improving the connectivity of the system; an expansion of the advanced aircraft transport and engine technology program in the subsonic, supersonic and hypersonic regimes; the expansion of VSTOL development to higher capability, quieter vehicles to test the market potential by 1976; an expansion of the development of tracked levitated vehicle systems to establish their potential for high speed intercity travel by 1976; and finally, the development of a nationwide cargo security system to reduce pilferage losses.

The aircraft portions of this program, while imbedded in the three objectives described above, will also be separately presented as a program package which is primarily a NASA responsibility.

2. Communications for Social Needs

Two approaches toward developing the social experiments and hardware technologies to demonstrate the application of improved communication capabilities to the needs described below are being developed by the Office of Telecommunications Policy and NASA under the chairmanship of Walter Hinchman and Leonard Jaffe, respectively.

An alternative wired community and an interactive satellite system capable of operation with augmented ground receivers will provide the basis for demonstrating the effectiveness of electronic mail service, the delivery of health care to city centers and rural communities, the delivery of social, educational and cultural services to rural and city center communities, and finally, the rapid dissemination of fingerprints and other services to enhance the administration of justice.

3. Natural Resources

Chairman: Dr. Frank Clarke, Dept. of the Interior
Deputies: Dr. Lindsay D. Norman, Interior
Dr. William S. Butcher, OST
Mr. Donald F. Moore, NOAA

The goals of this group are to provide technology opportunities to enhance the economic development of the natural resources of the United States in a manner that minimizes injury to the environment. Four major resources areas are discussed: water, mineral, continental shelf, and forest resources.

(a) In the water resources area an expansion of the desalinization technology development and demonstration program seems indicated if we are to meet the 1980 requirements in many portions of the country; a new program to improve the consumptive efficiency with which we use irrigation water from 50% to 70% seems promising; (If successful, we will have the remarkable result of providing for all municipal water requirements in the Southwest by the projected saving due to irrigation efficiency in that region.) a program to integrate the management of a typical river basin, the Susquehanna, taking into account all the separate activities of the Department of the Interior, Department of Agriculture, Corps of Engineers, Department of Transportation, and Environmental Protection Agency, and State and local authorities; and the development of technologies applicable to the more complete recycling of waste water.

(b) The mineral resources program has several objectives: technology to improve our ability to discover mineral resources; the extraction of resources from reserves that were previously economically unattainable; technologies useful to develop mining procedures that would be compatible with the environment; a program to improve the efficiency of underground mining; and finally, various mineral processing technologies relating to the extraction of alumina from clays, the use of non-magnetic taconite ores, and a way to produce synthetic rutile.

(c) The third element of the natural resource program is the development of technologies that will permit wider, more economic and environmentally sound exploitation of resources of the continental shelf. The living resources on the continental shelf can be more efficiently developed by mariculture experiments, more rapid surveying and monitoring methods to permit the timely prediction of the distribution and abundance of fish; and the development of an open sea stable platform to test systems to culture fin fish and shellfish in the open sea. The non-living resources of the continental shelf can be made more readily available by more extensive geophysical mapping of the resources area, by developing the technology to exploit sand and gravel deposits in an environmentally sound way; and by utilizing cool ocean water for power-plant cooling, and in some locations air conditioning and mariculture.

(d) The ability of our national forests to provide an additional two billion board feet may be developed if aerial logging techniques can be developed to be economic for sparse lumbering of steeper slopes under environmentally sound conditions.

4. Urban/Suburban Development

Chairman: Mr. Harold Finger, HUD

The economic preservation and development of the urban environment requires the accomplishment of certain social experiments and the development of some technologies. In the new technologies initiative program two social experiments are being proposed: (1) an experiment to determine the effectiveness of housing allowances as compared to housing subsidies; (2) experimental techniques to preserve neighborhoods that might otherwise be abandoned. A much enhanced program to understand urban development as driven by basic demographic changes and as satisfied by a variety of alternatives such as new cities, new cities within cities, or trend development, will be undertaken to determine the social capabilities of these various alternatives as well as their economic impacts; various policy options to achieve desirable alternatives will also be explored. A hard technology effort is proposed to develop an integrated utility system that will have minimum environmental impact and improve natural resources utilization. Initial cost studies have indicated that such an approach is more economic than current techniques. The purpose of this program will be to demonstrate that conjecture. This waste management system is applicable to dwelling unit aggregates of 3,000 to 6,000 units.

5. Productivity

Chairman: Dr. Robert W. Cairns, Commerce

Major inputs are being prepared by the following working groups. However, it is too early at this time in the development of their work to indicate which programs will survive.

(a) Working group on the international competitive stature and productivity of key industries.

Chairman: Dr. Harold C. Passer, Commerce

(b) Working group on technologies that are broadly supportive of productivity improvement or that can establish international commercial advantages.

Chairman: Dr. Lewis M. Branscomb, NBS

(c) Working group on the utility of State commerce extension services to enhance the efficiency of industry.

Chairman: Mr. William T. Knox, Commerce

(d) Working group on deep ocean platforms, ship automation and nuclear propulsion.

Chairman: Mr. Marvin Pitkin, MARAD

6. Health Care

Chairman: Dr. Merlin DuVal, HEW

This initiative consists of two major elements: one dealing with a program to enhance the nutritional quality of the food supply through technology, another dealing with technologies that can improve the efficiency with which we deliver health care and with expansion of the clientele that receives this care. The nutrition program first attempts to define dietary adequacy and then develops techniques to assure adequate diets by devising standards for nutrient fortification; the development of methods of processing, storing and preparing foods to minimize nutritative losses; the development of staple and processed foods with higher nutrient levels.

The health care delivery program is in an early stage of development.

7. Technology for Meeting the Air Quality Standards Economically

Chairman: Dr. Stanley Greenfield, EPA

This program addresses a variety of technological opportunities to attempt to meet the air quality standards with greater efficiency and economy than currently available. It consists of a proposed waste management pilot plant to be located at one of the four Chicago incinerators that will demonstrate the economy of existing technologies for the reclamation and recycling of the metal, mineral, fiber and energy values of urban refuse.

One of the purposes of a plant of this size would be to provide sufficient output of the reclaimed metals, glass and fiber products to establish their market value which in turn determines the economy of the overall process. Another program will propose to exploit, with industry participation, an advanced power cycle which will be a combined gas turbine/ steam turbine plant. Low cost high sulfur fuel is gasified. Hydrogen sulphide is recovered and the "clean" gas is then burned driving a gas turbine whose exhaust gases provide the energy for a steam turbine. If inlet blades of silicone nitride (or other materials) can tolerate a gas temperature of 2500° Fahrenheit, a thermodynamic efficiency of 45% to 50% is predicted. Another element of this program measures the regional production and ventilation of pollutants to confirm certain analytical models that have been developed. When confirmed, these models could be used to locate large emission sources at such points in a region to minimize their impact on the air quality. The last element in this program relates to a series of efforts to improve our understanding of the health disbenefits for various pollutant levels and the consideration of the strategies which in some sense best counter these effects.

8. Protection from Natural Disasters

Chairman: Dr. John W. Townsend, NOAA

There are several major technology efforts in this program. (1) relating to weather warning and modification; (2) relating to earthquake warning and modification, and volcano, flood and landslide damage prediction; (3) the application of technology to the early detection and suppression of forest fires; and (4) the development of technology and standards applicable to community actions for disaster protection.

Review of Technological Opportunities

	PSAC or Consultant	OST Staff
1. Transportation		
(a) Reduction in urban traffic congestion	Simon and Truxal	Luenberger
(b) Cleaner, quieter, safer transportation	"	"
Unconventional power supplies for autos	R. Gouse (with Simon)	Moe (with Balzhiser)
(c) Increased transportation productivity		
Northeast corridor improvements	Fitch	Martin
Aircraft developments	R. Miller	Drew
2. Communications for social needs		
-- Electronic mail service	Olsen	Drew and Noll
-- Health care	Smith	Laster
-- Educational and cultural service	Truxal	Mays
3. Natural resources		
(a) Water resources		
Water resources in agriculture	N. Brady	Caldwell
River basin management	L. Dworsky	Butcher
(b) Mineral resources	E. Gilliland	Balzhiser
(c) Continental shelf	W. Nierenberg	Blake
(d) Forest productivity	N. Brady	Caldwell

	PSAC or Consultant	OST Staff
4. Urban/Suburban development		
-- Housing and urban development	Moynihan and Coleman	Luenberger
-- Integrated utility system	L. Roddis	Gage
5. Productivity		
(a) International competitiveness	Haggerty	Neureiter
(b) Technologies for productivity improvement	Haggerty	Noll (with Beckler)
(c) State commerce extension	"	Beckler (with Luenberger)
(d) Ocean platforms, ship automation	Buchsbaum	McRae
6. Health care		
-- Health care delivery	Smith	Laster
-- Nutrition	Bennett	Caldwell
7. Air quality		
-- Waste management pilot plant	Cairns	Balzhiser
-- Advanced power cycle	Tape	Weinhold
-- Regional modelling of pollutants	Friedman	Blake
-- Health effects	N. Nelson	Burger
8. Protection from natural disasters		
-- Weather warning and modification, including forest fire supervision	W. Kellogg	Blake
-- Earthquake warning	F. Press	"
-- Standards for community action	Simon	Blake (with Lannan)

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When the problems of equipment to handle, read and produce on each end are solved, they may, without electronic transmission, solve much of the Post Office's problem.

If electronic mail is readily accepted by the public, it might be that if the bulk of its application is in the production of bills which would be largely local, there might be no need for large transmission facilities.

The system might become easily saturated and therefore very unpopular because it would be so easy to generate personalized junk mail.

If the costs of communications gets very low it would encourage competition, particularly if the Post Office lost its monopoly position. With low line costs, a network system like TELEX that presented facsimile or fast printing might take care of much of the business mail.

The proposal seemed to ask for much technology development to avoid the need for rational rate fixing. If each piece of mail was made to pay its fair share, it would help solve many of the problems of the Post Office.

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Basic Criteria for New Technology Initiatives Study

The study should apply these basic criteria to each technology project or program before any increased funding is recommended to the President.

1. Importance: Project or program must relate (a) to a significant and urgent national problem which is broadly recognized by the public, or (b) to a significant opportunity for economic growth, increased exports, or technological leadership.

2. Pay Off: The cost/benefit ratio must be favorable. What are the social and economic benefits - including impact on balance of trade, productivity and employment? What will be the distribution of benefits among different industries and areas of the country?

3. Public Impact: Can visible progress be shown within a reasonable period - including significant progress in planning and design by next summer? A timetable must be provided by fiscal year for each phase of development: planning, design, pilot, demonstration, etc.

4. Budget Impact: What are estimated long-term costs over next six years or full systems cost?

5. Non-Federal Support: What is the feasibility and likely maximum extent of cost sharing by industry? Can the project be achieved through steps short of direct Federal funding: regulation or de-regulation, standard setting?

6. Potential Problems: Are there potential institutional or economic barriers to acceptance and implementation of the technology and how are they to be overcome? Are there any undesirable side effects from the technology and how are they to be dealt with?

7. Organization and Management: Assuming several programs or projects meet the above criteria, what kind of organization (existing agencies, new agency, or quasi-public corporation) should be created (if any) or redirected to carry out these programs?

The study should have two phases: (1) an interim report due the President September 1, and (2) a final report due the President November 15.

Dr. Edward David, the Director of the Office of Science and Technology and the President's Science Adviser, will chair the sub-committee and John Whitaker will have Domestic Council staff responsibility.

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Chairman: Dr. Robert Cannon
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The transportation study has identified three transportation goals and the long- and short-term development programs that can achieve these objectives.

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(c) An effort to increase the efficiency and productivity of the movement of people and goods. A major development and implementation program to improve passenger and rail transportation on the Eastern Seaboard in time for the 1976 bicentennial celebration and the planning for extending these capabilities to a national rail system; relief of impending congestion in the Northeast Corridor intercity highway system by real time information systems and by improving the connectivity of the system; an expansion of the advanced aircraft transport and engine technology program in the subsonic, supersonic and hypersonic regimes; the expansion of VSTOL development to higher capability, quieter vehicles to test the market potential by 1976; an expansion of the development of tracked levitated vehicle systems to establish their potential for high speed intercity travel by 1976; and finally, the development of a nationwide cargo security system to reduce pilferage losses.

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FURTHER THOUGHTS ON TECHNOLOGICAL INITIATIVES

Society made some unbelievable organizational mistakes when computers came along. People concluded that the organizations responsible for certain activities, whether they be in the government, in business or in the local high schools, were not competent enough to use computers so they used experts to run the computers. With two groups sharing responsibility, no one could be blamed for failure and no one could fix the problems.

Five years ago, if the local high school consistently fouled up its schedules, they would have fired the administration. For the last four years the schedules have been unbelievably fouled up. Year after year everyone blames the computers and the software. The administration has no responsibility because the school board hired experts from the outside to do the job and the experts, of course, have very limited responsibility. This also goes on in the organization which I run and in almost every organization with which I have any contact.

We now have a wonderful new opportunity to do the same thing with communications. It is clear that HUD is not technically competent to use modern communications to solve their problems, so if we impose new communications experts on them they can have an excuse for failing in their commission and they can blame it on the communications software.

The only dehumanizing result of computers that I will admit to is where responsibility and authority for the solution of a problem is taken away from the only group commissioned to find a solution and given to someone else who runs the computer. We can further destroy this authority and responsibility by taking away the control of communications and giving that to an expert.

. . . .

Every experiment should be considered an experiment with a predetermined checkpoint and an algorithm on which the decision to continue or stop will be made. It is misleading to call something an experiment, but make a commitment to go on indefinitely.

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Five years ago, if the local high school consistently fouled up its schedules, they would have fired the administration. For the last four years the schedules have been unbelievably fouled up. Year after year everyone blames the computers and the software. The administration has no responsibility because the school board hired experts from the outside to do the job and the experts, of course, have very limited responsibility. This also goes on in the organization which I run and in almost every organization with which I have any contact.

We now have a wonderful new opportunity to do the same thing with communications. It is clear that HUD is not technically competent to use modern communications to solve their problems, so if we impose new communications experts on them they can have an excuse for failing in their commission and they can blame it on the communications software.

The only dehumanizing result of computers that I will admit to is where responsibility and authority for the solution of a problem is taken away from the only group commissioned to find a solution and given to someone else who runs the computer. We can further destroy this authority and responsibility by taking away the control of communications and giving that to an expert.

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10. It is worth noting that earlier accounts of point velocity thresholds describe a minimum at about 60 to 180 minutes of visual angle per second; see W. E. Hick, *Quart. J. Exp. Psychol.* **2**, 33 (1950); J. M. Notterman and D. E. Page, *Science* **126**, 652 (1957); J. M. Notterman, G. A. Cicala, D. E. Page, *ibid.* **131**, 983 (1960). These studies all involved isometric, 1.5-inch stimulus traverses, whereas the current study has 1 inch as a maximum. Therefore, our best guess as to the basis for the presence of a minimum Weber ratio concerns the length of stimulus traverse, probably as it influences duration of exposure regardless of mode of exposure. Data are available from a pilot subject which support this conjecture, in that Weber ratios were decreased by approximately half in going from 0.4 to 0.6 second of isochronal stimulus rate duration.
11. Two oscilloscopes (Tektronix model 535 and Hewlett-Packard model 130-A) were used to present identical, electronically generated stimuli to the two subjects simultaneously. Both oscilloscopes were fitted with P11 5-inch cathode ray tubes having relatively short persistence traces. Each oscilloscope's tube face illumination was adjusted to a low level of brightness (0.0057 millilamberts) and supplied the only ambient illumination in the otherwise dark subjects' cubicle. The spot-stimulus was 0.03 inch in diameter, and 0.029 millilamberts in brightness.
12. G. von Békésy, *Sensory Inhibition* (Princeton Univ. Press, Princeton, N.J., 1967), pp. 1–34.
13. Some unusual masking phenomena may be representative of these nonlinearities; see, for example, D. N. Robinson, *J. Opt. Soc. Am.* **58**, 2 (1968); E. Donchin and D. B. Lindsley, *Vision Res.* **5**, No. 1/2 (1965). Stevens [*Science* **170**, 1043 (1970)] offers valuable comment on perceptual nonlinearities and central processing.
14. See R. S. Woodworth and H. Schlosberg, *Experimental Psychology* (Holt, New York, 1954), p. 270.
15. Although the precise values of the thresholds obtained might differ under *contracting* conditions for the line (as well as for the circle), and for point movement from right to left instead of from left to right, we have no substantial reason to believe that the ordering of thresholds reported here would be altered.
16. A 400-hertz modulator was used in conjunction with PRO-203W RCA electroluminescent panels, cropped to 1 by 2 inches, to generate stimuli of varying luminance. A dimly illuminated fixation cross, etched on a Plexiglas plate, was centered on each panel. For the three standards, the maximum driving voltages were 120, 240, and 600 volts, respectively.
17. S. H. Bartley, in *Handbook of Experimental Psychology*, S. S. Stevens, Ed. (Wiley, New York, 1951), p. 945.
18. Averages were obtained by dividing the final luminance less the initial luminance (0.191 millilamberts) by 0.6 second.
19. R. D. L. Filion, thesis, Princeton University (19[illegible]3).
20. S. S. Stevens. *Science* **170**, 1043 (1970).
21. W. A. H. Rushton, in *Sensory Communication*, W. A. Rosenblith, Ed. (M.I.T. Press, Cambridge, Mass., 1961), p. 176.
22. Supported by U.S. Air Force Office of Scientific Research contract AF 49 (638)-1258. We are grateful to S. C. Fowler, C. E. Sherrick, and D. Weitzman for their comments on the manuscript. Dr. Fowler, who currently shares the senior author's laboratory, was especially generous with his time.

The Scientific Advisory System: Some Observations

This system has little effect on the broad technical decision made in Washington.

Martin L. Perl

Since World War II, scientists and engineers have been going to Washington in increasing numbers to help the government make decisions on technical questions. These questions concern every aspect of our technological society—nuclear weapons, missiles, space travel, cancer research, pesticides, and mental health. Some scientists and engineers go for 1 or 2 days a month; others take a leave of absence from their institutions or corporations and spend several years in Washington. Some serve on committees attached to the executive branch of the government; others serve through semigovernmental institutions like the National Academy of Sciences. A few work with the Congress. All of these scientists and engineers, the committees they serve on, and the positions they hold in Washington together constitute the scientific advisory system (*1*). This article is about that system, or more precisely, about a paradox connected with that system.

The paradox is easily presented. Most people will agree that the United States is besieged with perilous technological problems—how to stop the arms race and bring about nuclear disarmament, how to stop the technological destruction of the natural environment, how to raise the standard of living, or at least prevent mass starvation, in the poor countries. Most people will also agree that these problems have become much more severe in the last two decades. But in these same two decades, the United States has received enormous amounts of scientific and technical information and advice from the scientists and engineers of this country. This information is almost always technically correct and thorough; it is almost always given with the intention of solving or mitigating the problems sketched above. The paradox is simply this: How have we gotten into so much technological trouble while getting so much well-intentioned and correct technological advice?

A broad analysis of this paradox might require a study of the relationship between the scientific advisory system and the "technostructures" postulated by Galbraith (*2*). Or one might examine whether the advisory system is an example of the "techniques" that Jacques Ellul (*3*) believes are the essence of our technological society. However, I restrict my analysis to a discussion of the role played by the advisory system in the technical decision-making processes in Washington. In addition, I do not attempt to present a complete description and evaluation of the scientific advisory system, nor do I discuss the role of the scientific advisory system in the larger decisions on military technology.

Few people realize the size and complexity of the scientific advisory system, and I know of no complete study of the magnitude and structure of this system. Therefore, I refer here to a recent, but not exhaustive, study (*4*) that was carried out by a group of Stanford graduates and undergraduates, for whom I was faculty adviser. The study notes that the Executive Office of the President has advisory committees that involve several hundred prominent scientists and engineers. The best known of these committees is the President's Science Advisory Committee. Outside the Executive Office of the President, but inside the executive

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branch of the government, is a much larger advisory apparatus. This apparatus consists of thousands of scientists and engineers who serve on hundreds of committees, as well as in various temporary positions. Primarily, they advise the Department of Defense and other departments concerned with scientific, technical, or medical questions.

Semipublic institutions also provide a great deal of advice to the executive branch. For example, the National Academy of Sciences and the National Academy of Engineering, through the National Research Council, supervise the work of about 500 committees involving 7000 engineers and scientists. Other large sources of advice are the "think tanks." The Rand Corporation advises the Air Force, the Research Analysis Corporation advises the Army, the Center for Naval Analysis advises the Navy, and the Institute for Defense Analysis advises the entire Department of Defense. Taken together, these public and semipublic advisory groups involve more than 15,000 or 20,000 individual scientists and engineers.

On the other hand, very little scientific advice is given to Congress. Some technical information and advice is obtained through panels or committees attached to congressional legislative committees, and a few individual congressmen, particularly senators, receive some unofficial advice and information. Finally, the Science Policy Research Division and the Environmental Policy Division of the Legislative Reference Service provide reports and summaries on technical questions. But the total amount of scientific and technical information and advice given to Congress is very small compared to that given to the executive branch.

The Scientific Establishment

There is a large overlap between the scientists who lead the advisory system and the scientists who belong to what has been called by a sympathetic observer (5) the "scientific establishment." The scientific establishment comprises most of the prominent scientists and research engineers in the United States. Many of these individuals are deeply involved in science administration and in the making of science policy, both public and private. But usually their prominence has been attained through research rather than through administration or teaching. The scientific establishment has five functions or attributes.

1) Many members of the establishment are the heads of professional societies, the heads of university or industrial laboratories, and the chairmen of university science departments. Many are or have been university deans and presidents. Thus, the members of the establishment tend to be the administrators of the worlds of scientific and engineering research and education.

2) Members of the establishment represent their professions, institutions, and organizations before the federal government in requesting funds for research and education.

3) In the eyes of the press and the public, the establishment represents science and advanced technology. It is the members of the establishment who are most often interviewed and quoted. This comes about in part from their accomplishments and in part from their administrative positions.

4) Members of the establishment are the models for young scientists and engineers interested in research.

5) The establishment tends to guide the directions that research takes. This promotes the classification of a research subject as fashionable or unfashionable. This is a useful function in that it encourages researchers to leave unproductive fields, but it can also create difficulties for iconoclasts.

The scientific establishment is by no means a closed or fixed group. Not all eminent scientists and engineers are in the group, and individuals move in and out of the group as their attitudes and interests change. It should also be recognized that the establishment is not always united on issues—particularly on the allocations of funds for research.

Evaluating the Advisory System

I am mainly concerned with evaluating what I call the specific effectiveness of the scientific advisory system. Specific effectiveness is the measure of how well the system carries out its specific functions in the government. As I have already indicated, these functions are set almost entirely by the executive branch and are carried out almost entirely for the executive branch. One specific function is the gathering of information and the presentation of recommendations on limited, purely technical problems. Thus, an advisory committee might be instructed to determine if a newly discovered physical phenomenon could be used to detect submarines. Another specific function is an advisory committee's being asked to recommend a general governmental policy on a technical issue, for example pesticides.

I am also concerned with the general effectiveness of the scientific advisory system. By general effectiveness I mean the total and overall effectiveness of the advisory system in relation to the general processes of making technical decisions. In this country, technical decisions, like other governmental policy decisions, are arrived at through a complicated process. Formally, the process involves the executive branch and the Congress, but in reality much more is involved. Before a decision is made, the question may be argued in the press and by the public. The question may become an important issue in political campaigns for elective office. State and local governments may become involved and take the lead in making a decision, or they may impede a decision. Often the crucial decision is made in the courts, and only later does Congress extend it in the form of legislation. This is by no means a linear process, and most issues have to pass through it several times before they are resolved. This totality, then, comprises the processes by which decisions, including technical decisions, are made in this country. By examining the relationships of the scientific advisory system to these processes, one can determine the general effectiveness of the advisory system.

An evaluation of the scientific advisory system is greatly impeded by the confidentiality of the advising process. The advice given to a government official or to a governmental agency is almost always received under the condition that it may be kept confidential by the official or agency. That is, the advice need not be released to the press, to the public, to Congress, or even to other parts of the executive branch. Large numbers of advisory reports are made public; but, unfortunately, it is just those reports which concern the most controversial and the most important technical questions that are often never made public, or only after long delay. This is unfortunate, not only for those who wish to study the advisory system, but, more important, for the process of making technical decisions in a democracy.

The largest portion of the work of the scientific advisory system is devoted to limited technical questions. "How does method A for water desalination compare in energy requirements to method B?" "How does missile guidance system A compare in reliability to missile guidance system B?" It is with these limited technical questions that the advisory system is most successful. This success results from the competency of the advisers and from the great amount of effort that is applied to these problems. Thus, the advisory system ranks high in specific effectiveness, with respect to limited technical questions.

But suppose the questions are not limited and are not purely technical. Suppose that another specific function of the advisory system, the recommendation of general technical policies, is involved. Or suppose that the technical decision has public policy, economic, or ideological implications. Such questions I shall call broad technical questions. These broad, technical questions severely test the specific effectiveness of the scientific advisory system.

Environmental Questions

The Stanford Workshop (*4*) studied six broad, technical questions related to the environment and public health: the supersonic transport (SST), cyclamates, the safety of commercial nuclear power plants, the safety of underground nuclear tests, pesticide regulation, and herbicide use in Vietnam. On broad technical questions, the work of the advisory committees may be divided into three parts. First, the committee studies the technical and scientific aspects of the question. Here, as in limited technical questions, the committee generally exhibits high effectiveness.

The second part of the committee's work is usually the development of a program for further study and research. In this, the local effectiveness of the advisory system seems to be reasonable but not high. For example, the 1963 report of the President's Science Committee, entitled *Use of Pesticides* (*6*), recommended an extensive research program to study the safety of pesticides. Many of those research recommendations appear to have been carried out. On the other hand, the government rejected an advisory committee recommendation that additional study be devoted to the safety of some types of commercial nuclear reactors before those reactors were licensed for use (*4*).

The third part of the advisory committee's work on broad technical issues usually involves recommendations that certain technical policies be adopted by the executive branch. *Use of Pesticides* recommended that there be an "orderly reduction in the use of persistent pesticides" and that, as a "first step," the government "restrict wide-scale use of persistent pesticides [such as DDT] except for the necessary control of disease vectors." With respect to such policy recommendations, which I call action recommendations, the effectiveness of the advisory system is low. The executive branch will usually ignore the policy recommendation of the advisory committee if (i) the recommendation is contrary to existing policies of the executive branch, (ii) the adoption of the policy would expose the Administration to congressional or electoral difficulties, or (iii) there are strong pressures from special interest groups that are opposed to the new policy. These pressures may often be traced to industries, labor unions, or municipalities, which think their economic well-being depends upon the continuation of the existing policy. In some cases, such as those related to atomic energy, the recommendations of the advisory committee may also be opposed by strong technological interests within the government itself. As an illustration of the failure of an action recommendation, consider the 1963 recommendation that the widespread use of DDT be drastically reduced: this "first step" has yet to be completed in 1971. Its beginning is the result of 8 years of public pressure and of litigation by environmental and consumer groups.

As another illustration of the fate of action recommendations, consider the SST (*7*). In the beginning of 1969, as the controversy over the SST began to increase, President Nixon appointed an advisory committee to study the issue. This was a rather high-level committee, involving the undersecretaries of many federal departments. The committee and its subcommittees were charged with studying not only the technological and environmental aspects of the SST, but also the economic, balance of payment, and international aspects. The appointment of the committee was attended by much publicity that emphasized the Administration's concern with the problem. In March 1969, the committee presented a report that was almost entirely unfavorable to the SST. Lee DuBridge, a committee member and the President's science adviser, wrote (*8*):

> Granted that this [the SST] is an exciting technological development, it still seems best to me to avoid the serious environmental and nuisance problems and the Government should not be subsidizing a device which has neither commercial attractiveness nor public acceptance.

In spite of this strong disapproval, the President and his Administration continued to support the SST fully and enthusiastically. To prevent the report from being used by the opponents of the SST, it was kept confidential, even though there is nothing in it having to do with national security or military matters. Not even Congress, which had to decide on future SST appropriations, was allowed to see it. Only in October 1969 was Representative S. R. Yates (D–Ill.) able to obtain partial release of the report.

It is reasonable to require, as one of the tests of the specific effectiveness of the scientific advisory system, that the executive branch be fairly responsive to the policy recommendations of its advisory committees. Furthermore, the crucial test is its responsiveness to action recommendations. By this test, the advisory system has substantially failed on broad technical issues.

Failure on Broad Technical Issues

While some observers will agree with me that the scientific advisory system has not done well on broad technical issues, they argue that the advisory system has accomplished all that could be done. These supporters point out that there are immense political, economic, and ideological pressures that prevent rational decisions on the environment and public health. However, other groups have made progress against these pressures. For example, there is a strong environmental and consumer protection movement in this country. The originators and leaders of this movement are people like Rachel Carson and Ralph Nader, not members of any strong self-interest group. While there are scientists and engineers in this movement, few of them are members of the scientific establishment. Thus, we are still faced with the question of why the advisory system, with its large membership, its great technical and scientific competence, and its prominent men, has not been more successful on the broad technical issues.

There are a number of reasons for the system's lack of specific effectiveness on these issues.

1) *The many functions of the scientific establishment.* The functions and attributes of the scientific establishment severely limit the influence of the advisory system. In a democratic country such as ours, important decisions are not made through a set procedure of debates and position papers, but through a long and messy process. The scientific establishment, because of its functions of representing and protecting research and technical education, is reluctant to take part in much of this process. Usually its members enter the decision-making process through the advisory system at only one point—when the Administration is considering a technical issue. For this reason, the influence of members of the scientific establishment is easily negated. The withholding of reports from the public is just one aspect of that process of negation.

2) *Confidentiality and legitimization.* I have emphasized that the information and advice provided by the advisory system can be declared confidential by the official or agency that receives it, and that it is up to the official or agency to release the information. Although every government official is certainly entitled to some completely private and permanently confidential advice, the problem is that the use of confidentiality is so widespread that very often the only technical reports available on the subject are declared confidential. In that case, the press, the public, and the Congress are left with very incomplete technical information. Thus, on technical issues, the decision-making process is seriously impeded and, in many cases, the system of checks and balances nullified.

There is another aspect to the confidentiality of the advice given by the advisory system. The press, the well-informed citizen, and the Congress know that the executive branch obtains vast amounts of correct technical information and advice. They know that this advice comes from the best and most prominent scientists and engineers in the country. The final technical policy decisions made by the executive branch become associated with this knowledge. One thinks either that the technical advice has been followed or that it has been seriously considered and then overridden by other, more serious and more profound considerations. Thus the scientific advisory system, as presently constituted, provides a facade of prestige which tends to legitimize all technical decisions made by the President.

The executive branch is well aware of the legitimizing effect of the advisory system. For example, public concern about a technical issue can often be mollified by appointing a committee to study the issue in detail. There is often the hope that, by the time the report appears, public pressure will have decreased. Indeed, this technique extends far outside the sphere of technical issues. If the report appears and is favorable to the policies of the executive branch, it can be released with much publicity. Otherwise, the principle of confidentiality can be imposed. Even an unfavorable report can be used by releasing not the report itself, but a distorted summary of it. Just such a maneuver was used (*4*) with the unfavorable report on the SST.

The legitimizing aspect of the advisory system is eliminated only when some members of the system directly or indirectly disregard the principle of confidentiality, for example in testimony before Congress on the antiballistic missile and the SST. However, such actions are still rare.

3) *Socialization in Washington.* The basic way to get something done in the executive branch is to work from the inside. This means that one must be practical and hardheaded. One must work for small gains and progress in small steps. For the adviser it is a slow process, with respect to both his influence and his achievements. The adviser works first in less important committees on more restricted issues. As he demonstrates his ability, his reliability, and his reasonableness, he progresses to more important committees and to more important issues. But when he finally achieves a position of influence, his freedom to act is quite limited. This limitation comes not from any rules, but from the methods he learned while working with the executive branch. Thus, in order to retain his position of influence, he may not protest some decisions he intensely dislikes. He wants to reserve his influence for some other issue upon which he has concentrated his interest. Ultimately, the adviser may fall into the trap of considering, above all else, the technique of preserving his influence in Washington [I use the term "technique" here as it is used by Ellul (*3*)].

Socialization explains a number of things. It explains, for example, why the principle of confidentiality is so universally honored in the advisory system. The socialization also explains why the legitimizing effect is so strong. I note again that this socialization in Washington is something that happens to economists, accountants, labor leaders, and businessmen as well as to scientists and engineers. I only emphasize it here because we scientists tend to think that our objectivity and our scientific training constitute a magic cloak that protects us from socialization. It does not.

I have given some of the reasons that the scientific advisory system has a great deal of specific effectiveness on limited technical questions, yet little specific effectiveness on broad technical questions. Now what about the general effectiveness of the scientific advisory system? How does it enter into the decision-making processes for general technical questions in this country? The answer is evident from my discussion: the advisory system does not usually enter into the decision-making processes for general technical questions. Thus its general effectiveness is very low, the only exceptions being when individual members of the advisory system testify before Congress or work with congressmen. But most members of the advisory system do not believe in working in the decision-making process outside of the executive branch. They believe that, if they increase their general effectiveness, they will decrease their specific effectiveness.

The Scientific Community

My colleagues in the advisory system have sometimes agreed with the analysis I have presented. But they then say, "All right, we in the advisory system work from the inside doing what we can. Perhaps we are not as effective as you wish us to be. Why don't you work from the outside? There are 10 or 20 thousand people in the advisory system, but there are several hundred thousand scientists and engineers who are not in the advisory system. They can all work from the outside." There are, unfortunately, a number of reasons that this division of labor does not work.

1) *The scientific establishment as a*

model for the scientific community. Those members of the establishment who are in the advisory system are models for the less well-known and younger scientists and engineers. An example of consciously setting a standard of behavior is the recruitment of young theoretical physicists into summer work with the Institute of Defense Analysis. Until recently, it was customary to ask the brightest and most promising young theorists to join in this summer work. Since the invitation was extended by some of the best of the older theoretical physicists, it was very flattering to receive one. Being invited to work with the Institute was, at least for a while, a mark of attainment in theoretical physics.

It is difficult for the scientific community to work on broad technical questions from the outside when the leaders are working from the inside. After all, only a few well-known scientists, men like Pauling, Lapp, and Commoner, work on the outside. Therefore, scientists who wish to serve the country in the technical decision-making process have tended to join the advisory system. In the last few years, there has been some opposition to this tendency, primarily from the environmental and consumer movements and from the various student movements.

2) *The "don't rock the boat" attitude.* I have pointed out that the multiple functions of the establishment and the overlap of the establishment and the advisory system cause a very cautious attitude among advisers. There is a widespread feeling that the advisers should not oppose the technical policies of the Administration too vehemently or too publicly. If they do, members of the establishment fear, federal or even public support for science research and education may be adversely affected. There is certainly some truth in this fear.

This "don't rock the boat" attitude extends into most of the scientific community. This is partly because of the model of behavior set by the establishment; but there is a more compelling reason for this attitude. The natural way for the scientific community to critically and publicly examine the government's technical policies is to use the independent scientific institutions—the professional and scientific societies and the engineering and science departments of universities. Yet these are just the institutions that are being protected by the "don't rock the boat" attitude. For this reason, the scientific community and the scientific establishment will not use independent institutions in the technical decision-making process. It is usually said that these institutions must be kept "neutral."

3) *Professional rewards for service in the advisory system.* There is a grave imbalance between the professional rewards (other than direct monetary rewards) for helping the government make technical decisions from the inside and the rewards for helping from the outside. Almost all universities encourage the public service activities of their faculties if these activities bring honor or influence to the university; teaching or administrative duties may be reduced to allow for them. But almost always, these must be official public service activities. Working within the scientific advisory system is official public service, but, except for a very few universities, working with unofficial neighborhood or consumer groups to reduce the pollution from a local factory is not considered public service. Thus, for the energetic, ambitious young faculty member who wishes to help in the making of technical decisions there are strong career pressures that push him into the advisory system.

Even for the senior scientist the advisory system has career rewards. To be in Washington, to work with other members of the establishment, and to get to know government officials can be of help in a number of ways. It is helpful when seeking funds for a department or for the research of younger people. It also makes a scientist more influential in his home institution.

4) *The "it's in good hands" attitude.* Consciously and unconsciously the members of the advisory system often present the attitude that the role of the scientist and engineer in the technical decision-making process is completely filled by the advisory system. This often takes the form of such statements as, "Don't worry about it, it's in good hands." It is often implied that the members of the advisory system are professional experts on this or that technical question. Other scientists or engineers who are outside the advisory system are regarded as amateurs. This attitude depresses attempts by the scientific community at large to enter the technical decision-making process. It also encourages government officials to ignore scientists and engineers who are not in the advisory system.

Summary

The scientific advisory system is effective on limited technical questions, and such questions provide much of its work. On broad technical questions, however, the scientific advisory system is not effective. Unfortunately this category includes most of the crucial environmental questions. Finally, the advisory system, as presently constituted, combined with the multiple functions of the scientific establishment, is detrimental in important ways to the process of technical decision-making in this country. This is because the combined effect of the advisory system and the establishment is to impede the development of a more effective and comprehensive role for the scientific community in the technical decision-making process.

References and Notes

1. The scientific advisory system is described in several articles in *Scientists and National Policy Making* [R. Gilpin and C. Wright, Eds. (Columbia Univ. Press, New York, 1964)]; a description of other advisory systems is provided by *The Presidential Advisory System* [T. E. Cronin and S. D. Greenberg, Eds. (Harper & Row, New York, 1969)].
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WRITE IT - Don't say it

TO: K. Olsen | DATE: 10-26-71 | TIME: 17:30

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Although much of this applies primarily to scientists rather than to engineers or engineering management, some of it seems relevant to your position on the Advisory Committee

SIGNED: Eric Peabody DEPT: Programming

DEC 5–(641)–1011A–R371

10. It is worth noting that earlier accounts of point velocity thresholds describe a minimum at about 60 to 180 minutes of visual angle per second; see W. E. Hick, *Quart. J. Exp. Psychol.* 2, 33 (1950); J. M. Notterman and D. E. Page, *Science* 126, 652 (1957); J. M. Notterman, G. A. Cicala, D. E. Page, *ibid.* 131, 983 (1960). These studies all involved isometric, 1.5-inch stimulus traverses, whereas the current study has 1 inch as a maximum. Therefore, our best guess as to the basis for the presence of a minimum Weber ratio concerns the length of stimulus traverse, probably as it influences duration of exposure regardless of mode of exposure. Data are available from a pilot subject which support this conjecture, in that Weber ratios were decreased by approximately half in going from 0.4 to 0.6 second of isochronal stimulus rate duration.
11. Two oscilloscopes (Tektronix model 535 and Hewlett-Packard model 130-A) were used to present identical, electronically generated stimuli to the two subjects simultaneously. Both oscilloscopes were fitted with P11 5-inch cathode ray tubes having relatively short persistence traces. Each oscilloscope's tube face illumination was adjusted to a low level of brightness (0.0057 millilamberts) and supplied the only ambient illumination in the otherwise dark subjects' cubicle. The spot-stimulus was 0.03 inch in diameter, and 0.029 millilamberts in brightness.
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14. See R. S. Woodworth and H. Schlosberg, *Experimental Psychology* (Holt, New York, 1954), p. 270.
15. Although the precise values of the thresholds obtained might differ under *contracting* conditions for the line (as well as for the circle), and for point movement from right to left instead of from left to right, we have no substantial reason to believe that the ordering of thresholds reported here would be altered.
16. A 400-hertz modulator was used in conjunction with PRO-203W RCA electroluminescent panels, cropped to 1 by 2 inches, to generate stimuli of varying luminance. A dimly illuminated fixation cross, etched on a Plexiglas plate, was centered on each panel. For the three standards, the maximum driving voltages were 120, 240, and 600 volts, respectively.
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18. Averages were obtained by dividing the final luminance less the initial luminance (0.191 millilamberts) by 0.6 second.
19. R. D. L. Filion, thesis, Princeton University (19?3).
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22. Supported by U.S. Air Force Office of Scientific Research contract AF 49 (638)-1258. We are grateful to S. C. Fowler, C. E. Sherrick, and D. Weitzman for their comments on the manuscript. Dr. Fowler, who currently shares the senior author's laboratory, was especially generous with his time.

Science, 24 Sept. '71

The Scientific Advisory System: Some Observations

This system has little effect on the broad technical decision made in Washington.

Martin L. Perl

Since World War II, scientists and engineers have been going to Washington in increasing numbers to help the government make decisions on technical questions. These questions concern every aspect of our technological society—nuclear weapons, missiles, space travel, cancer research, pesticides, and mental health. Some scientists and engineers go for 1 or 2 days a month; others take a leave of absence from their institutions or corporations and spend several years in Washington. Some serve on committees attached to the executive branch of the government; others serve through semigovernmental institutions like the National Academy of Sciences. A few work with the Congress. All of these scientists and engineers, the committees they serve on, and the positions they hold in Washington together constitute the scientific advisory system (*1*). This article is about that system, or more precisely, about a paradox connected with that system.

The paradox is easily presented. Most people will agree that the United States is besieged with perilous technological problems—how to stop the arms race and bring about nuclear disarmament, how to stop the technological destruction of the natural environment, how to raise the standard of living, or at least prevent mass starvation, in the poor countries. Most people will also agree that these problems have become much more severe in the last two decades. But in these same two decades, the United States has received enormous amounts of scientific and technical information and advice from the scientists and engineers of this country. This information is almost always technically correct and thorough; it is almost always given with the intention of solving or mitigating the problems sketched above. The paradox is simply this: How have we gotten into so much technological trouble while getting so much well-intentioned and correct technological advice?

A broad analysis of this paradox might require a study of the relationship between the scientific advisory system and the "technostructures" postulated by Galbraith (*2*). Or one might examine whether the advisory system is an example of the "techniques" that Jacques Ellul (*3*) believes are the essence of our technological society. However, I restrict my analysis to a discussion of the role played by the advisory system in the technical decision-making processes in Washington. In addition, I do not attempt to present a complete description and evaluation of the scientific advisory system, nor do I discuss the role of the scientific advisory system in the larger decisions on military technology.

Few people realize the size and complexity of the scientific advisory system, and I know of no complete study of the magnitude and structure of this system. Therefore, I refer here to a recent, but not exhaustive, study (*4*) that was carried out by a group of Stanford graduates and undergraduates, for whom I was faculty adviser. The study notes that the Executive Office of the President has advisory committees that involve several hundred prominent scientists and engineers. The best known of these committees is the President's Science Advisory Committee. Outside the Executive Office of the President, but inside the executive

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branch of the government, is a much larger advisory apparatus. This apparatus consists of thousands of scientists and engineers who serve on hundreds of committees, as well as in various temporary positions. Primarily, they advise the Department of Defense and other departments concerned with scientific, technical, or medical questions.

Semipublic institutions also provide a great deal of advice to the executive branch. For example, the National Academy of Sciences and the National Academy of Engineering, through the National Research Council, supervise the work of about 500 committees involving 7000 engineers and scientists. Other large sources of advice are the "think tanks." The Rand Corporation advises the Air Force, the Research Analysis Corporation advises the Army, the Center for Naval Analysis advises the Navy, and the Institute for Defense Analysis advises the entire Department of Defense. Taken together, these public and semipublic advisory groups involve more than 15,000 or 20,000 individual scientists and engineers.

On the other hand, very little scientific advice is given to Congress. Some technical information and advice is obtained through panels or committees attached to congressional legislative committees, and a few individual congressmen, particularly senators, receive some unofficial advice and information. Finally, the Science Policy Research Division and the Environmental Policy Division of the Legislative Reference Service provide reports and summaries on technical questions. But the total amount of scientific and technical information and advice given to Congress is very small compared to that given to the executive branch.

The Scientific Establishment

There is a large overlap between the scientists who lead the advisory system and the scientists who belong to what has been called by a sympathetic observer (*5*) the "scientific establishment." The scientific establishment comprises most of the prominent scientists and research engineers in the United States. Many of these individuals are deeply involved in science administration and in the making of science policy, both public and private. But usually their prominence has been attained through research rather than through administration or teaching. The scientific establishment has five functions or attributes.

1) Many members of the establishment are the heads of professional societies, the heads of university or industrial laboratories, and the chairmen of university science departments. Many are or have been university deans and presidents. Thus, the members of the establishment tend to be the administrators of the worlds of scientific and engineering research and education.

2) Members of the establishment represent their professions, institutions, and organizations before the federal government in requesting funds for research and education.

3) In the eyes of the press and the public, the establishment represents science and advanced technology. It is the members of the establishment who are most often interviewed and quoted. This comes about in part from their accomplishments and in part from their administrative positions.

4) Members of the establishment are the models for young scientists and engineers interested in research.

5) The establishment tends to guide the directions that research takes. This promotes the classification of a research subject as fashionable or unfashionable. This is a useful function in that it encourages researchers to leave unproductive fields, but it can also create difficulties for iconoclasts.

The scientific establishment is by no means a closed or fixed group. Not all eminent scientists and engineers are in the group, and individuals move in and out of the group as their attitudes and interests change. It should also be recognized that the establishment is not always united on issues—particularly on the allocations of funds for research.

Evaluating the Advisory System

I am mainly concerned with evaluating what I call the specific effectiveness of the scientific advisory system. Specific effectiveness is the measure of how well the system carries out its specific functions in the government. As I have already indicated, these functions are set almost entirely by the executive branch and are carried out almost entirely for the executive branch. One specific function is the gathering of information and the presentation of recommendations on limited, purely technical problems. Thus, an advisory committee might be instructed to determine if a newly discovered physical phenomenon could be used to detect submarines. Another specific function is an advisory committee's being asked to recommend a general governmental policy on a technical issue, for example pesticides.

I am also concerned with the general effectiveness of the scientific advisory system. By general effectiveness I mean the total and overall effectiveness of the advisory system in relation to the general processes of making technical decisions. In this country, technical decisions, like other governmental policy decisions, are arrived at through a complicated process. Formally, the process involves the executive branch and the Congress, but in reality much more is involved. Before a decision is made, the question may be argued in the press and by the public. The question may become an important issue in political campaigns for elective office. State and local governments may become involved and take the lead in making a decision, or they may impede a decision. Often the crucial decision is made in the courts, and only later does Congress extend it in the form of legislation. This is by no means a linear process, and most issues have to pass through it several times before they are resolved. This totality, then, comprises the processes by which decisions, including technical decisions, are made in this country. By examining the relationships of the scientific advisory system to these processes, one can determine the general effectiveness of the advisory system.

An evaluation of the scientific advisory system is greatly impeded by the confidentiality of the advising process. The advice given to a government official or to a governmental agency is almost always received under the condition that it may be kept confidential by the official or agency. That is, the advice need not be released to the press, to the public, to Congress, or even to other parts of the executive branch. Large numbers of advisory reports are made public; but, unfortunately, it is just those reports which concern the most controversial and the most important technical questions that are often never made public, or only after long delay. This is unfortunate, not only for those who wish to study the advisory system, but, more important, for the process of making technical decisions in a democracy.

The largest portion of the work of the scientific advisory system is devoted to limited technical questions. "How does method A for water desalination compare in energy requirements to method B?" "How does missile guidance system A compare in reliability to missile guidance system B?" It is with these limited technical questions that the advisory system is most successful. This success results from the competency of the advisers and from the great amount of effort that is applied to these problems. Thus, the advisory system ranks high in specific effectiveness, with respect to limited technical questions.

But suppose the questions are not limited and are not purely technical. Suppose that another specific function of the advisory system, the recommendation of general technical policies, is involved. Or suppose that the technical decision has public policy, economic, or ideological implications. Such questions I shall call broad technical questions. These broad, technical questions severely test the specific effectiveness of the scientific advisory system.

Environmental Questions

The Stanford Workshop (*4*) studied six broad, technical questions related to the environment and public health: the supersonic transport (SST), cyclamates, the safety of commercial nuclear power plants, the safety of underground nuclear tests, pesticide regulation, and herbicide use in Vietnam. On broad technical questions, the work of the advisory committees may be divided into three parts. First, the committee studies the technical and scientific aspects of the question. Here, as in limited technical questions, the committee generally exhibits high effectiveness.

The second part of the committee's work is usually the development of a program for further study and research. In this, the local effectiveness of the advisory system seems to be reasonable but not high. For example, the 1963 report of the President's Science Committee, entitled *Use of Pesticides* (*6*), recommended an extensive research program to study the safety of pesticides. Many of those research recommendations appear to have been carried out. On the other hand, the government rejected an advisory committee recommendation that additional study be devoted to the safety of some types of commercial nuclear reactors before those reactors were licensed for use (*4*).

The third part of the advisory committee's work on broad technical issues usually involves recommendations that certain technical policies be adopted by the executive branch. *Use of Pesticides* recommended that there be an "orderly reduction in the use of persistent pesticides" and that, as a "first step," the government "restrict wide-scale use of persistent pesticides [such as DDT] except for the necessary control of disease vectors." With respect to such policy recommendations, which I call action recommendations, the effectiveness of the advisory system is low. The executive branch will usually ignore the policy recommendation of the advisory committee if (i) the recommendation is contrary to existing policies of the executive branch, (ii) the adoption of the policy would expose the Administration to congressional or electoral difficulties, or (iii) there are strong pressures from special interest groups that are opposed to the new policy. These pressures may often be traced to industries, labor unions, or municipalities, which think their economic well-being depends upon the continuation of the existing policy. In some cases, such as those related to atomic energy, the recommendations of the advisory committee may also be opposed by strong technological interests within the government itself. As an illustration of the failure of an action recommendation, consider the 1963 recommendation that the widespread use of DDT be drastically reduced: this "first step" has yet to be completed in 1971. Its beginning is the result of 8 years of public pressure and of litigation by environmental and consumer groups.

As another illustration of the fate of action recommendations, consider the SST (*7*). In the beginning of 1969, as the controversy over the SST began to increase, President Nixon appointed an advisory committee to study the issue. This was a rather high-level committee, involving the undersecretaries of many federal departments. The committee and its subcommittees were charged with studying not only the technological and environmental aspects of the SST, but also the economic, balance of payment, and international aspects. The appointment of the committee was attended by much publicity that emphasized the Administration's concern with the problem. In March 1969, the committee presented a report that was almost entirely unfavorable to the SST. Lee DuBridge, a committee member and the President's science adviser, wrote (*8*):

> Granted that this [the SST] is an exciting technological development, it still seems best to me to avoid the serious environmental and nuisance problems and the Government should not be subsidizing a device which has neither commercial attractiveness nor public acceptance.

In spite of this strong disapproval, the President and his Administration continued to support the SST fully and enthusiastically. To prevent the report from being used by the opponents of the SST, it was kept confidential, even though there is nothing in it having to do with national security or military matters. Not even Congress, which had to decide on future SST appropriations, was allowed to see it. Only in October 1969 was Representative S. R. Yates (D–Ill.) able to obtain partial release of the report.

It is reasonable to require, as one of the tests of the specific effectiveness of the scientific advisory system, that the executive branch be fairly responsive to the policy recommendations of its advisory committees. Furthermore, the crucial test is its responsiveness to action recommendations. By this test, the advisory system has substantially failed on broad technical issues.

Failure on Broad Technical Issues

While some observers will agree with me that the scientific advisory system has not done well on broad technical issues, they argue that the advisory system has accomplished all that could be done. These supporters point out that there are immense political, economic, and ideological pressures that prevent rational decisions on the environment and public health. However, other groups have made progress against these pressures. For example, there is a strong environmental and consumer protection movement in this country. The originators and leaders of this movement are people like Rachel Carson and Ralph Nader, not members of any strong self-interest group. While there are scientists and engineers in this movement, few of them are members of the scientific establishment. Thus, we are still faced with the question of why the advisory system, with its large membership, its great technical and scientific competence, and its prominent men, has not been more successful on the broad technical issues.

There are a number of reasons for the system's lack of specific effectiveness on these issues.

1) *The many functions of the scientific establishment.* The functions and attributes of the scientific establishment severely limit the influence of the advisory system. In a democratic country such as ours, important decisions are not made through a set procedure of debates and position papers, but through a long and messy process. The scientific establishment, because of its functions of representing and protecting research and technical education, is reluctant to take part in much of this process. Usually its members enter the decision-making process through the advisory system at only one point—when the Administration is considering a technical issue. For this reason, the influence of members of the scientific establishment is easily negated. The withholding of reports from the public is just one aspect of that process of negation.

2) *Confidentiality and legitimization.* I have emphasized that the information and advice provided by the advisory system can be declared confidential by the official or agency that receives it, and that it is up to the official or agency to release the information. Although every government official is certainly entitled to some completely private and permanently confidential advice, the problem is that the use of confidentiality is so widespread that very often the only technical reports available on the subject are declared confidential. In that case, the press, the public, and the Congress are left with very incomplete technical information. Thus, on technical issues, the decision-making process is seriously impeded and, in many cases, the system of checks and balances nullified.

There is another aspect to the confidentiality of the advice given by the advisory system. The press, the well-informed citizen, and the Congress know that the executive branch obtains vast amounts of correct technical information and advice. They know that this advice comes from the best and most prominent scientists and engineers in the country. The final technical policy decisions made by the executive branch become associated with this knowledge. One thinks either that the technical advice has been followed or that it has been seriously considered and then overridden by other, more serious and more profound considerations. Thus the scientific advisory system, as presently constituted, provides a facade of prestige which tends to legitimize all technical decisions made by the President.

The executive branch is well aware of the legitimizing effect of the advisory system. For example, public concern about a technical issue can often be mollified by appointing a committee to study the issue in detail. There is often the hope that, by the time the report appears, public pressure will have decreased. Indeed, this technique extends far outside the sphere of technical issues. If the report appears and is favorable to the policies of the executive branch, it can be released with much publicity. Otherwise, the principle of confidentiality can be imposed. Even an unfavorable report can be used by releasing not the report itself, but a distorted summary of it. Just such a maneuver was used (*4*) with the unfavorable report on the SST.

The legitimizing aspect of the advisory system is eliminated only when some members of the system directly or indirectly disregard the principle of confidentiality, for example in testimony before Congress on the antiballistic missile and the SST. However, such actions are still rare.

3) *Socialization in Washington.* The basic way to get something done in the executive branch is to work from the inside. This means that one must be practical and hardheaded. One must work for small gains and progress in small steps. For the adviser it is a slow process, with respect to both his influence and his achievements. The adviser works first in less important committees on more restricted issues. As he demonstrates his ability, his reliability, and his reasonableness, he progresses to more important committees and to more important issues. But when he finally achieves a position of influence, his freedom to act is quite limited. This limitation comes not from any rules, but from the methods he learned while working with the executive branch. Thus, in order to retain his position of influence, he may not protest some decisions he intensely dislikes. He wants to reserve his influence for some other issue upon which he has concentrated his interest. Ultimately, the adviser may fall into the trap of considering, above all else, the technique of preserving his influence in Washington [I use the term "technique" here as it is used by Ellul (*3*)].

Socialization explains a number of things. It explains, for example, why the principle of confidentiality is so universally honored in the advisory system. The socialization also explains why the legitimizing effect is so strong. I note again that this socialization in Washington is something that happens to economists, accountants, labor leaders, and businessmen as well as to scientists and engineers. I only emphasize it here because we scientists tend to think that our objectivity and our scientific training constitute a magic cloak that protects us from socialization. It does not.

I have given some of the reasons that the scientific advisory system has a great deal of specific effectiveness on limited technical questions, yet little specific effectiveness on broad technical questions. Now what about the general effectiveness of the scientific advisory system? How does it enter into the decision-making processes for general technical questions in this country? The answer is evident from my discussion: the advisory system does not usually enter into the decision-making processes for general technical questions. Thus its general effectiveness is very low, the only exceptions being when individual members of the advisory system testify before Congress or work with congressmen. But most members of the advisory system do not believe in working in the decision-making process outside of the executive branch. They believe that, if they increase their general effectiveness, they will decrease their specific effectiveness.

The Scientific Community

My colleagues in the advisory system have sometimes agreed with the analysis I have presented. But they then say, "All right, we in the advisory system work from the inside doing what we can. Perhaps we are not as effective as you wish us to be. Why don't you work from the outside? There are 10 or 20 thousand people in the advisory system, but there are several hundred thousand scientists and engineers who are not in the advisory system. They can all work from the outside." There are, unfortunately, a number of reasons that this division of labor does not work.

1) *The scientific establishment as a*

model for the scientific community. Those members of the establishment who are in the advisory system are models for the less well-known and younger scientists and engineers. An example of consciously setting a standard of behavior is the recruitment of young theoretical physicists into summer work with the Institute of Defense Analysis. Until recently, it was customary to ask the brightest and most promising young theorists to join in this summer work. Since the invitation was extended by some of the best of the older theoretical physicists, it was very flattering to receive one. Being invited to work with the Institute was, at least for a while, a mark of attainment in theoretical physics.

It is difficult for the scientific community to work on broad technical questions from the outside when the leaders are working from the inside. After all, only a few well-known scientists, men like Pauling, Lapp, and Commoner, work on the outside. Therefore, scientists who wish to serve the country in the technical decision-making process have tended to join the advisory system. In the last few years, there has been some opposition to this tendency, primarily from the environmental and consumer movements and from the various student movements.

2) *The "don't rock the boat" attitude.* I have pointed out that the multiple functions of the establishment and the overlap of the establishment and the advisory system cause a very cautious attitude among advisers. There is a widespread feeling that the advisers should not oppose the technical policies of the Administration too vehemently or too publicly. If they do, members of the establishment fear, federal or even public support for science research and education may be adversely affected. There is certainly some truth in this fear.

This "don't rock the boat" attitude extends into most of the scientific community. This is partly because of the model of behavior set by the establishment; but there is a more compelling reason for this attitude. The natural way for the scientific community to critically and publicly examine the government's technical policies is to use the independent scientific institutions—the professional and scientific societies and the engineering and science departments of universities. Yet these are just the institutions that are being protected by the "don't rock the boat" attitude. For this reason, the scientific community and the scientific establishment will not use independent institutions in the technical decision-making process. It is usually said that these institutions must be kept "neutral."

3) *Professional rewards for service in the advisory system.* There is a grave imbalance between the professional rewards (other than direct monetary rewards) for helping the government make technical decisions from the inside and the rewards for helping from the outside. Almost all universities encourage the public service activities of their faculties if these activities bring honor or influence to the university; teaching or administrative duties may be reduced to allow for them. But almost always, these must be official public service activities. Working within the scientific advisory system is official public service, but, except for a very few universities, working with unofficial neighborhood or consumer groups to reduce the pollution from a local factory is not considered public service. Thus, for the energetic, ambitious young faculty member who wishes to help in the making of technical decisions there are strong career pressures that push him into the advisory system.

Even for the senior scientist the advisory system has career rewards. To be in Washington, to work with other members of the establishment, and to get to know government officials can be of help in a number of ways. It is helpful when seeking funds for a department or for the research of younger people. It also makes a scientist more influential in his home institution.

4) *The "it's in good hands" attitude.* Consciously and unconsciously the members of the advisory system often present the attitude that the role of the scientist and engineer in the technical decision-making process is completely filled by the advisory system. This often takes the form of such statements as, "Don't worry about it, it's in good hands." It is often implied that the members of the advisory system are professional experts on this or that technical question. Other scientists or engineers who are outside the advisory system are regarded as amateurs. This attitude depresses attempts by the scientific community at large to enter the technical decision-making process. It also encourages government officials to ignore scientists and engineers who are not in the advisory system.

Summary

The scientific advisory system is effective on limited technical questions, and such questions provide much of its work. On broad technical questions, however, the scientific advisory system is not effective. Unfortunately this category includes most of the crucial environmental questions. Finally, the advisory system, as presently constituted, combined with the multiple functions of the scientific establishment, is detrimental in important ways to the process of technical decision-making in this country. This is because the combined effect of the advisory system and the establishment is to impede the development of a more effective and comprehensive role for the scientific community in the technical decision-making process.

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SCIENCE & GOVERNMENT REPORT

No. 1 Washington, D.C. Feb. 1, 1971

President Nixon's proposal to add some $100 million to the budget of the National Science Foundation, plus another $100 million to the National Institutes of Health budget for "cancer research," is being touted as evidence of a renaissance of federal fervor for science. And, in particular, NSF Director William D. McElroy and White House Science Adviser Edward E. David Jr. are being cited for persuasiveness with the White House inner councils. At least in regard to the NSF budget—the cancer scheme being a political ploy aimed at heading off a Kennedy-backed move for even greater demands on the Treasury—the two officials must be credited with delivering an unanticipated fiscal package. While most other Federal agencies are being held more or less level, NSF is pointed significantly upwards, and there is reason to believe that Congress will react sympathetically. This is not one of those schemes where the Executive can propose spending with confidence that the Congress will say "no" and thereby merit the blame for being the villian. But, like most else in the budget, the NSF entry is not what it seems to be on first examination; moreover, obscured in the intricacies of the Nixon proposal are some profound issues of scientific and educational policy that ought to be given close examination before the Treasury Department starts writing checks.

First, a look at some of the realities of the NSF budget: About $40 million of that additional $100 million will be for the purpose of NSF picking up the costs of research activities now financed by the Department of Defense and the National Aeronautics and Space Administration. Without the NSF money, these would probably wither, as a good many, in fact, already have under the impact of the Mansfield restriction on Defense supporting research remote from military application. Nevertheless, what is involved here is a transfer—not an expansion. It is also worth noting that NSF does not intend to support *all* the academic-style research that NASA and Defense are dropping. Only some of the survivors are going to be picked up out of the water. Add to this the fact that NSF, with a finger to the congressional wind and an ear cocked toward the utilitarians who dominate the White House Office of Management and Budget, is now bound full speed and wallet bulging into supporting research related to "social problems." Preliminary work in this area got underway last year under the auspices of NSF's program of Interdisciplinary Research Relevant to the Problems of Society. IRRPOS, as it comes out in acronym, was well received in Congress and is said to have pleased the White House budgetmakers, the latter being an occurrence so rare as to merit prompt notation by aspiring historians of the Nixon era. IRRPOS, however, was simply an appendage of NSF's Office of Interdisciplinary Research—way down in a crowded table of organization. However, hand in hand with the new budget, it is going to be expanded into a full-fledged, self-contained division, to be known as the Division of Research Applicable to National Needs, which skeptics no doubt will promptly be referring to as also-RANN. Its objectives are already known: They will be in the fields of ecology, population, transportation, and urban studies, with high priority going to proposals that not only cross disciplinary lines but that also involve the collaborative efforts of several institutions, preferrably across the boundaries of academe, industry, and government. RANN is slated for a big chunk of the budget increase.

With all this going on, annual support for basic research, which, after all, is why the Foundation is there in the first place, is scheduled nevertheless to go from the present figure of $180 million to $265 million. The growth of basic research support will come in part from the $100 million expansion, but a good deal of it is scheduled to come from pruning or terminating existing programs. On the termination list is one of NSF's most politically popular and academically important programs: support of institutional development, which currently provides about $30 million a year—in grants of $2 million to $5 million each—for raising the quality of research and science education in lesser-ranking universities. Started at the direction of President Johnson under the banner of promoting the creation of new "centers of excellence," the program is now regarded by Nixon's planners as simply a means for promoting the production of more academically certified unemployables. Congress willing, which is far from certain when so much is at stake for so many congressional districts, the program is slated for termination.

With the Office of Management and Budget run by what one NSF official derisively describes as "a bunch of economists," the addition of some $100 million to the NSF budget—for whatever purpose—can only be regarded as a triumph for Science Adviser David. Taking over the shambles left him by his predecessor, the venerable Lee DuBridge, David has worked quietly and industriously at the prime task of anyone occupying an administration post in which potential influence is high but authority is virtually nil: He has striven to gain the confidence of the humorless, narrow-visioned and intensely loyal staff immediately around Nixon. What goes on in that process is something that is rarely spoken of in public. But DuBridge was swiftly frozen out when the Nixon men concluded that he was operating in large part as a representative of the scientific community, rather than as a wholly commited member of the Nixon team. DuBridge tried to warm his way back in by publicly representing the Administration as kind to science; he also spoke out in behalf of the anti-ballistic missile, an act that mainly served to alienate his colleagues on the President's Science Advisory Committee. In any case, he was out almost from the beginning.

Five months in office, David has been generally reticent in public, taking refuge in the once-reasonable but decreasingly valid point that he needs time to learn his way around before pronouncing on controversial public issues. Several persons who have been at inter-agency committee meetings with him say his practice is to listen attentively and say little or nothing. A talk he gave Jan. 8 at the National Bureau of Standards identified a variety of science-policy issues, but David refrained from saying where he stood on any of them. One little-noted episode, however, points to his determination to develop the best of all possible relationships with the Nixon staff. Six weeks ago, when the Senate was blocking the Administration's proposal to go ahead with development of the supersonic transport, David issued a statement in behalf of the SST with supporting signatures from 34 scientists and engineers of one sort or another, including Raymond L. Bisplinghoff, the number two man at NSF; Stark Draper, of the MIT Instrumentation Laboratory; Frank T. McClure, of the Johns Hopkins Applied Physics Laboratory; William A. Nirenberg, of the Scripps Institution of Oceanography, and Edward Teller, of the University of California. The David statement was pure pro-SST: "Our society must not suppress technological advances," it said, "but through research, development, and experimentation make sure that those advances are obtained without undesired side effects. Instead of canceling work on the SST, we should mount a vigorous program aimed not only at solving the technical problems of economic supersonic transportation but also at assuring no undesireable effects." In the hubub of the post-election pre-Christmas session, the incident passed without much notice, except for insertion of the statement and signatures in the *Congressional Record* (Dec. 15, P. S20156) by Senator Barry Goldwater (R-Ariz.).

Goldwater, reacting to an anti-SST statement of six scientists offered by Senator Charles Percy (R-Ill.), accompanied David's statement with the observation that "the scientific enemies of the SST include some scientists who were doubtful some years ago that we could even travel beyond the speed of sound without dire consequences. And this is the part of the scientific community also from which technical opposition to the development of the H-bomb came. The argument then was similar to the one used against the ABM–that it could not be perfected without tremendous danger to the entire world."

With the President's budget now up for examination by Congress, a key figure in the fate of the NSF portion will be NSF Director McElroy. He, as it turns out, is something of a rare phenomenon in science politics these days: a topflight scientist whose manner and instincts fit in well with the peculiar ambience of Capitol Hill. In appearance and style, McElroy comes across like central casting's stock entry for a ward politician, rather than as the distinguished academic biochemist that he was for many years before taking over at NSF. In fact, at the moment there is no one around who comes up to McElroy in rapport with Congress on scientific matters. David has been making himself known to various congressmen simply by asking to see them; he has made a favorable impression but is yet to conduct any serious business on Capitol Hill. Academy President Handler is an inveterate traveler to the Hill and an eager witness whenever there is a hint that a committee might hear him, but since he has nothing to dispense but his own brand of wisdom, congressmen accord him ceremonial courtesy, but otherwise do not take him very seriously. Robert Q. Marston, director of NIH, is a pale figure when it comes to congressional affairs. NASA still lacks a fulltime head, and as for AEC Chairman Glenn T. Seaborg, his milk-toast management of the AEC is an endless source of dispair to the Joint Committee on Atomic Energy. (Commissioner James T. Ramey is widely said to be the strong personality on the AEC, but being an avowed Democrat, he can get into the White House only as a tourist.)

In contrast to all the above, McElroy has successfully tuned in to what Congress is all about: power, influence, and personal glorification of the membership, with the furtherance of the public well-being sometimes an acceptable ingredient. On the basis of personal performance, he is now regarded as the shrewdest scientific operator to ascend the Hill since NIH's James Shannon went there some years back to coax out several odd billion dollars for a breakneck expansion of medical research and training.

The main difficulty, of course, is that Shannon found quick harmony with two influential legislators who, if anything, were more fervent believers in medical research than he himself was: the late Rep. John Fogarty (D-R.I.) and the now-retired Senator Lister Hill (D-Ala.). No two legislators of that faith and influence are currently available to harmonize with McElroy, but he has been making do with what there is. Whereas his predecessors in the NSF directorship often prided themselves on their aloofness from the indelicacies of the congressional scene, McElroy has been vigorously cultivating the people who command the fate of his agency. Rep. John W. Davis, the Georgia Democrat who heads the subcommittee that will handle the authorizing bill for the NSF budget, was recently taken to the Antarctic to tour NSF activities there. Earlier, NSF squired him to New York to visit an oceanographic vessel that NSF supports. Davis, according to close associates, has been heard to say that the day is not long off when the NSF budget, currently set by Nixon for $622 million, will hit $1 billion. NSF also recently arranged for a member of Davis's subcommittee, Charles A. Mosher (R-Ohio) to visit the Arecibo radio astronomy center in Puerto Rico.

Traditionally, the Senate has been kind to NSF, and little cultivation is required there, but McElroy is not unmindful of the fact that Gordon Allott (R-Colo.), who sits on the appropriations subcommittee that handles the NSF budget, has long mixed his sympathy with rigorous scrutiny. It was Allott, after all, who did more than any other legislator to bring the Mohole project to its disastrous conclusion. Accordingly, McElroy has struck up a congenial relationship with Allott, and keeps him well advised of the Foundation's programs and aspirations.

The plans embodied in the new NSF budget raise several public policy questions that might stir up Congress if it chooses to pay attention, which is by no means certain, since NSF actually figures small in the congressional view of the world. Though it is obviously politically expedient, is it appropriate for NSF to be plunging into the support of "socially relevant" research? If resources and attention are to be diverted in that direction, what will be the effect on the support of basic research over the long run? Also, it is worth recognizing that implicit in the termination of the institutional development program is a decision to turn off the expansion of high quality higher education. In the present circumstances, perhaps that is a wise move, but it would be desireable to have such a policy decision brought out into the open, rather than have it obscured inside a tome of budget figures.

The $100 million that Nixon proposed for cancer research is best understood in terms of his efforts to preempt any attractive political ground that might be taken over by potential political rivals. (He has done it all along in regard to Senator Muskie's efforts to command the pollution issue, even to the point of not inviting Muskie to the White House signing of Muskie's own Clean Air bill.) Over the past year, the health lobby, with Democrat Mary Lasker at its center, has been cooking up a scheme to take cancer research out of NIH and establish an independent, highly visible, and heavily funded National Cancer Authority. A proposal to that effect was issued in December by an advisory panel appointed by the Senate Committee on Labor and Public Welfare. Last week, Senator Edward Kennedy (D-Mass.) followed this up with a proposal to establish the authority and put virtually unlimited funds at its disposal. Whatever the prospects may be for that proposition, they are not enhanced by Nixon's proposal to add another $100 million to NIH's budget for cancer research.

Target: AEC, NIMH

In Print

Penetrating attacks on two of the federal government's largest research enterprises are contained in several current periodicals. Together they reflect a growing public unease about new technologies as well as an increasing skepticism toward "expert" assurances of public benefit and safety. An article in the February *Atlantic*, titled, "Precautions Are Being Taken by Those Who Know," written by Paul Jacobs, a wide-ranging freelance writer and social critic, seriously questions the adequacy of the AEC's radiation safety standards, and questions the Commission's honesty in dealing with public concern. A similar theme is taken up in the January/February issue of *The Center Magazine*, published by the Center for the Study of Democratic Institutions, Santa Barbara, Calif. There, the author is Jean Schrader, identified as a member of the Center's secretarial staff; the article is titled, "Atomic Doubletalk." The Jan. 23 *New Republic* contains the first of a series of articles on "The Nuclear Power Controversy," by Ralph E. Lapp, a physicist who has written extensively on nuclear policy issues. Temperate and well-documented, the article argues that the AEC should not be permitted to serve as both promoter and regulator of atomic power.

Two of the nation's top radical journalists, Andrew D. Kopkind and James Ridgeway, take on "The Mental Health Industry" in the February *Ramparts*. In an article subtitled, "This Way Lies Madness," they indict the National Institute of Mental Health as a self-serving bureaucracy working in tandem with the pharmaceutical industry, and, in effect, favoring social control and adjustment over social reform.

Science, Technology, and American Diplomacy, a 70-page congressional document, is described as first in a series of 16 studies on the "Evolution of International Technology." It was prepared by the Science Policy Research and Foreign Affairs Division of the Legislative Reference Service, Library of Congress, for the subcommittee on National Security Policy and Scientific Developments of the House Committee on Foreign Affairs. It's a pretty bland product, well filled with conventional wisdoms about the power of technology, the associated dangers, the need for national development and the need for international cooperation. Copies available without charge: Committee on Foreign Affairs, Room 2170, Rayburn Building, Washington, D.C.

Federal Funds for Research, Development and Other Scientific Activities: Fiscal years 1969, 1970, 1971, 264 pp. Produced by NSF, this collection of statistics, charts, and analyses is indispensable for anyone interested in the federal role in research. Available for $2 from the Superintendent of Documents, US Government Printing Office, Washington, D.C.

"I regret to inform you that . . ."

Grant Swinger

Periods of financial retrenchment understandably have a depressing effect upon the morale of the research community. Since the long-term prognosis is bright, it is at times like this that an historical perspective is especially useful. With this in mind, the Breakthrough Institute, in collaboration with the Center for the Absorption of Federal Funds, has undertaken an extensive review aimed at elucidating key events in the evolution of the grant. The project is at an early stage and is far short of the point where conclusions may be confidently drawn, but in view of the present situation, the advisory committee thought it desireable to make public certain archival materials that have come to light. Several of these follow:

Mr. Karl Marx
c/o The British Museum
London

Dear Mr. Marx:

I regret to inform you that our social studies panel has rendered a negative decision on your request for support of an examination of the relationship between selected economic factors and various aspects of social and economic development. It was the judgment of the panel that, while the proposed project deals with matters of considerable importance, it would be adviseable for a study of this ambitious scope to be undertaken by a multi-disciplinary team, rather than by an individual. We feel that this would increase the likelihood of success, particularly in terms of achieving a balanced approach. If you wish to rewrite the proposal, please be advised that we would be willing to reconsider it again, though I must stress that funds are limited and many worthy proposals are currently awaiting support.

If you do resubmit the proposal, please be certain to state your institutional affiliation, which was omitted on the original application form.

Mr. Charles Darwin
Christ's College, Cambridge

Dear Mr. Darwin:

Because of a general shortage of space on oceanographic vessels, the committee is compelled to limit its support to senior investigators with on-going research programs. However, please be assured of our best wishes for progress in your field of interest, and please feel free to re-apply at a later date. I might add, however, that if you do re-apply, it might be adviseable to recast your project to some extent, as we are informed that several other investigators are currently working on nearly identical problems.

* * *

Mr. Albert Einstein
Swiss Patent Office, Bern

Dear Mr. Einstein:

This journal serves as a medium of communication among academic researchers. Therefore, we regret that we are unable to accept your paper, which is herewith returned.

* * *

Mr. Eli Whitney
Mill Rock, Conn.

Dear Mr. Whitney:

Further regarding your proposal for a device for cleaning cotton. As you will recall, several objections were raised on the ground that the device might have an adverse social impact. I am pleased to inform you that the matter has been thoroughly examined by our technology assessment panel, which has concluded that these fears are essentially groundless. However, funds are in extremely short supply at this time, and we are, regretably, unable to provide any assistance.

* * *

Dr. Louis Pasteur
Academy of Medicine, Paris

Dear Dr. Pasteur:

1. Your time and effort report for the past quarter is considerably overdue, and the business office requests that it be forwarded at the earliest possible date.

2. The supply department has notified me of still another requisition from your laboratory for canine experimental subjects. As these are expensive both to acquire and maintain, we are providing instead a shipment of guinea pigs, which I am certain you will find satisfactory.

SCIENCE & GOVERNMENT REPORT © by Science & Government Report, publisher Daniel S. Greenberg; published twice monthly at 1629 Columbia Road, N.W., Washington, D.C. 20009. Telephone: 202-232-2035. Address all correspondence to PO Box 21123, Washington, D.C. 20009. Feb. 1, 1971, Number 1.

An Advisory "No" on Extending JFK Airport

Environment

A long-delayed, still unpublished airport expansion study organized by the National Academy of Sciences (NAS) will come out strongly on the side of the ecological angels, but mainly as a result of threats by a majority of the study group to break away and independently release their findings to the public. The 25-member study group's strongwilled assertion of independence, plus its freewheeling consumption of funds provided by a public agency, have sent tremors of anguish through the executive suite of the traditionally timorous Academy. Academy President Philip H. Handler held that the study group was seeking to exceed its mandate, but following a threat of revolt, the hardhitting report was discreetly broken into two portions—one containing recommendations; the other, expressions of views by individual members as well as committees of the study group. Together, however, the two documents constitute a powerful environmentalist brief.

The study, concerning proposals to extend JFK International Airport into Jamaica Bay, was conducted by a diverse and professionally high-powered group selected by the Academy's Environmental Studies Board under contract to the New York Port Authority, which has been confronted by virtually solid political opposition to expansion of the airport. Originally estimated to cost $280,000, and due for publication last November, the study ran up a bill of approximately $350,000, and, at this writing, has not progressed beyond the galley stage. A good portion of the funds went for the hire of 34 motel rooms for all of August in the Long Island resort town of Hampton Bay for members of the study group and, if they chose, their families. All participants were reimbursed for expenses; in addition, non-government members received $100 a day. Some $10,000 was expended on the rental of office space at nearby Southampton College. The study group also hired a houseboat on the Bay, and the Academy has allocated about $10,000 for printing costs.

The study, headed by James A. Fay, who is professor of mechanical engineering at MIT and chairman of the Boston Air Pollution Commission, was given the task of determining whether expansion of JFK's runways would have significantly adverse effects upon the ecology of Jamaica Bay. That is what the Port Authority, faced with widespread opposition, paid to have studied. The study group members, however, decided virtually at the outset that the question was too narrow, and, drawing upon a letter from Transportation Secretary James A. Volpe in which he expressed general concern about the problems of airport expansion, decided upon a comprehensive approach. The result was what one member described as "a tough document" that, in part, went beyond the issue of JFK into questions concerning national transportation policy and longterm planning for coordinating various modes of transport. "NAS got edgy," this source said, "when we went beyond the issue of the ducks and started raising questions about raising landing fees at certain hours to provide incentives for better use of the existing facilities. Things got to the name-calling stage and there was a threat of a rebellion and going to the press with an independent report if the Academy tried to suppress our conclusions. So, it was decided that there would be a two-part report. One on the ecology issues and the other containing individual and group expressions of views. Otherwise, a lot of us would have refused to sign it."

Overall, the report comes out against expansion of the airport. Specifically, it recommends that the Port Authority cooperate with federal agencies in working out more efficient use of existing facilities before any expansion is considered. It also urges accelerated work on the development of quieter aircraft engines. And it urges that the Bay should be developed for recreational purposes and that emphasis should be placed on assessing human effects in any cost/effectiveness analysis of airport expansion.

A top-level government environmental official who has seen the report describes it as "a superb document." Meanwhile, rumbles are still being heard from the Academy business office.

The Port Authority, which has maintained a hands-off attitude since contracting for the study, says that it is still waiting to be informed of the contents. It is doubtful, however, that it will be pleased with the study, especially since by going beyond the narrowly stated mandate of simply studying the JFK issue, the study group contributed to undermining another long-sought objective of the Port Authority: construction of a fourth jetport in the New York metropolitan region.

It does not often happen that an NAS study group runs away with its mandate; the Academy is neither inclined toward nor built for that purpose. But when it happens, it demonstrates the potential potency of expert opinion that dovetails with public sentiment. If there was any life left in the JFK expansion proposal, the NAS report will almost certainly douse it.

In Brief

Pat Moynihan, who recently resigned as Nixon's top adviser on urban affairs, has accepted appointment to the President's Science Advisory Committee.

Emilio Q. Daddario, the longtime friend of the scientific community who gave up his congressional seat in an unsuccessful bid for the governorship of Connecticut, has announced his plans. He's taking a post as senior vice president of the Precision Engineering Company, of Manchester, Conn., a holding of the Gulf & Western conglomerate. Daddario will also retain a senior partnership in a Hartford, Conn., law firm. Chances for his return to Congress are not considered too bright at present. The seat he surrendered was won by a fellow Democrat, and it will be 1974 when the next senatorial election takes place in the state. The incumbent there, too, is a Democrat, Abraham A. Ribicoff.

Senator Edward Kennedy (D-Mass.) has introduced a bill (S.32) to authorize the expenditure of $500 million over a three-year period to assist individuals and communities that have been affected by cutbacks in government support of research and development activities. Titled the Conversion Research, Education, and Assistance Act of 1971, the bill is an expanded version of a similar measure that Kennedy introduced toward the end of the last session of Congress. It provides for NSF to administer the bulk of the money for retraining scientists, engineers, and technicians. Funds would also be made available for setting up "small scientific and technical firms," and for hiring technically trained personnel for state and local positions.

A Science Reorganization?

State of the Union

President Nixon's State of the Union proposal for miniaturization of the federal government was a broad-brush presentation that is to be followed by detailed recommendations. But the plan as it now stands strongly suggests a massive reshuffling of government research and education activities. These, of course, have been among the fastest growing of federal programs, and have long attracted the attention of would-be reorganizers, sometimes with success, as in the recent creation of the Environmental Protection Agency (EPA) and the National Oceanographic and Atmospheric Agency (NOAA). More often, however, reorganization schemes have been thwarted either by lack of consensus as to their utility or by hard lobbying on the part of established bureaucracies and allies who fear they stand to lose out in the change.

One of the biggest battles likely to grow out of the reorganization scheme will center on Nixon's proposal to include "energy and mineral resources" in a newly created Department of Natural Resources. That is the President's minimally provocative way of saying that the Atomic Energy Commission, plus the government's coal, oil, and gas research and regulatory activities should be brought together under one administrative scheme to replace the present pattern of each going its own way, often in conflict with the others. The proposal has an influential, though publicly undisclosed, parentage, having originated with the executive reorganization commission that Roy L. Ash, president of Litton Industries, headed up for Nixon. That commission, which is yet to have any of its recommendations made public, has, in fact, achieved quite a batting average. EPA, NOAA, and the Council for Environmental Quality were established upon its advice to the President, as was the little-known but apparently highly important White House Office of Telecommunications, which, contrary to a general impression, is concerned with policymaking for the multi-billion dollar communications industry, rather than with running the White House switchboard.

The prospects of moving the quasi-independent AEC into a cabinet-level department are not at all enhanced by certain peculiarities on the congressional scene. Operating with unique authroity as overseer of the AEC, the Joint Committee on Atomic Energy has always fought hard and usually successfully against any attempt to reduce its role to that of just another congressional committee. Since its creation at the end of World War II, the committee has had one passion—to prod the US government into underwriting the development of a huge and fastgrowing nuclear industry. And one of the chief prodders throughout most of that period has been the senior House Democrat on the Joint Committee, Chet Holifield, of California, who has alternated in the chairmanship with his Senate counterpart, John O. Pastore, of Rhode Island. Holifield, however, has announced that, though he will remain a member of the Joint Committee, he is giving up his right to the chairmanship of the House Government Operations Committee, which, among other things, possesses jurisdiction over executive reorganization plans.

Under Nixon's proposal, the Department of Human Resources would include education, manpower, and health services, while the Department of Economic Development would take in "science and technology." It is not clear what, if anything, this arrangement would mean for the often-proposed amalgamation of similar research and education activities now supported by the National Science Foundation, the National Institutes of Health, and the Office of Education. In the last Congress, Rep. Emilio Q. Daddario proposed the establishment of a National Institute of Research and Advanced Studies that would pull together many activities of these agencies, but the proposal never received any significant support. Presidential Science Adviser Edward E. David Jr. has not commited himself on the subject, but in his recent talk at the National Bureau of Standards he observed, "I personally feel that the 'neatness complex,' as many people call it, has been the primary motivation behind many proposed reorganizations" of scientific agencies.

PSDC Initiative

Basic Criteria for New Technology Initiatives Study

The study should apply these basic criteria to each technology project or program before any increased funding is recommended to the President.

1. Importance: Project or program must relate (a) to a significant and urgent national problem which is broadly recognized by the public, or (b) to a significant opportunity for economic growth, increased exports, or technological leadership.

2. Pay Off: The cost/benefit ratio must be favorable. What are the social and economic benefits - including impact on balance of trade, productivity and employment? What will be the distribution of benefits among different industries and areas of the country?

3. Public Impact: Can visible progress be shown within a reasonable period - including significant progress in planning and design by next summer? A timetable must be provided by fiscal year for each phase of development: planning, design, pilot, demonstration, etc.

4. Budget Impact: What are estimated long-term costs over next six years or full systems cost?

5. Non-Federal Support: What is the feasibility and likely maximum extent of cost sharing by industry? Can the project be achieved through steps short of direct Federal funding: regulation or de-regulation, standard setting?

6. Potential Problems: Are there potential institutional or economic barriers to acceptance and implementation of the technology and how are they to be overcome? Are there any undesirable side effects from the technology and how are they to be dealt with?

7. Organization and Management: Assuming several programs or projects meet the above criteria, what kind of organization (existing agencies, new agency, or quasi-public corporation) should be created (if any) or redirected to carry out these programs?

The study should have two phases: (1) an interim report due the President September 1, and (2) a final report due the President November 15.

Dr. Edward David, the Director of the Office of Science and Technology and the President's Science Adviser, will chair the sub-committee and John Whitaker will have Domestic Council staff responsibility.

D. Beckler
2/22/72

Draft Proposal

PSAC PROJECT GIST

(Goals in Science and Technology)

Purpose: To provide the next President with a statement of concrete goals for science and technology that can serve as a basis for planning the policies and programs of his Administration.

Scope: The study will cover all sectors -- federal and local government, industry and the universities from the standpoint of federal programs and policies.

Emphasis: Emphasis will be given to:

(a) Identification of priority national problems for research, development and innovation;

(b) General assessment of the state of available technology to attack these problems;

(c) Needed S & T programs and policies (with a 4 year time horizon for planning purposes);

(d) Identification of the barriers to technological innovation and ways to overcome them;

(e) Evaluation of the capabilities of the federal government to formulate and manage effective programs and policies, at all levels, and the needs for organizational improvements and change.

Timeframe: The study will seek to identify problems in the forseeable future that require the initiation of policies or programs during the next Administration.

Report: The report will be under 100 pages (about 5 pages single spaced) and will be submitted to the President shortly after his Inauguration, with a briefing by the Committee.

Organization:

(a) There will be a study director selected by PSAC from among its members or consultants-at-large;

(b) The study group will consist mostly of PSAC members who will have responsibility for the drafting of given chapters and will have the assistance of an assigned OST staff member;

Organization: (Cont'd)

(c) Each member of the study group will submit a study plan and the names of 5 - 6 consultants he would like to use in preparing his chapter;

(d) The overall report outline and study plan will be approved at the March PSAC meeting;

(e) Preliminary work and discussions will be undertaken during the next 4 months leading to a 2-week intensive summer session during July or August. The first week will be given to group discussions (in parallel) for each chapter, resulting in drafts that would be debated the following week by the chapter leaders and PSAC members, to arrive at the first draft of the complete report by the end of the session;

(f) Time would be devoted during the fall PSAC meetings to further refine the report.

Source Materials:

(a) Semi-final draft of "The Annual Report" (with conclusions and recommendations);

(b) PSAC and OST reports on energy, environment, education, health and biomedical sciences, military technology, space, basic science, scientific and technical manpower, international scientific cooperation and technical assistance, and national science policies.

(c) Prior reports of Presidential task groups on science and technology (Stever and Mettler reports).

PSAC PROJECT GIST

Possible Assignments

Suggested Topics	PSAC Member or Consultant	OST Staff
Summary & Introduction	(Study Director to be selected)	(to be designated)
National Defense	Tape	V. McRae
Environmental Quality	Cairns	Balzhiser
Economic Progress	Olsen	DeSimone
Education	Truxal	Mays
Health	Smith	Laster
Community Development	Moynihan	Luenberger
Transportation	Piore	Goldmuntz
Natural Resources	Garwin	Blake
Space	Friedman	Drew
Energy	Buchsbaum	Weinhold
Communications & Computers	Simon	Noll
International S & T Cooperation	Bronk	Neureiter
International Development	Handler	Neureiter
Basic & Exploratory Research		
Natural Sciences	Fitch	York
Social Sciences (inc. innovation)	Coleman	Luenberger
Scientific & Engineering Manpower	DuBridge	York
Govt. Organization & Management	Haggerty	Beckler
Food and Agriculture	Wood	Caldwell

JAN 26 1972

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20506

January 22, 1972

SCIENCE AND TECHNOLOGY

Mr. Kenneth H. Olsen
President, Digital Equipment Corporation
Maynard, Massachusetts 01754

Dear Ken:

Enclosed is a copy of "Technological Innovation: Its Environment and Management," which I promised to send to you.

I'll be away most of next week but will be in touch with you when I get back so that we can talk about the proposed PSAC Panel.

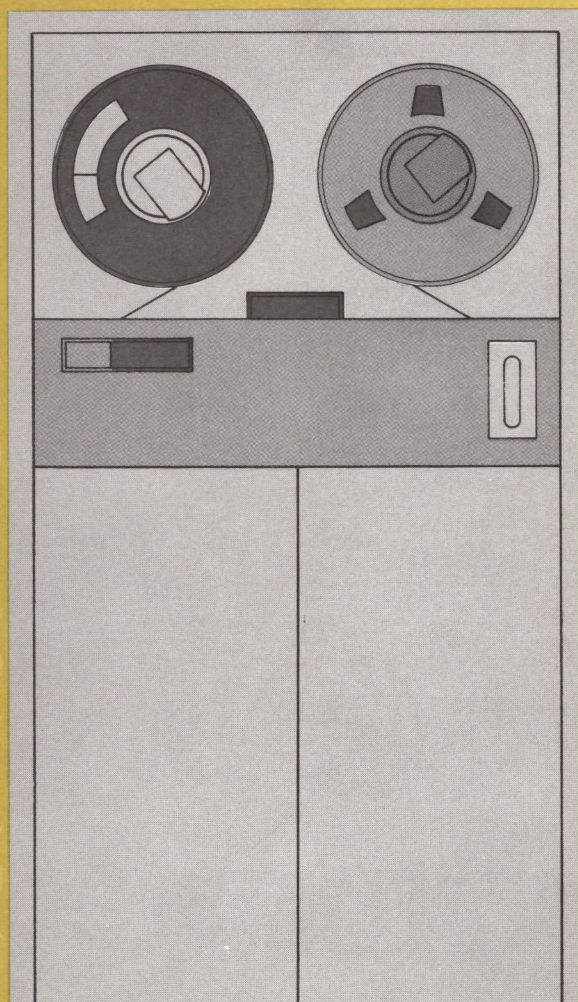
Sincerely,

Dan

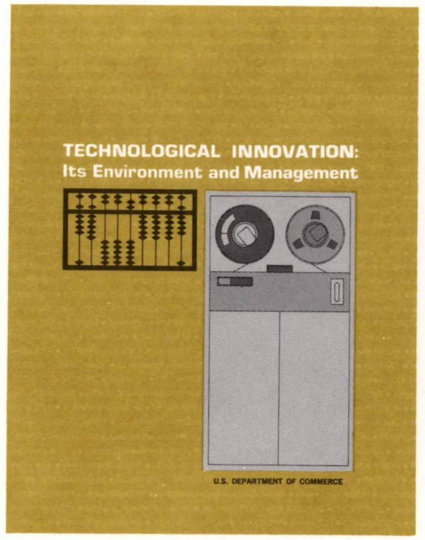
Daniel V. De Simone

Enclosure
(Dictated but not read)

TECHNOLOGICAL INNOVATION:
Its Environment and Management



U.S. DEPARTMENT OF COMMERCE



Early forms of the abacus, a manually operated biquinary computer, were introduced as early as 3,000 B.C. The electronic digital computer, capable of vastly more complex and speedy computations, was introduced in the early 1950s.

TECHNOLOGICAL INNOVATION:
Its Environment and Management

This report, prepared by Daniel V. De Simone, represents the views of the Panel on Invention and Innovation, an advisory committee of private citizens convened by and reporting to the Secretary of Commerce. The views of the Panel do not necessarily represent those of the Department of Commerce or of any other agency of the federal government.

January 1967
Reprinted, September 1967

U.S. DEPARTMENT OF COMMERCE
John T. Connor, Secretary

J. Herbert Hollomon, Assistant Secretary for Science and Technology

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PANEL ON INVENTION AND INNOVATION*

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SUMMARY

In accordance with its charter, the Panel considered three main factors affecting invention and innovation: taxation, finance, and competition. On the basis of its analysis, the Panel concluded that there was no need to recommend any major changes in the present laws governing these three areas. However, it did make a number of specific proposals * aimed at improving the environment for invention and innovation.

With respect to the field of taxation, the Panel made several specific recommendations which it felt could provide justifiable encouragement to inventors and innovators. Among these recommendations are proposals providing for a more equitable treatment of innovation losses, an improvement of the stock option to make it a more effective instrument for attracting critically important management personnel to fledgling firms, and a reasoned approach to tax-deduction problems posed by several other areas of the tax laws.

The Panel found no reason for proposing any new federally supported programs to furnish venture capital for the financing of new, technologically based enterprises. It did, however, make recommendations concerning the communication of venture-capital opportunities and the establishment of an effective Federal spokesman for such enterprises.

The Panel's review of the interaction between competition and innovation showed a need for greater understanding of this interaction and improvements in the coordination of antitrust and regulatory policies affecting both competition and innovation. No new antitrust or regulatory legislation was recommended, but the Panel did recommend, among other proposals, the establishment of a group to serve as an advisory resource to the antitrust and regulatory agencies, as well as a strengthening of the professional staffs of these agencies.

Throughout its review, the Panel was impressed by the need for promoting a basic understanding of the innovative process in all sectors of our society. The Panel felt that it would be highly desirable to encourage educational programs, studies, and regional seminars to further this understanding. Accordingly, the Panel's concluding recommendation proposes a White House conference on technological innovation, to dramatize the importance of this vital process, and urges that this conference be followed by a nationwide program for broadening recognition, understanding, and appreciation of the problems and opportunities associated with technological change.

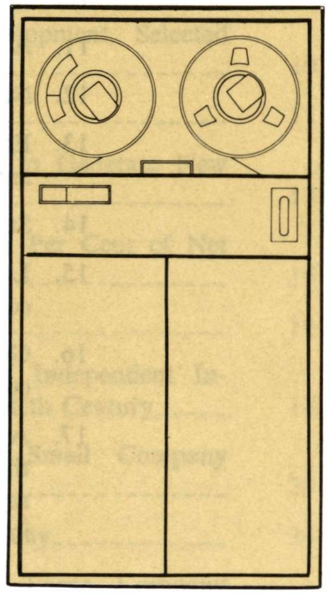
* *The complete list of the Panel's recommendations is set forth in Appendix E, page 79.*

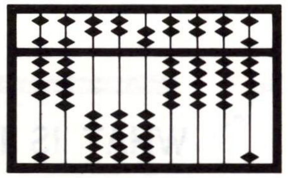
CONTENTS

CHARTS

LIST OF RECOMMENDATIONS*

* *The recommendations are recapitulated, in full, in Appendix E, page 79.*





INTRODUCTION AND SETTING

In 1964 the President of the United States directed the Department of Commerce to explore new ways for "speeding the development and spread of new technology." [1] Because one of the ways in which a government can accomplish this end is to improve the *climate* for technological change, the Secretary of Commerce created an ad hoc *Panel on Invention and Innovation* and asked it to explore the opportunities for improving such climate-setting policy areas as antitrust, taxation and the regulation of industry. What follows is the report of the Panel.

[1] *Economic Report of the President to the Congress of the United States, 1964.*

We began our investigation by asking ourselves some very basic questions. The climate for invention and innovation could be improved by providing reasonable incentives to these processes of technological change and by removing or lessening unreasonable barriers that impede or stifle them. But what is reasonable or unreasonable? The reasonableness of our proposals would depend upon an appreciation of other national goals upon which these proposals might impinge—for example, the preservation of competition and fiscal integrity. And incentives and barriers to what? What is the anatomy of invention and innovation in the American economy? We had to analyze illustrative cases, demonstrating some of the problems and characteristics associated with the processes of invention and innovation, before we could rationally weigh incentives and barriers. Our analysis had to tell us something about the people who power invention and innovation, for these are largely "people" processes.

We shall develop illustrative cases as we get to the specific recommendations of this report. In the meantime, however, we need to make some initial distinctions between the processes of invention and innovation, for incentives and barriers to one may not be to the other.

Very simply, the difference between the processes of invention and innovation is the difference between the verbs "to conceive" and "to use."

CHART 1

WHAT IS INVENTION? INNOVATION?

Invention . . . TO CONCEIVE . . . The idea.

Innovation . . . TO USE . . . The process by which an invention or idea is translated into the economy.

To be sure, innovation is not limited to technological products and processes in the business world. But that is the principal sense in which we were asked to be concerned with innovation. Much of what is said in these pages, however, applies as well to fields where non-technological innovation is of great importance—for example, social institutions and relationships. For invention and innovation encompass the totality of processes by which new ideas are conceived, nurtured, developed and finally introduced into the economy as new products and processes; or into an organization to change its internal and external relationships; or into a society to provide for its social needs and to adapt itself to the world or the world to itself.

INNOVATION AND ECONOMIC PROGRESS

The next basic question we asked ourselves was: Why should the government have an interest in invention and innovation?

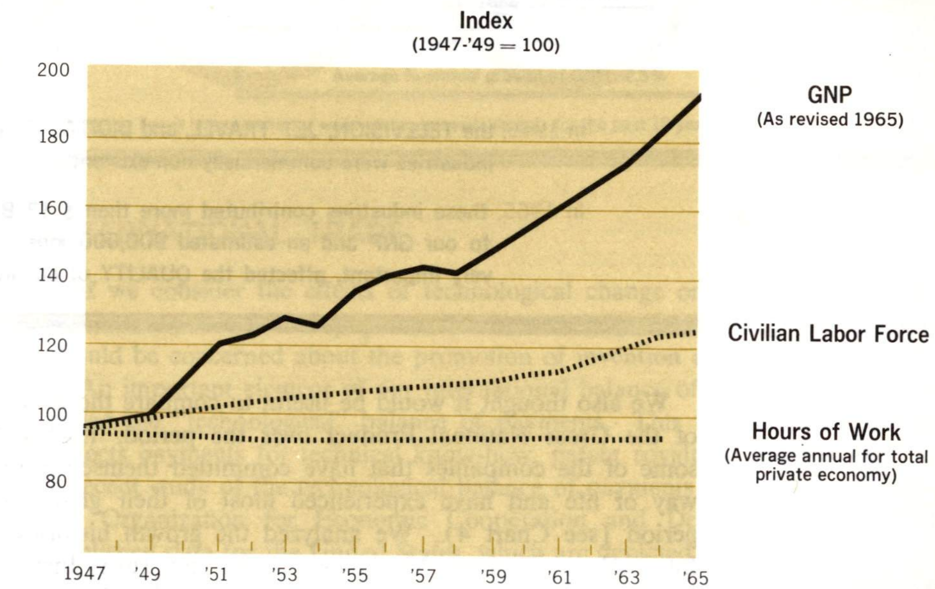
The answer is that invention and innovation lie at the heart of the process by which America has grown and renewed itself.

Let us expand upon this simple truth and explore more specifically some of the reasons why the Federal Government must be concerned about the climate for invention and innovation.

First, there is a very significant relationship between innovation and economic growth. Although estimates of the contribution of technological progress to increases in the Gross National Product (GNP) are imprecise, economists agree that the contribution is substantial.[2] For example, if we compare the change in the labor input ("Hours of Work" in Chart 2) with the change in GNP over the period 1947-1965, we see a marked difference between these two factors.

CHART 2

INDEXES OF GROSS NATIONAL PRODUCT, LABOR FORCE, ANNUAL HOURS WORKED, 1947-1965



The average annual hours of work remained practically constant, while the GNP rose substantially during the period in question. Indeed, the GNP nearly doubled. Without presuming to say how much of this increase in GNP was attributable to technological innovation, we are confident that

[2] *See, for example, Denison, E.,* The Sources of Economic Growth in the United States, *Committee for Economic Development, 1962; Kendrick, J.,* Productivity Trends in the United States, *National Bureau of Economic Research, 1961; and Solo, R., "Technical Change and the Aggregate Production Function,"* Review of Economics and Statistics, *1957.*

technological innovation played a major role. We realize that data such as the GNP are abstract statistical notions. By and large, they fail to excite the imagination, for they do not have the impact of specific examples. So we thought it would be instructive to look at the histories of three industries which were commercially non-existent in 1945, but over the past 20 years have contributed significantly to the nation's growth. We chose the television, jet aircraft, and digital computer industries.

CHART 3

ECONOMIC EFFECTS OF ONLY THREE TECHNOLOGICAL INDUSTRIES OUT OF MANY

In 1945, the TELEVISION, JET TRAVEL, and DIGITAL COMPUTER industries were commercially non-existent.

In 1965, these industries contributed more than $ 13 BILLION to our GNP and an estimated 900,000 jobs . . . and very important, affected the QUALITY of our lives.

We also thought it would be useful to compare the average annual growth of the Gross National Product over the period, 1945-1965, with that of some of the companies that have committed themselves to innovation as a way of life and have experienced most of their growth over the 20-year period (see Chart 4). We analyzed the growth histories of Polaroid, 3M, International Business Machines, Xerox, and Texas Instruments. While the average annual growth of the GNP over this period advanced at a rate of 2.5%, the average annual net-sales growth of these companies ranged from 13% to 29% and averaged, for the group, nearly 17%[3]. At the same time, the average yearly growth in jobs ranged from 7.5% to almost 18%.

Here we see some large, successful, innovative companies which grew from relatively small beginnings and have contributed very significantly to the GNP and employment opportunities. Many other companies have had similar experiences.

[3] *Texas Instruments, which had the highest growth rate and would have raised the over-all average, was nontheless excluded, since data for the company were not available for the year 1945.*

CHART 4

A FEW EXAMPLES OF TECHNOLOGICALLY INNOVATIVE COMPANIES THAT HAVE EXPERIENCED MUCH OF THEIR GROWTH IN THE LAST 20 YEARS (1945-1965)

AVG. % ANNUAL GROWTH (Compounded)

	Net Sales	Jobs
Polaroid	13.4%	7.5%
3M	14.9%	7.8%
IBM	17.5%	12.1%
Xerox (Haloid Co.)	22.5%	17.8%
Texas Instruments (1947-1965)	28.9%	10.0%

Average % annual sales growth of above companies*: 16.8%
Average % annual growth of GNP: 2.5%

*Excluding Texas Instruments for which data are available only for the past 18 years.

INTERNATIONAL TRADE

If we consider the effects of technological change on international trade, we can see another very persuasive reason why the Federal Government should be concerned about the promotion of invention and innovation.

An important element of our international balance of payments is what is called the "technological" balance of payments. This international account reflects payments for technical know-how, patent royalties, and the like. In a recent study of the technological balance of payments of various countries, the Organization for Economic Cooperation and Development (OECD) published data for the United States, which are depicted in Chart 5.

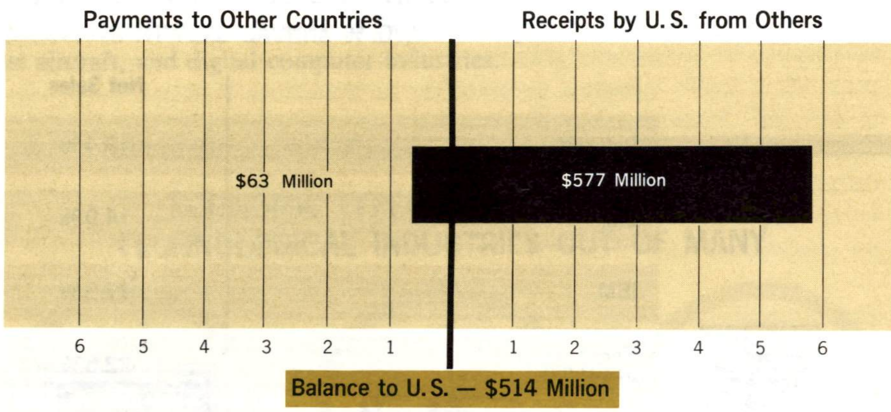
The OECD compilation shows the United States receiving roughly ten times as much in technological payments from abroad as goes out in payments to other nations. This is a very significant secondary effect of innovation in the American economy.

Technological change affects international trade in subtle ways. Let us consider, for example, the so-called "displacement" innovations. These do not have the dramatic result of a new company, such as the Xerox Corporation or an entirely new product or process for which no substitute existed before—the electronic computer is a good example. "Displacement" innovations displace existing products or processes. The effect of such innovations is illustrated by the invasion of the cotton and wool fiber market by synthetic fibers.

CHART 5

U. S. TECHNOLOGICAL BALANCE OF PAYMENTS

Payments for Technical Know-how, Patent Royalties, etc.



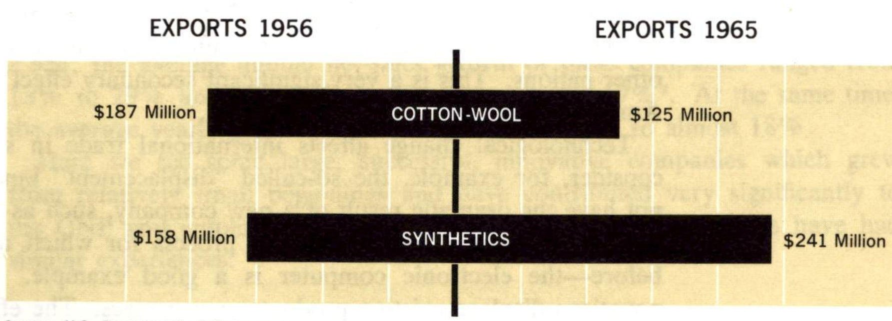
Source: OECD (1965) — Figures for 1961

It is very difficult to measure the full significance of "displacement" innovations in the United States, because such displacement is a *domestic* give and take. But if we look at the international picture, we can get a better feeling for the significance of these kinds of innovations. We chose as an example the yarns and fabrics industry and we compared synthetics with cotton and wool.

CHART 6

INNOVATION AND INTERNATIONAL TRADE

An Example: U.S. Exports of Yarns & Fabrics
Synthetics (High Technology)
Cotton & Wool (Low Technology)



Source: U.S. Department of Commerce.

We can see in Chart 6 that synthetics, which sprang from considerable innovative effort, have maintained our share of the international yarns and fabrics market. The total exports of cotton and wool yarns and fabrics have declined by about a third over the period 1956-1965, whereas the total exports of synthetic yarns and fabrics have increased by over 50%. The export of high-technology synthetic yarns and fabrics has therefore maintained the U.S. export of yarns and fabrics roughly at the level it was in 1956.

We could give other examples of the secondary effects of innovation. We are satisfied that the international stature of a nation with respect to trade—and, it is important to note, assistance to under-developed countries—becomes increasingly dependent upon its innovative performance.

INNOVATION AND COMPETITION

There are other reasons why the Federal Government should be interested in promoting invention and innovation, among which is the close and complementary interaction between innovation and competition.

Competition has traditionally involved rivalry among manufacturers of like products, as well as the stimulating effect of innovators who introduce new products and reduce costs through new methods of production and distribution. For example, the advent of the airplane had a powerful influence on competition in public transportation, and the automobile brought entirely new forces into the private transportation sector. To take more recent examples, the introduction of the transistor and integrated circuits has stimulated competition in the electronics industry.

The influence of innovation on competition has become stronger and clearer with the accelerated pace of technological change. Competition has developed between entirely new types of products that perform old functions better or make possible entirely new functions. To give just three examples, consider electrostatic copying ("xerography"), synthetic wash and wear fabrics, and instant photography.

The importance of innovation has become so strong that no longer may we look only to the conventional limits of a given industry to examine competition. Increasingly, innovations of importance are coming from companies that do not fit within the conventional classifications of individual industries. For example, synthetic fibers came from the chemical industry, not the textile industry. High-speed ground transportation is now as much the domain of the aerospace and electrical manufacturing industries as it is that of the automotive and railroad industries. Instant photography (the Polaroid camera) was not developed by the photographic industry. And electrostatic copying came from outside the conventional office equipment industry.

It is easy to see, therefore, that innovation from the outside (across conventional industry boundaries) is a powerful force influeneing competition. Consequently, a climate conducive to technological progress is important not only with respect to economic growth and international stature, but is also essential to the maintenance of a vigorous, competitive, economic climate.

Reading for Business

* * *

Invention's Mothers

Can the rate of invention and innovation be accelerated?

An affirmative answer would have important implications for economic growth—and corporate success. This may explain why President Johnson directed the Secretary of Commerce to explore new ways of "speeding the development and spread of new technology." Hence the Secretary's ad hoc Panel on Invention and Innovation made up of businessmen, academicians and attorneys.

The panel's provocative report, **Technological Innovation: Its Environment and Management** (U.S. Government Printing Office, Washington, D.C., 90 pages, $1.25), was prepared by Daniel V. De Simone, director of the U.S. Office of Invention and Innovation. A companion work, equally provocative but more theoretical and extensive, is **Invention and Economic Growth** (Harvard University Press, 347 pages, $9.95) by Jacob Schmookler, professor of economics at the University of Minnesota.

It is Professor Schmookler who really comes to grips with the role of intellectual stimuli in influencing technology. So, while necessity may be the mother of invention, Professor Schmookler wonders just what makes inventors invent and innovators innovate.

What, for example, motivated John Rust to invent the mechanical cotton picker, Willis Carrier the air conditioner, Samuel Ruben the mercury dry cell, John Harwood the self-winding wristwatch, Eugene Houdry the catalytic cracking of petroleum and John Tytus the continuous hot-strip rolling of steel?

* * *

Before serving up an answer Professor Schmookler provides a brilliant overview of the inventive process. He notes technology is a seamless web, stretching all the way back to the unknown Bronze Age inventor of the wheel, with the result that invention breeds invention, that technological advances in one field can hasten technological advances in another, that the climate for invention is terribly important to the rate of invention.

He also notes that the trend of invention correlates closely with the trend of investment—that, in other words, the amount of invention is largely a function of the extent of the market. On this point, he draws persuasive comparisons over time between railroad patents and railroad investment and between petroleum patents and petroleum investment.

This brings up the Schmookler answer to why inventors invent. He says they do so, in the main, in the pursuit of profit, in response to specific market demand and, yes, to Mother Necessity.

Profit motivation is also explored by the Commerce Secretary's panelists, who include Lawrence S. Apsey, general counsel of Celanese; Robert A. Charpie, president of Union Carbide Electronics; John F. Dessauer, executive vice president, research and engineering, of Xerox; Peter G. Peterson, president of Bell & Howell, and Dan Throop Smith, professor of finance at the Harvard Business School.

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

THE WALL STREET JOURNAL,

MONDAY, MAY 1, 1967

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The panelists observe the hard truth that nothing productive happens to a technological idea—sometimes a "garage" or "cellar" operation until it gets financial backing: Venture capital. Venture capital is high-risk money, they hold, and high-risk money requires high potential returns.

Financing, then, is a classic bugaboo of the small technologically based business. Its losses, the panelists recommend, should be allowed as a carry-forward against profits for ten instead of only five years, and its stock option rules liberalized by reducing the holding period required to receive capital gains treatment to as little as six months.

* * *

Clearly the panelists, notwithstanding quite a few big business connections, are sympathetic to the problems of small technologically based business. A good reason for their sympathy is seen in their data that although a relative handful of large companies account for around 85% of research and development expenditures, it is the independent inventors and small businesses that have often outperformed their big brothers in coming up with important inventions and innovations.

Why is this? The panelists say that big business is sometimes given to flabbiness, to complacency, to in-breeding, to an over-concern with the time value of money—with the upshot of a preference for less ambitious short-run technological opportunities over long-run possibilities of greater potential.

Still, this is, to an extent, a problem of organization. For, big or small, business, like invention, needs incentives. And, apparently, the greater the incentives the greater the volume of business—and the greater the rate of invention and innovation.

As Jacob Schmookler quotes John Stuart Mill: "The labour of Watt in contriving the steam-engine was as essential a part of production as that of the mechanics who build or the engineers who work the instrument; and was undergone, no less than theirs, in the prospect of remuneration from the produce."

—MARY JEAN BENNETT

THE WALL STREET JOURNAL,
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II

INNOVATION IN CONTEXT

We have already noted that technological innovation, in the sense we have been asked to be concerned with it, is a complex process by which an invention is brought to commercial reality. It is our thesis that if we are interested in increasing our rate of economic growth and the vigor of competitive forces in our society, we need to remember that these goals cannot be satisfactorily achieved in the absence of technological progress—i.e., the bringing of new products, processes and services to market.

We need also to bear in mind that the path between an invention (or idea) and the market place is a hazardous venture, replete with obstacles and substantial risks. It is ordinarily a very costly, time-consuming, and difficult task that the innovator faces.

INNOVATION IS NOT SIMPLY R&D

Continuing the series of basic questions we put to ourselves, we asked what it is the Government should seek to promote. Should attention be focused on the total process of innovation or merely on the research and development phase of the total process?

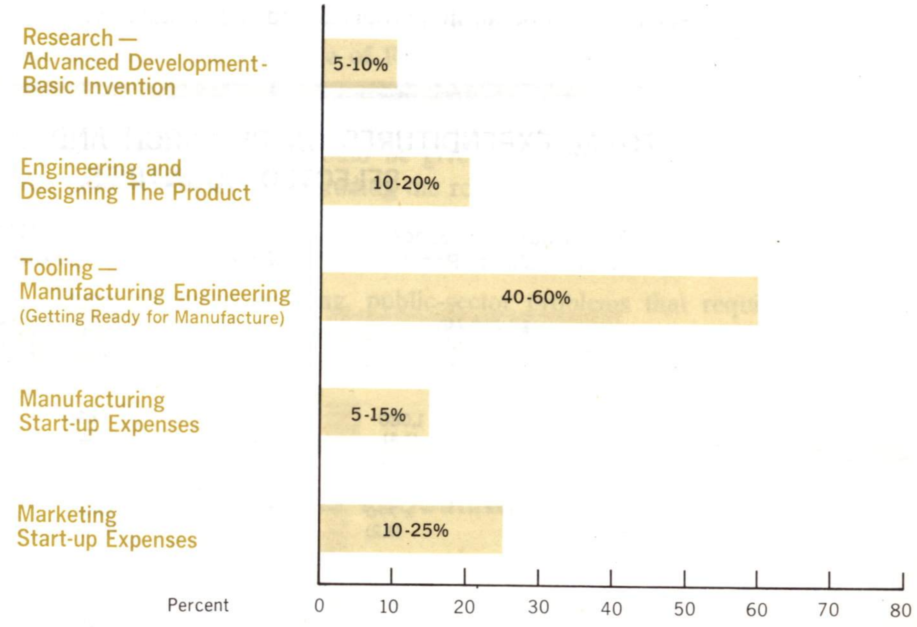
We came to realize early in our analysis how very little statistical evidence there is on the innovative process. Such data as are available primarily concern research and development, not the *total* innovation process, of which R&D is only a part. These data give us a reasonable indication of the investment in R&D, who is performing it and to what extent. But they are not reliable indications of *innovative* performance. They do not tell us, for example, what the total investment in innovation is in the United States. Such information would be very useful to have. Indeed, it would be highly desirable to encourage systematic studies of the innovative process in order to clarify the strategic elements which stimulate and further innovation.

We wish to make quite clear, therefore, that our analysis could not be based upon empirical data on the innovative process. Rather, we have had to rely on personal experience and knowledge and, where appropriate, data concerning R&D.

Accordingly, in order to arrive at a reasonable indication of the distribution of costs in successful product innovations and, particularly, to examine the role of research and development in the total process of bringing a new product to market, we pooled the knowledge of experienced members of the Panel. On this basis, we tried to discern a representative pattern in the distribution of costs in successful product innovations. There was sufficient similarity in the experiences we covered to convince us that it would be desirable to present the following "rule of thumb" figures as the basis for our discussion.

CHART 7

TYPICAL DISTRIBUTION OF COSTS IN SUCCESSFUL PRODUCT INNOVATIONS



This breakdown of cost and effort indicates that the step we commonly call research, advanced development or basic invention, accounts, typically, for less than 10% of the total innovative effort. The other components, which we do not usually associate with the innovative process, account for something like 90% of the total effort and cost. Engineering and designing the product, tooling and manufacturing-engineering, manufacturing start-up expenses, and marketing start-up expenses, are all essential to the total process. It is obvious, therefore, that research and development is by no means synonymous with innovation.

The above analysis concerns successful product innovations. We tried to

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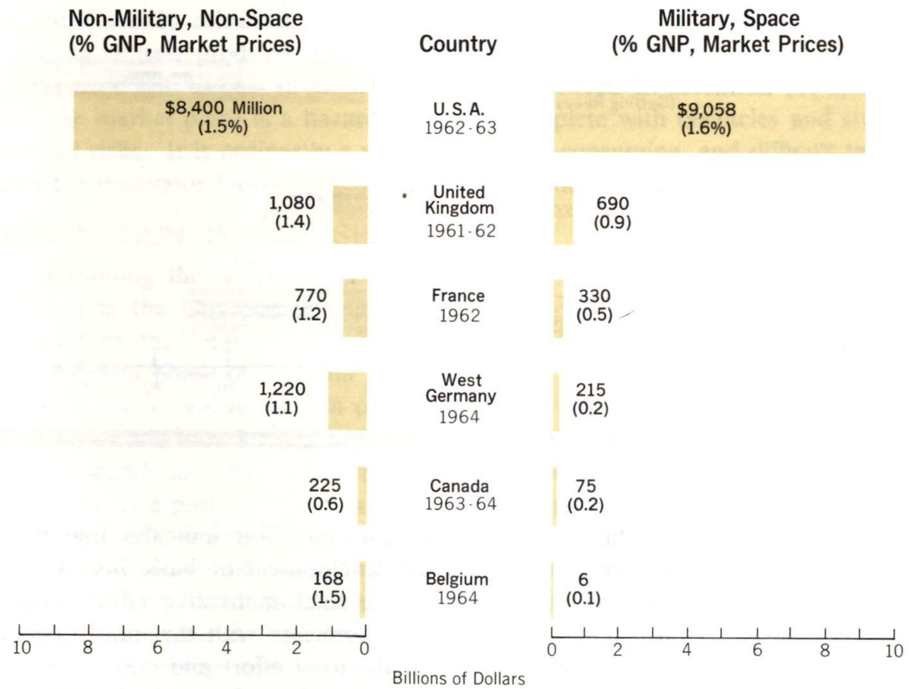
get some indication of the ratio of R&D costs to the total costs of innovative activities, both successful and unsuccessful. As a very rough measure of this, we compared total company expenditures on R&D in the manufacturing sector with the total net sales of these companies.[1] The latest year for which such data are available is 1964. We make no pretense about the adequacy or relevancy of these data. The total net sales for 1964 amounted to $293 billion; company-financed R&D expenditures totaled $5.7 billion. The ratio of R&D costs to net sales was therefore approximately two per cent, which would indicate that R&D costs are a small part of the total effort in the manufacturing sector.

Another illustration of the need for careful study of the innovative process is the indiscriminate use of statistical aggregates purporting to show the comparative innovative performance of various countries—in particular, statistics comparing research and development expenditures as a percentage of gross national product. As a measure of our innovative performance as a nation, data such as in the following tabulation are occasionally cited. We believe such data to be an inappropriate index of innovative performance.

CHART 8

TOTAL EXPENDITURES ON RESEARCH AND DEVELOPMENT, SELECTED COUNTRIES.



Source: OECD (in U.S. dollars)

[1] *"Basic Research, Applied Research, and Development in American Industry, 1964,"* Reviews of Data on Science Resources, *No. 7, January 1966, National Science Foundation, Washington, D. C.*

If R&D percentages of GNP were an appropriate measure of innovative performance, the above data, compiled by the Organization for Economic Cooperation and Development (OECD), would imply that innovation is as significant a factor in the non-military, non-space sectors of the United Kingdom (1.4%) and Belgium (1.5%) as it is in the United States (1.5%). However, it is clear that these countries are not running a close race with respect to innovative successes and economic growth. Such R&D data are obviously misleading when they are relied upon as indexes of innovative capability or accomplishment.

It is important to bear in mind, therefore, that an oversimplified assumption is probably made whenever it is assumed that more money spent on research and development automatically has some kind of multiplier effect on innovation into the market place. Those who equate R&D expenditures with innovative accomplishment are not looking at the innovative process the way businessmen must. For the main concern of businessmen is the total cost and the total profitability or loss of the *entire* venture.

This is not to say that R&D is unimportant. It should be understood that we appreciate the vital role of R&D and that our discussion is not meant to imply that there are not important sectors of the economy in which additional R&D effort would be desirable. For we believe that there are several sectors of the economy which should be given special attention in any analysis of the innovative process, including the role of R&D.

SOCIAL INNOVATION IN THE PUBLIC SECTOR

There are many pressing, public-sector problems that require innovative solutions. By way of illustration, we have listed a few examples of some of the problems that call for social innovation.

CHART 9

SOME PROBLEMS REQUIRING SOCIAL INNOVATION

Environmental Pollution	Urban Redevelopment
Fresh Water	Poverty
Crime Prevention	Highway Safety
International Organization	Urban Transportation

Arms Control and Disarmament

Any consideration of the total innovative process should include analysis of the interrelations between social and private innovation. Private innovation in the industrial sector has produced conditions which call for social innovation in the public sector. Moreover, advances in private innovation are dependent upon the climate provided by social innovation.

For example, the development of the automotive industry and the introduction of various forms of chemical processing have created conditions leading to the pollution of water and air. In this respect, private innovation has created environmental conditions which call for social innovation. New industrial innovations requiring additional supplies of fresh water and a substantial number of well-educated workers will depend, in turn, on social innovation. For without improvements in water supply and in our educational system, it would seem that future industrial innovation will be limited. On the other hand, improvements in the educational system are at least partially dependent upon innovation in teaching aids such as audio-visual instrumentation. There is a mutual interdependence between social and private innovation.

We have considered the possible sources of social innovation and the roles of government and industry with respect to its performance. Social innovation in the public sector must depend upon private as well as public resources. As an illustration, improvements in the control of water and air pollution must stem from private innovations producing changes in automobiles and in industrial processes such that the polluting elements which are discharged into the environment will be reduced or eliminated.

We believe it is incumbent upon government, both local and national, to provide the essential framework for social innovation. As a general principle, moreover, government should encourage the use of private resources for social innovation whenever possible. In this effort we conceive of governmental functions along the following lines:

a. Defining the social problems and the priorities for their solutions.
b. Intensifying the planning for such solutions.
c. Encouraging private enterprise to seek profit-making opportunities in the development of such solutions.
d. Developing regulatory and other mechanisms, such as government purchasing policies, to compel or encourage industries to modify productive processes and products in such ways that they will contribute to the betterment of the social sector (for example, regulations regarding water and air pollution).
e. Carrying on the necessary technological developments, when it is clear that private resources cannot be depended upon to undertake them satisfactorily.

The prosecution of this program on the part of the government would call for careful, intensive analyses of each of the areas requiring social innovation. No pat formulas can indicate which paths would be more productive. Social problems may arise which are not susceptible to solution via the private sector of the economy, in which case the government would have to accept the primary or exclusive burden of performance. Again, however, we believe the only reasonable generalization which can be made in tackling these problems of social innovation is that the government should give careful consideration to the utilization of private industry for this purpose before it undertakes investment of public funds and resources.

REGIONAL DIFFERENCES

Cities and regions appear to vary markedly with respect to successful generation of new technologically based enterprises. Unfortunately, there are no statistical data to show this. But our personal experiences—and we claim no more proof than that—tell us that cities and regions do vary widely in their propensity to exploit their innovative potential. We surmise that important factors exist which go beyond such indexes as the total number of scientists in the area, or the total R&D expenditures, or the availability of capital.

CHART 10

VARIATIONS — CITY TO CITY IN THE PROPENSITY TO GENERATE NEW TECHNOLOGICALLY BASED COMPANIES

e. g., Many Such Companies	e. g., Few Such Companies
Boston	Philadelphia
Palo Alto	Chicago
Washington, D.C.	Kansas City
Pittsburgh	Atlanta

We tried to analyze—again, of necessity, largely on the basis of our personal experiences—what differentiates cities with respect to their propensity to generate new technological enterprises. As we have indicated, Boston is an area which generates many new technological enterprises, whereas Philadelphia, by comparison, apparently generates few. We asked ourselves, first of all, whether the difference between these two areas is due to the existence of greater potential venture capital in one over the other—whether this factor is a major barrier to the creation of new technological enterprises. We are unaware of any evidence to this effect.

There is abundant potential venture capital available in the Philadelphia area. What we are led to believe is that in the Philadelphia area there is poor linkage, poor communication, between potential venture capital sources and technological entrepreneurs. There are also other factors that bear on this problem. We shall explore them, but at this time it would be well to analyze the one piece of evidence we have that compares the attitudes of technological entrepreneurs in the Philadelphia and Boston areas with respect to the climate for generating new technological enterprises in these localities. This evidence was developed by the Federal Reserve Bank of Philadelphia.[2] It is a report based on interviews with scientist-businessmen regarding the problems of seeding science-based industry.

[2] *Elizabeth P. Deutermann, "Seeding Science-Based Industry,"* Business Review, *Federal Reserve Bank of Philadelphia (May 1966).*

The author carefully and objectively selected several research-oriented firms in the Delaware Valley area and in the Boston area and asked the founders of these companies several questions, among which the following two are of greatest interest: (1) "Do local universities play any role in stimulating new science-based firms?" (2) "What is the attitude of local banks toward financing for the small, science-based firm?" The Boston entrepreneurs, in response to the first question, replied to a man that the universities play an important role. In striking contradistinction, the Philadelphia entrepreneurs were of the unanimous view that universities play a small role.

In response to the second question, the Boston entrepreneurs replied unanimously that the attitude of local banks to the financing of small science-based firms was "good" or "excellent." Again, in marked contrast, the Philadelphia entrepreneurs said, without exception, that the attitude of their local banks was "unreceptive," "poor," or "bad."

It is true that the number of firms interviewed by the author was small (there were 13 all together), but the likelihood of getting these completely disparate views with respect to the attitudes of banks and the importance of universities is so remote that the results are significant. There is at least some reason to believe that the apparent difference in attitudes among venture capital sources, technological entrepreneurs, and universities in these two areas bears upon their propensity to generate new technological enterprises.

THE TOTAL ENVIRONMENT

In our over-all deliberations, we came to some general conclusions about the kind of *total* environment that seems to encourage the creation of new technological enterprises. Included in this environment are:

a. Institutional and individual venture capital sources that are (i) "at home" with technologically oriented innovators and (ii) have the rare business appraisal capabilities necessary to diagnose the prospects of translating a technical idea into a profitable business.

b. Technologically oriented universities, located in an area with a business climate that encourages staff, faculty, and students to study and themselves generate technological ventures.

c. Entrepreneurs, who have been influenced by examples of entrepreneurship (for it is our contention that entrepreneurship *breeds* entrepreneurship).

d. Close, frequent consultations among technical people, entrepreneurs, universities, venture capital sources, and others essential to the innovative process.

Professor Cole has drawn an analogy between the elements of an entrepreneurial environment and the charges in an electric field. A beneficial environment requires, he has said, "a sympathetic alignment of institutions . . . pointing in the same direction, or charged with the same brand of electricity." [3]

[3] *Arthur H. Cole,* Business Enterprise and Its Social Setting, *Harvard University Press, 1959, p. 245.*

Viewed in this sense, unsympathetic bankers, inattentive educational institutions, overzealous tax authorities, and other environmental barriers, are negative charges that work against the entrepreneur.

VARIATIONS AMONG INDUSTRIES

Many industries are apparently under-spending on innovation. (Again, we must emphasize that we lack adequate empirical data to substantiate this feeling.) A number of factors bear on this problem, the most important of which would be the absence of adequate managerial and technological skills in an industry. We often see companies with an abundance of these skills enter such an industry for the first time and make significant contributions. The invasion of the textile industry by the chemical industry (Nylon, Acrilan, etc.) is a case in point.

We looked at variations among selected "big sales" industries. Since empirical data on *innovation* were unavailable, we resorted again to R&D percentages. In particular, we selected the steel, transportation, chemical, and drug industries—and noted the variation in the ratio of company-financed R&D to net sales.

CHART 11

VARIATIONS IN COMPANY-FINANCED R & D AS A PER CENT OF NET SALES, BY INDUSTRY

	Net Sales (Billions)	R & D (Billions)	R & D / Net Sales
Steel (Primary ferrous products)	17.8	0.111	0.6%
Transportation Equipment (Excluding aircraft)	34.3	0.865	2.5%
Chemicals	25.6	0.830	3.2%
Drugs	5.03	0.224	4.5%

Source: NSF (1966) — Figures are for 1964.

The above tabulation shows the steel industry (primary ferrous products) spending, in 1964, a mere 0.6% of its $17,800,000,000 in net sales on R&D. In contrast, the drug industry was spending 4.5% of its $5,400,000,000 in net sales on R&D, a percentage almost eight times that of the steel industry.

We asked ourselves several questions about the differences between highly innovative industries and those which are relatively uninnovative.

Are the highly innovative industries progressive because of the manner in which they respond to technological opportunities? Are they primarily this way because their managements have extraordinary capabilities for grasping and managing technological change? What characterizes the relatively uninnovative industries? Are they this way because they failed to exploit innovative opportunities? Because they possess excessive built-in barriers to technological change? Is it that their managements have not learned the importance of utilizing technological opportunities and innovative skills?

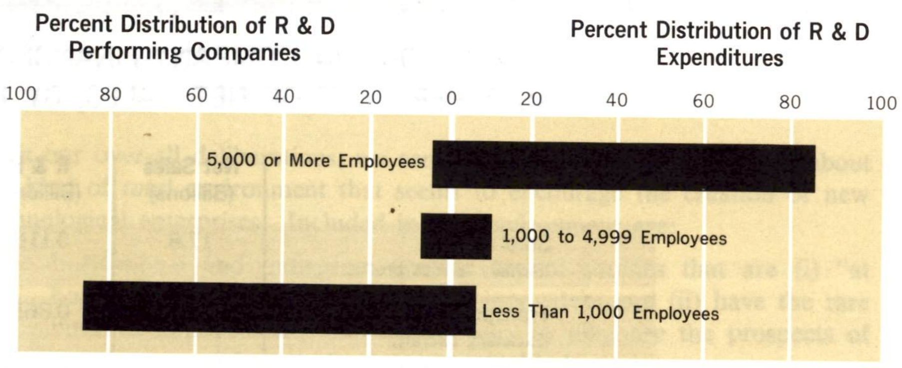
We find that we must answer each of these questions affirmatively. The major barrier is one of attitude and environment. It is primarily a problem of *education*—not of antitrust, taxation, or capital availability.

THE SIGNIFICANCE OF SIZE

We have examined variations in innovative performance between the public and private sectors, different regions, and different industries. We turn now to a consideration of innovative performance as a function of company size. Again, however—because we have no choice in the matter—we have been forced to resort to data concerning R&D, *not* the total innovative process.

CHART 12

VARIATIONS IN R & D, BY SIZE OF COMPANY



Source: Basic research, applied research, and development in industry, 1962, NSF 65-18, 1965.

The above data show that a handful of large companies (having 5000 or more employees) perform almost all of the R&D, although, as we have illustrated, this is not necessarily indicative of *innovative* performance.

It is important to distinguish between large and small sources of invention and innovation, for the resources available to them are different and, not surprisingly, the riskiness of a venture and the manner in which it is undertaken are generally a function of the available resources. We therefore analyzed several studies on the sources of invention and innovation. These studies were unusually consistent in indicating that independent inventors (including inventor-entrepreneurs) and small technologically-based companies are responsible for a remarkable percentage of the important inventions and innovations of this century—a much larger percentage than their relative investment in these activities would suggest.

—Professor John Jewkes, et al, showed that out of 61 important inventions

and innovations of the 20th century, which the authors selected for analysis, over half of them stemmed from independent inventors or small firms.[4]

—Professor Daniel Hamberg of the University of Maryland studied major inventions made during the decade 1946-55 and found that over two-thirds of them resulted from the work of independent inventors and small companies.[5]

—Professor Merton Peck of Harvard studied 149 inventions in aluminum welding, fabricating techniques and aluminum finishing. Major producers accounted for only one of seven important inventions.[6]

—Professor Hamberg also studied 13 major innovations in the American steel industry—four came from inventions in European companies, seven from independent inventors, and none from inventions by the American steel companies.[7]

—Professor John Enos of the Massachusetts Institute of Technology studied what were considered seven major inventions in the refining and cracking of petroleum—all seven were made by independent inventors. The contributions of large companies were largely in the area of improvement inventions.[8]

Chart 13, which is based on the above studies, illustrates some of the important inventive contributions made by independent inventors and small companies in this century. One finds the range and diversity of these inventions impressive. Indeed, the mercury dry cells in our electronic watches, the air conditioners in our homes, the power steering in our automobiles, the FM circuits and vacuum tubes in our Hi-Fi and television sets, the electrostatic-copying machines in our offices, the penicillin and streptomycin in our medicine cabinets, and the list goes on—all of these inventions, which are generally taken for granted, take a new meaning when one identifies them with their sources. The point to be made is that independent inventors and small firms are responsible for an important part of our inventive progress, a larger percentage than their relatively small investment in R&D would suggest.

[4] *J. Jewkes, D. Sawers, and R. Stillerman,* The Sources of Invention, *St. Martin's Press, 1958, particularly pp. 72-88, and Part II.*

[5] *D. Hamberg, "Invention in the Industrial Research Laboratory,"* Journal of Political Economy, *April 1963, p. 96. See also,* Concentration, Invention, and Innovation, *U. S. Senate Antitrust Subcommittee, 89th Cong., Part III (Government Printing Office, 1965), p. 1286.*

[6] *M. J. Peck, "Inventions in the Post-War American Aluminum Industry," in* The Rate and Direction of Inventive Activity: Economic and Social Factors, *National Bureau of Economic Research, (Princeton, New Jersey, 1962), pp. 279-92. See also, U. S. Senate Antitrust Subcommittee, op. cit., p. 1296 and 1438-1457.*

[7] *Hamberg, op. cit., p. 98. See also U. S. Senate Antitrust Subcommittee, op. cit., p. 1287.*

[8] *J. L. Enos, "Invention and Innovation in the Petroleum Refining Industry," in* Rate and Direction of Inventive Activity, *op. cit., pp. 299-304. See also, U. S. Senate Antitrust Subcommittee, op. cit., p. 1287 and pp. 1481-1503.*

CHART 13

SOME IMPORTANT INVENTIVE CONTRIBUTIONS OF INDEPENDENT INVENTORS AND SMALL ORGANIZATIONS IN THE TWENTIETH CENTURY

Xerography Chester Carlson	**Shrink-proof Knitted Wear** Richard Walton	**Mercury Dry Cell** Samuel Ruben
DDT J. R. Geigy & Co.	**Dacron Polyester Fiber "Terylene"** J. R. Whinfield/J. T. Dickson	**Power Steering** Francis Davis
Insulin Frederick Banting	**Catalytic Cracking of Petroleum** Eugene Houdry	**Kodachrome** L. Mannes & L. Godowsky Jr.
Vacuum Tube Lee De Forest	**Zipper** Whitcomb Judson/Gideon Sundback	**Air Conditioning** Willis Carrier
Rockets Robert Goddard	**Automatic Transmissions** H. F. Hobbs	**Polaroid Camera** Edwin Land
Streptomycin Selman Waksman	**Gyrocompass** A. Kaempfe/E. A. Sperry/S. G. Brown	**Heterodyne Radio** Reginald Fessenden
Penicillin Alexander Fleming	**Jet Engine** Frank Whittle/Hans Von Ohain	**Ball-Point Pen** Ladislao & Georg Biro
Titanium W. J. Kroll	**Frequency Modulation Radio** Edwin Armstrong	**Cellophane** Jacques Brandenberger
Shell Molding Johannes Croning	**Self-Winding Wristwatch** John Harwood	**Tungsten Carbide** Karl Schroeter
Cyclotron Ernest O. Lawrence	**Continuous Hot-Strip Rolling of Steel** John B. Tytus	**Bakelite** Leo Baekeland
Cotton Picker John & Mack Rust	**Helicopter** Juan De La Cierva/Heinrich Focke/Igor Sikorsky	**Oxygen Steelmaking Process** C. V. Schwarz/J. Miles/R. Durrer

It goes without saying that the United States could not depend solely on the innovative contributions of small firms. The large firms are indispensable to technological and economic progress. From a number of different points of view, however, we are persuaded that a unique cost-benefit opportunity exists in the provision of incentives aimed at encouraging independent inventors, inventor-entrepreneurs, and small technologically based businesses. The cost of special incentives to them is likely to be low. The benefits are likely to be high.

III

THE SMALL COMPANY ENVIRONMENT

We turn now to an analysis of the environment for innovation at the company level. We will do this first for an illustrative small company, then for a large company. We will analyze these large and small company environments by describing their growth cycles and some of the characteristics and problems encountered in each case. Our recommendations will then be made in reference to these factors.

We analyzed the growth cycle of an illustrative technologically based small company and divided the cycle into what we perceived for our purposes to be the key stages of growth. These are shown in Chart 14.

Let us discuss each of the stages of the growth process in detail.[1]

THE IDEA STAGE

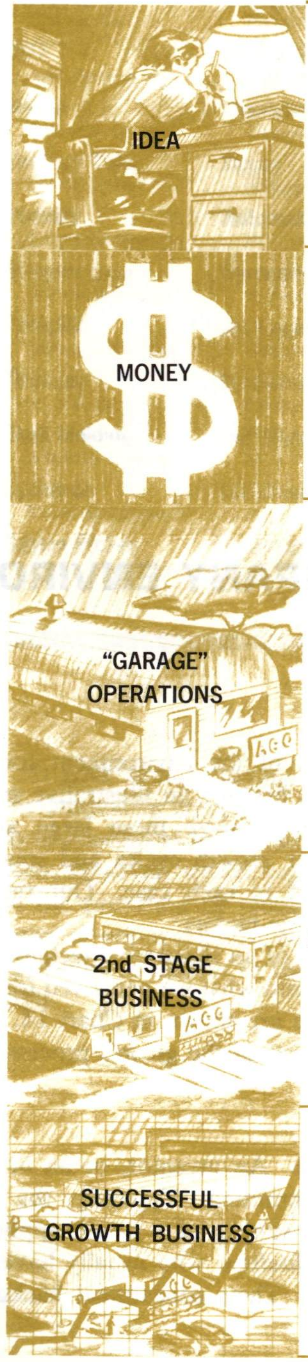
We begin with the idea stage. An inventor, or an inventor-entrepreneur, has an idea to which he is committed. Typically, the product or process which underpins the idea is the subject of a patent application. The people we are talking about are *individualists,* who usually have voluntarily "spun-off" from another organization. Their educational backgrounds are usually in science or engineering.

[1] *Italicized words in the text correspond to terms appearing in Chart 14.*

CHART 14

MANAGING TECHNOLOGICAL INNOVATION

SMALL COMPANY ENVIRONMENT



	CHARACTERISTICS	PROBLEMS
IDEA	Individualists Technical Uncertainty No business experience Total commitment	Capital? In business?
MONEY	High risk requires high potential return Relatively small $ No technical experience	Appraisal Lack of understanding • Banks • Industry • Government • Universities
"GARAGE" OPERATIONS	Losing money Less than • 100 employees • $1 million capital • 5 years old Technology oriented High ratio technical men Government contracts Fast reaction time One or few customers Custom manufacture High return on investment High value added	Key management Incentives Fringe benefits Government procurement Total commitment
2nd STAGE BUSINESS	New kind of financing Dilution of equity Many impersonal customers Product oriented High volume manufacture More than • 100 employees • $1 million capital • 5 years old	Key functional staff Control techniques Market analysis World wide marketing Costs Competition
SUCCESSFUL GROWTH BUSINESS	Growth Jobs Products	Escape Merger Sell out Antitrust Timing

UNDERSTANDING (spans Idea through "Garage" Operations stages)

As we have noted, the path between an invention and the market place is a very tortuous obstacle course and, therefore, in this first stage of the cycle, there is a high degree of *uncertainty* as to the ultimate outcome of the venture.

Typically, these individualistic, technical people have little or *no business experience,* but are *totally committed* and prepared to risk their livelihoods and their future security in order to champion their idea.

We turn now to the problems the inventor and the entrepreneur have in this stage of their venture. We have listed two which are pertinent to some of the recommendations that we shall make. First of all, they need *capital.* As a rule they have none, and nothing will happen to their idea until they get some financial backing. It is not just any kind of money they are seeking. What they require is venture capital, and they must know something about the intricacies of venture capital acquisition or find somebody who does.

Secondly, they are faced with a legal issue of whether or not they are *"in business."* As we shall see, this question is important from the standpoint of the tax laws, for the deductibility of expenses that they incur at this stage in the growth cycle of their hoped-for company will depend upon, first of all, their tax acumen and, secondly, whether or not they are in business. Although we shall explore this question in detail later, it may be helpful to note at this point that even if the Internal Revenue Service regards them as being in business at this stage, they probably have no personal income against which to deduct the expenses in excess of income which the "business" is incurring.

THE MONEY STAGE

Venture capital is very *high risk* money. High risk money requires *high potential return.* It is important to note the very *high risk* that venture capital sources assume in underwriting the formation of new technologically based enterprises; and governments, the universities, and society need to understand this risk. There must be opportunities for large gains from a few successful ventures to offset the risk of losses from the many failures. Notwithstanding the risk element, venture capital *is* available (to those who know where and how to get it) precisely because there are extraordinarily high potential returns for the successful undertakings. We need only recall the histories of the ventures listed in Chart 4, Chapter I.

The money needs of a fledgling technological venture in its first two years are *comparatively small,* typically under $500,000. These costs, however, are much greater now than they were only twenty years ago.

By and large, the technical people, who have the idea and want to build a company on it, have little if any business experience and know nothing about the venture capital market. On the other hand, the sources of capital —banks, wealthy individuals, underwriters, investment trusts, and others— usually have *no technical background* and only rarely have available to them adequate staffs to perform the complex investment appraisals required to measure the merit of any single entrepreneurial proposal. We are dealing here with ideas that have high technical content. The venture capitalist needs to weigh their prospects. He may have a great many new ideas presented to him. He must pick winners some of the time and make educated gambles all of the time; and to do this he has to have adequate appraisal resources at hand. One cannot overstate the pivotal importance of adequate appraisals. There truly are very few capital sources who understand equally well the nuances of convertible debentures and the intricacies of gas laser technology.

The "appraisal gap" is a rather specific example of our principal theme, that if any problem can be singled out as the central obstacle to the small technologically based enterprise, it is the need for *understanding*. Too few leaders in industry, government, the universities, and the financial community truly understand the business and human dynamics of the innovation process.

THE "GARAGE" OPERATION

The Company obtained the needed capital. It is now in business, but it is *losing money*. Let us put some rough dimensions on the firm at this stage. It is small, lean, proud, hard working. It is quartered, we may say, in a "garage"—in any case, very modest facilities. During this "garage" stage, it is typically less than five years old, has less than one hundred employees and less than $1 million in capital. Some of these firms may have one tenth of these resources.

The company is *technology oriented* and has a high ratio of technical to non-technical staff. Often, it is seeking government research and development contracts.

This kind of company has a *fast reaction time;* it is quick on its feet. It has to be: the distance from the front to the back of the garage or from smooth sailing to bankruptcy is very short, indeed. Each adversity is a major crisis for the fledgling enterprise.

It has limited marketing problems, because it typically has only a *few customers*. One dissatisfied customer, and the firm may face disaster, so it naturally tries a little harder to please. Because its market is limited, it often produces on a custom basis.

All of the above characteristics—high ratio of technical people, emphasis on know-how, a high-technology product or service, and so on—indicate that the firm's output probably has a *high value added*. This, in turn, means that if the company matures to a successful growth business, there will be a very high return on the *initial* investment.

But let us turn now to some of the problems. Management problems are foremost. They present the greatest frustrations. The typical inventor, prime mover, man with the idea, lacks managerial skills. The firm needs these skills, but how does it get them? The salaries, pensions, and other fringe benefits used by successful large firms to lure and hold key people cannot be offered by a struggling small company which is fighting for its survival. Other incentives must be found. To lure *key managers,* who are willing to share the *total commitment* of the company founders, the company must be able to point to a high return if the high risks are overcome. Our recommendation concerning stock options (Recommendation 2) is directed to this end.

Government procurement procedures may pose a problem to our new firm. Procurement regulations and policies do not take the peculiar problems of small, technological firms into account. For example, the summary cancellation of one government contract may be disastrous to a small firm. A large firm, on the other hand, can probably survive such a cancellation, although we appreciate that such a cancellation is always a shock to any organization.

THE SECOND STAGE BUSINESS

Our company is maturing. It is now maybe as much as five years old, has annual sales in the millions of dollars, and is in business in every sense of the word. The loss of a single customer is no longer decisive. It now has many impersonal customers.

The company is no longer solely dependent on technology. Its central problems are now related to product manufacturing—to improving product quality and lowering manufacturing costs.

It needs a *new kind of financing*. But this new money will not be exclusively high-risk, high-return, venture-type capital. The earlier risks and uncertainties have been reduced and, therefore, obtaining secondary financing is usually easier than was the acquisition of venture capital. This time the company can look to conventional sources of capital—through public stock offerings, for example. After additional financing has been acquired, the equity of the original owners of the company has probably been significantly diluted in terms of the degree of ownership control they can exercise.

What are some of the new problems? To get to this stage, a company has to solve the key management problem we discussed with respect to the previous stage of its life. But now *key functional staff* are probably missing. Research, development, marketing, and production are new problem areas, and skilled personnel are needed to handle them. *Control techniques* are now needed to keep the business on course and operating effectively and efficiently. Costs have taken a new meaning and complexity.

Market analysis is also a new problem. In this stage of its life the firm may find that its product is not just a domestic item, but has international possibilities.

The company has become successful and, thus, has attracted other companies to its field. The competition intensifies.

A SUCCESSFUL GROWTH BUSINESS

The company, in its wisdom, persistence and good fortune, has solved its initial problems. It has become a successful growth business. Its contribution to the gross national product is growing, its products are filling many additional demands, and it is employing many more people.

It has new problems. The founders—the entrepreneur and the inventor—are not the central figures they used to be. They may want to escape. They championed their idea into a success story and the challenge may not be there any more. The time for taking a high return on their total commitment over the years may have come. They might want to do this by selling their interest in the company. Or they might want to sell the company or merge it with another corporation. For the first time, a new word appears in their vocabulary: "Antitrust." To them it may appear as an unwarranted governmental restriction that prevents them from realizing the maximum possible return on their personal investment and commitment; and yet, in larger perspective, the restriction may be required to safeguard the public interest.

IV

THE LARGE COMPANY ENVIRONMENT

The innovation process in a large company is, in many respects, similar to that in a small company. But the risk of any single venture to the future of a large company is nowhere near as great, for the large technologically based company can spread its risks by undertaking several innovation projects at once. Moreover, because a large company normally has profits against which it can offset costs, the government, in effect (through the corporate income tax), shares in 48% of the innovation project losses of the company. As we have seen, this is not true of a typical small company in its early stages.

THE PROBLEMS OF GROWTH

To illustrate the basic problem of the large company with growth objectives, let us consider the following hypothetical case.

CHART 15

GROWTH PROBLEM IN A SUCCESSFUL LARGE COMPANY

(Hypothetical Case)

Annual Sales	$1,000,000,000	
Sales Decline (Oldest Products)	5% Per Year	$70,000,000
Price Erosion	2% Per Year	
Typical Market Penetration	25%	
Growth Target	10% Per Year	$100,000,000
		$170,000,000

Such a company needs $170,000,000 of new sales from a combination of
(a) established products
(b) new products in established businesses
(c) new businesses

Ultimately this company must seek to enter completely new businesses or abandon its growth objective

The company has annual sales of one billion dollars, derived from established products, in a series of markets which it has penetrated, on the average, to the extent of 25%. The total demand for the oldest of these products is falling at a rate of 5% per year ($50 million). Moreover, the price erosion of its whole range of products is 2% per year ($20 million).

This company is well-managed and has substantial resources. It is not content to deteriorate by $70,000,000 each year. Nor will it be satisfied merely to remain static. On the contrary, it wishes to grow at a fairly high rate—say, 10% per year ($100 million). Adding these figures up, then, this company finds that it needs $170 million of added sales in the first year of its growth program.

The new sales can only come from a combination of (a) increased sales of its established products through greater market penetration or the invasion of new markets, (b) development of new products in its current businesses, or (c) entry into completely new businesses.

With the demand for some of its established products declining, an increase in the sales of its better performing products (amounting to a 17% year-to-year rise) will be hard to achieve, particularly in view of the substantial market penetration the company already has. Ultimately, therefore, the company will have to enter new business fields or abandon its growth objective. The important point to bear in mind, as we proceed now to discuss briefly an example of the large company environment, is that this requirement for growth leads a large company to launch innovative business ventures. The small, fledgling firm is therefore not alone in this respect. Whatever the differences between the small and large firm, the goal in each case is a successful new growth business.

For purposes of discussion, we have divided the management of technological innovation in a large company into four stages, as shown in Chart 16.

We identify the first phase as the business planning stage. Next comes the period of experimental appraisal. Out of this, if all goes well, an embryo business appears. And if everything falls into place, the result is a successful growth business. Let us consider each of these stages in turn.

BUSINESS PLANNING

In almost every detail the large company environment for innovation is different from the small company situation we have discussed. In one crucial respect, however, they are identical. At the *very* beginning of a new "business innovation project" there is an individual who has an idea on how to solve a problem, or how to create a novel product, or how to fill a need which he believes will be manifested in the market place.

Because the company is committed to innovation, this individual has an opportunity to perform some experiments to develop his concept; he then has a chance to present his idea for consideration by management.

We come now to an important difference between new and established companies. In the large company the merit of the idea is judged by analyzing the totality of the proposed new business venture as an alternative investment opportunity. This analysis in the most sophisticated companies can be used to establish a "best guess" for the net present value of the new venture con-

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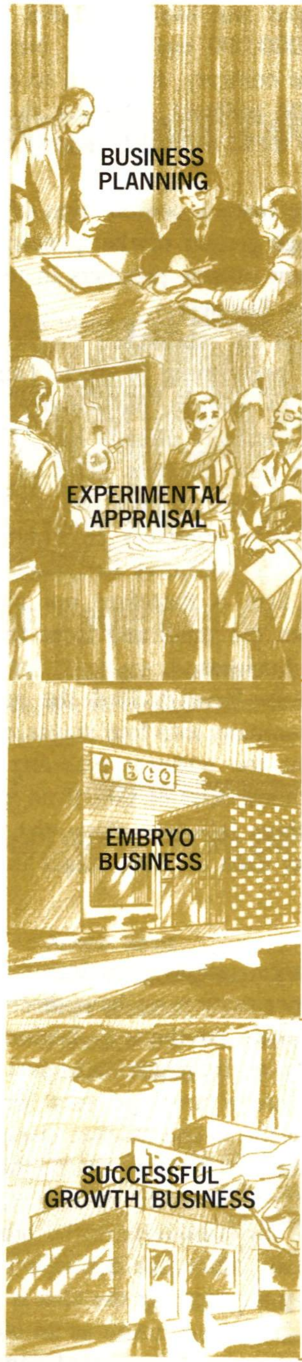
CHART 16

MANAGING TECHNOLOGICAL INNOVATION

LARGE COMPANY ENVIRONMENT



	CHARACTERISTICS	PROBLEMS
BUSINESS PLANNING	Venture analysis Directional planning Business objectives control	Not invented here Time value of money Inbreeding Lack of specific market experience often kills good projects
EXPERIMENTAL APPRAISAL	Complex enterprise **Has** R/D organization May lack certain technical skills	Entrepreneurs missing Know-it-alls Risk vs. Cost emphasized Extend present businesses
EMBRYO BUSINESS	Outside inputs needed Incentives available Continuing R&D effort	Failure to meet return on investment criteria in early years Antitrust Key management
SUCCESSFUL GROWTH BUSINESS	Growth Jobs Products	Assimilation Antitrust

UNDERSTANDING

cept, taking into account the risk of failure, the time value of money, and the company's performance in its established businesses. The new idea is thus judged as an alternative to other investment opportunities available to the company. Such alternatives are not available to a new company of the kind we explored in Chapter III.

As part of its *venture analysis* [1] the company also engages in directional planning, based on the realities of the market place and aspirations and capabilities of the organization. Directional planning involves questions such as: "Where are we?" "Where are we going?" "How will we get there?" "How did we get to where we are?" "What business are we in?" "What should we be in?" "How does the idea we're considering fit in with what we are or should be?"

Despite the logic and helpfulness of the planning process, it cannot cope with certain internal barriers to the new idea being considered. If it has come from outside the company, the new idea may undergo a fatal battering because of the *"not invented here"* syndrome. As Charles Kettering once put it, "The greatest obstacle course in the world is trying to get a new idea *into* a factory." [2]

A large company has greater concern for the *time value of money*. Unlike a small company beginner, a large established company has the option of applying its money to a number of alternatives. An investment that will not yield returns for several years is made less attractive because it is discounted substantially. As a consequence, the company may choose less ambitious shorter-run opportunities.

A large company tends to be *inbred;* in extreme cases the company may thereby actively resist any change. More important, however, is the problem that a new market represents to the large company's established marketing staff. Indeed, there is no question that good innovative opportunities often are not exploited because the company lacks the requisite *market familiarity*. The irony, as we have seen, is that new markets are the key to the kind of new growth businesses that the large company needs to develop.

EXPERIMENTAL APPRAISAL

In those cases, however, where the large company management elects to try to develop a new business opportunity, it proceeds next to an experimental appraisal of the key elements of the new business. This often involves a research effort for which the company has an *institutionalized research* and development activity.

However, the company may be missing some of the technical skills needed in the new field it is exploring. If, for example, its traditional business is in electronics, but the new venture has to do with washing machines, its technical people may not possess the required mechanical skills for the new business. But a large company has the resources to acquire these skills.

The large company is a complex social organization. The fast reaction

[1] *Italicized words in this chapter correspond to terms appearing in Chart 16.*

[2] *See* Concentration, Invention and Innovation, *U. S. Senate Antitrust Subcommittee (Government Printing Office, 1965), pp. 1099, 1115.*

time we discussed in reference to the small company environment is not easily attainable here. The distance from the chief executive's office to the maintenance shop may be a long way. He is, in fact, often removed from the operational details of his company; surely, he is not familiar in detail with each new venture early in its lifetime. The complexity of the organization itself leads to certain problems.

There are the *"know-it-alls."* They explain that they have thought about similar new ideas many times before, and have concluded that there are many, many reasons why each new concept cannot succeed. Or, it will not work because it has never been done before. There are many other reasons why, in this experimental appraisal stage, prior experiences and predispositions rise up to block innovation. Often these take the form of an overly conservative estimate of *risk-versus-probable cost* for new ventures. It is easy to make such decisions because there is always the choice of *extending the present business* rather than taking the organization into unknown territory. As we have noted, the beginning small business has no analogous option.

These are different kinds of problems from those we discussed in reference to the small company environment. There, when the problem was to obtain initial financing for the incipient firm, the problems were largely external ("Can we get the capital?"). Here, we are concerned with what may be a lack of entrepreneurial spirit and commitment within a well-established, well-financed organization. In a complex organization the overriding problem often is maintaining an adequate commitment to a new idea in the face of internal obstacles to change. There is an understandable reluctance to depart from what has been a successful pattern of business. So we come back again to the need for *understanding,* within and outside the company, of the special problems of managing and exploiting technological change. These problems are no less formidable in a large organization than they are in a small firm. They are just different.

THE EMBRYO BUSINESS

The experimental appraisal is over and the idea has proved itself. An embryo business is formed within the framework of the corporation. Because of its ancestry, the business needs no major effort to establish a long-range R&D program. It has the tradition and the backing to fill in gaps in the R&D sector.

But the embryo business usually does *need outside inputs*—in the marketing area, for instance. Key management is also important. The established company can get these inputs more easily than can the small firm, for it can offer the *incentives* of high salaries, security, and other inducements already mentioned.

But sometimes the most effective strategy is to purchase the needed elements by acquiring assets from another company or merging with it. Here, again, *antitrust* considerations play an important role in limiting the company's course of action.

At an equivalent point in its growth pattern, a small company is in a "do or die" situation. The large company, however, may still elect to abandon the venture if it fails to show signs of measuring up. For example if, in the early

years, the embryo business fails to meet the established criteria for *return on investment,* the large company may drop the venture altogether.

A SUCCESSFUL GROWTH BUSINESS

Just as the desired final stage of the small-company cycle was a successful growth business, so it is for the new business development within a large technologically based company. Here, too, the characteristics of the firm include growth contributing to the gross national product, jobs to provide new employment opportunities, and products to fulfill needs and to diffuse technology.

Antitrust can be a problem if, for example, the corporation seeks to enhance its new business by acquiring other companies that are capable of complementing it. It should also be noted that if, in the first instance, the large corporation, instead of developing a new business venture completely internally (as in our illustrative example), had preferred to add a new business through *external* acquisition or merger, antitrust questions could have arisen then.

As a further observation on the large-company example discussed in this chapter, we should mention the difficult problem of *assimilating* the new growth business into the parent corporation. Adjustments and dislocations are inevitable; disharmonies will occur. This is a painful but absolutely necessary step, since the full value of the new business cannot be realized if it operates separately from the supportive strength of the entire company, to which it can also add strength and skill.

It is apparent, therefore, that small and large technologically based companies have similar goals and problems, though different environments. Both wish to develop successful growth businesses, but they go about the task in very different ways.

No attempt has been made to construct a *generic* model of the innovation process as it occurs in "the" small firm or in "the" large firm. We chose instead two illustrative examples of the process. Much more could have been said about the problems and characteristics of large and small technologically based companies. We believe, however, that we have identified an adequate number of problems and characteristics of the innovation process in large and small firms to enable us to explore, in a more reasoned approach, possible ways to improve the environment for technological change.

Moreover, what we have noted regarding the *respective* characteristics and problems of large and small technologically based firms suggests an important challenge to the business world. The challenge is to explore new ways for large companies to work with small technologically based companies, while maintaining the creative qualities of each—or, alternatively, for large companies to develop, *within* themselves, sub-environments that foster the enthusiasm and entrepreneurial spirit of the small firm, while benefitting from the over-all resources of the total corporate environment.

V

PROBLEMS AND RECOMMENDATIONS

Having explored various aspects of incentives and barriers to technological change and having analyzed some of the salient features of small and large companies in the management of technological innovation, we are in a position now to present our recommendations. For reasons already stated, and which will be supplemented, they are aimed primarily at the problems encountered in the small company environment.

A. TAXATION [1]

1. THE PROCESS OF SELECTION

We have reviewed many tax proposals aimed at either (1) encouraging innovation in a positive way, or (2) eliminating disincentives or barriers to innovation. We are recommending only a few, having rejected most of the proposals we considered. It would please us to be able to say that our evaluation was made on the basis of clear, statistical evidence of the prevalence and importance of a given barrier to innovation, or on the basis of a sophisticated cost-benefit study of the impact of a given tax change on the amount of innovation or even on the level of tax revenues.

Unfortunately, there are few such data available. In fact, the lack of objective data, in or out of government, on the innovation process, in general, and the technologically based firm, in particular, is symptomatic of a very serious deficiency in our thinking regarding technological innovation. As we have said earlier, too few people in government, in industry, in banks, and in universities understand the special forces at work in the conception, appraisal and nurturing of the innovative, technological enterprise. Yet, even a casual reading of the business history of this country makes it clear these innovative

[1] *See Appendix D for provisions of the Internal Revenue Code discussed in this chapter.*

enterprises are an important part of the process that differentiates our rate of progress from that of the rest of the world.

How, then, have we decided to recommend some tax proposals while rejecting so many others? We have tried to give adequate consideration to tax incentives that operate across the total process of innovation, and have avoided recommendations which, in our view, would result in unreasonable or unjustified economic distortions. We are wary of proposals that would lead one to believe that a tax incentive for R&D alone would automatically lead to major increases in innovation.

In this vein, a common proposal is a 75% tax credit on all R&D expenditures. Let us review our reasoning in *rejecting* this proposal. Its cost in lost tax revenues would fall in the range of *1.25 to 1.5 billion dollars a year,* for between 5 and 6 billion dollars per year is now being spent on industry-supported research. It should be understood that a 75% tax *credit* means the government would, in effect, be bearing three-fourths of the cost of industry-supported R&D. At the present corporate tax rate of 48%, it bears roughly half the cost. An additional 25% of the burden would therefore be a very costly tax change.

This recommendation generally flows from an assumption that what our society really needs to get more innovation is simply more research and development. We have indicated earlier that we are unable to conclude that our country is lacking in this regard. Also, and more important, we believe we must look increasingly at the innovative process the way businessmen do—that is, at the *total* new venture, the *total* cost, the *total* profitability or loss, not just the R&D portion, which is usually only a small segment of this total.

It is very likely that an across-the-board (and therefore costly) tax credit would be enjoyed largely by the very large and already technologically-oriented companies. As recently as 1960, only 300 companies accounted for 90% of the R&D expenditures. As we have already noted, to many of these companies, research and development is increasingly a way of life.

We should seek to provide incentives that will increase the nation's total innovative potential and should aim our efforts at companies where the extra incentives are genuinely needed, or will provide the maximum innovative response per dollar spent. We do not believe an across-the-board 75% tax credit for R&D expenditures meets these criteria.

In looking for unique cost-benefit relationships, we were impressed, as we have already noted, by the apparent leverage of small companies and individual inventors and entrepreneurs in the whole process of invention and innovation. We were also impressed by the great difficulty that apparently exists in communicating the availability of tax benefits to small companies and individuals.

It is not enough to say that a given tax change will produce dramatic results. Even if the economic theory is sound, this assumes people will know about the tax change and grasp its implications. The Sloan School at the Massachusetts Institute of Technology recently conducted a study of the impact of tax benefits on small technologically based companies.[2] It would

[2] *Baty, Gordon,* Initial Financing of the New Research-Based Enterprise in New England, *Report to Federal Reserve Bank of Boston No. 25 (1964), Master's Thesis, M.I.T., pp. 72-73.*

appear from the study that Section 1244 (which allows an ordinary deduction, instead of a capital loss, for losses incurred in the stock transactions of certain small business corporations) did not have a substantial influence on many of these companies. Because a tax provision of such potential benefit is still apparently not widely appreciated and used, one is led to conclude that not enough is being done to provide better education for administrators, businesses, and individuals on the availability and meaning of *existing* tax provisions. One needs to ask, moreover, whether a given tax problem, such as that to which Section 1244 was directed, while noticed by sophisticated tax experts, really affects only a very small percentage of the potential innovators.

To propose that far-reaching, across-the-board tax benefits are the major requirement for higher levels of innovation requires an explanation of why, with existing tax benefits, some areas like Boston, Palo Alto, Pittsburgh, and northern New Jersey have produced many more technologically based innovative companies than have other major areas with equivalent or greater numbers of scientists. A study we have already alluded to suggests that other factors—attitudes of universities and banks, for example—play a major role.[3]

Thus, where we were not impressed that a *pervasive* and *important* need existed for a tax proposal, we were not persuaded to recommend it, however technically elegant the proposal may have been. On this basis, we eliminated a large number of specific, technical tax recommendations that may have made sense in their own terms, but which, in our view, were likely to have limited impact. In this process of selection, we have focused on the special problems of the inventor, the entrepreneur and the small technological enterprise. We turn now to our specific proposals.

2. MORE TIME FOR SMALL BUSINESS DEDUCTIONS

A large corporation engaged in research, development and innovation projects generally has profits against which losses incurred on these projects may be deducted. As a result, it may be said that the Government shares in the cost of these innovation losses to the extent of 48% of the cost. On the other hand, a small corporation that has no profits from which it may deduct R&D expenditures bears the entire cost of that expenditure. While those losses may be carried forward against profits of the succeeding five years, this places the unprofitable corporation in a disadvantageous position as compared with the large corporation, because (1) the Government's contribution is deferred until profits are realized, and (2) if profitable operations are postponed beyond the fifth year after the loss is incurred, the Government is never called upon to "contribute" its share of the loss. A similar result obtains in the case of the individually operated business, except that here the time limitation on the loss carry-over provisions also wipes out the deductions for personal exemptions and non-business income. Our review of several successful, technologically based companies indicates that it is not uncommon for even the successful ones to have lost money for at least five years. To recapitulate:

[3] *Deutermann, Elizabeth P., "Seeding-Science Based Industry,"* Business Review, *Federal Reserve Bank of Philadelphia (May 1966), pp. 3-10.*

CHART 17

LARGE vs. SMALL COMPANY IMPACT OF CURRENT 5 YEAR LOSS CARRY FORWARD

(1) Large companies generally have other profits against which innovation project losses can be written off immediately...therefore,

Government shares currently in 48% of these losses.

(2) Small companies often do not make profits for five years or longer...therefore,

The government either defers its contribution until profits are realized, or if losses persist for longer than five years, the government is never called upon to share in these losses.

Our task is to look for ways to remove tax disincentives or provide incentives for innovation. Tax changes that have little effect on *innovation* are not within the scope of our mission. Thus, if we are to favor extension of the period of loss carry-forward, as we do, we feel it desirable to limit the applicability of this extension to companies or activities that involve innovation.

We have struggled with this question. To allow such an extension for *all* companies would be to often allow benefits for incompetence rather than risky innovation. On the other hand, to allow such benefits only for *projects* that are "innovative" would be to require advance *certification* procedures which would likely be cumbersome at best and destructive of the innovation process, at worst.

We have therefore decided that the approach most likely to strike the right balance in defining the right targets for tax incentives, without imposing anti-innovative certification procedures, is to describe the kinds of companies that are most likely to produce the desired kind of innovation.

As we indicated in our analysis of the small company environment (Chapter III), small, technologically based companies, which in the past have generated so much effective innovation, would probably have

1. A product or know-how that can be sold or licensed.
2. A high ratio of technical people to the total number of employees.
3. A high value added as percentage of sales.
4. A small size in terms of (1) number of people, (2) dollar sales, and (3) net worth.
5. No affiliations with other companies (e.g., as a subsidiary).

These are illustrative criteria. A more refined and definitive list should be based on a detailed, empirical study of the characteristics of such firms.

RECOMMENDATION 1

We recommend that losses of small, technologically based companies, meeting criteria along the lines we have suggested, be allowed as a carry-forward against profits of the succeeding ten years instead of only five years.

This would assure those businesses which contemplate a longer than five year period of development that the Government would bear an equitable share of the losses, as it does in the case of the large profitable enterprises. Such an extension of the loss carry-forward period for small technologically-based companies would certainly help to equalize their treatment with that of the larger profitable organizations.

And yet, conceptually, it is clear that our recommendation is really only a *partial* equalization of treatment. The large corporation is often a conglomerate of a number of different businesses, some profitable and others not. In particular, the new and innovative businesses are often not profitable, at least for some time. The Government shares *currently* these losses of large profitable companies.

On the other hand, the small, technologically based company, as we have seen, often has its total commitment in one or a very limited number of product lines. Thus, its losses from its new product lines may often be unaccompanied by offsetting profits from profitable product lines.

We have explored the concept of suggesting that the Government share *annually* in the losses of these small, technologically based companies through a *tax credit*—a negative tax, as it were. It has been suggested that the concept of the Government's sharing in the losses (they share in the gains) makes good economic sense—particularly since this kind of firm contributes significantly to invention and innovation. Nevertheless, we are aware of the political and philosophical objections to such a proposal. We are not inclined to favor a tax recommendation as far-reaching as this at a time when even the most "conservative" and "modest" proposals for tax incentives are likely to be viewed with great caution, both by the makers of fiscal policy and respected commentators in the field.[4] However, we would be remiss if we did not point out that we seriously debated the merits of such a proposal, and there is something to be said for it conceptually.

3. A LIBERALIZED STOCK OPTION FOR THE SMALL FIRM

There are few subjects less popular and perhaps less likely to receive favorable consideration than any proposal for the liberalization of stock options.[5] And yet, our study of small technologically based companies indicates they and the pace of their innovation have probably been affected adversely by the tightened provisions of the 1964 tax revisions. We note in the following chart three of the major stock option revisions that were enacted in 1964.

[4] *See, for example, Peckman,* Federal Tax Policy, *Brookings Institution, 1966.*
[5] *See, for example, Eisenstein,* The Ideologies of Taxation, *Ronald Press, 1961.*

CHART 18

SOME OF THE MAJOR 1964 REVISIONS OF STOCK OPTION PLANS ENTITLED TO CAPITAL GAINS TREATMENT

	Before 1964	After 1964
Minimum Purchase Price of Stock	85% of Market Value	100% of Market Value
Maximum Time to Exercise Option	10 Years	5 Years
Minimum Holding Time Between Purchase and Disposition of Stock	6 Months	3 Years

The latter two changes pose, we believe, especially significant problems for the small company. We believe that at the time of the change, the major thrust of Congress' intent was to minimize certain abuses of *large company* option holders. We question whether there was adequate understanding, at the time, of the special impact of this change on the small company. But first, let us consider the small technically based company's need to attract and motivate experienced managerial talent.

As we noted in the discussion of these small companies (Chapter III), they tend to go through a growth cycle where, in the early stages, technical know-how is the dominant skill required. Then, commercial products are developed from this know-how. Initially, the number of customers is very limited. Later, as markets grow, new requirements develop: how to manufacture and market products on a broader scale and how to control increasingly complex operations. This stage requires managerial talents that are more likely to be found in larger companies than in the small companies.

The problem, of course, is how to attract these men from the larger companies. Stock options in the small companies are, relatively speaking, substantially less desirable than they were, and less desirable than many large-company options. There are at least two reasons for this:

—First, the absence of a broadly based public market for the stock of many small, technologically based companies increases substantially the borrowing difficulties of the sought-after employee (the stock can be offered as security on loans), especially over a three-year period.

—Second, the employee of a large company can limit his downside risks, in the event the stock market declines, by selling his stock *immediately* should the stock fall below a given point. The very limited market for the stocks of many small companies makes the downside hazard of the stock option of such companies much greater than that of a large company.

For reasons we have already expressed, it is our belief that there would be a net, national gain in industrial innovation if these small technologically based companies could attract more skilled, *managerial* talent from the *larger* companies. Liberalized stock options for these small companies could be an important incentive.

RECOMMENDATION 2

We recommend a liberalization of the stock option rules for small technologically based companies by (1) extending the permissible option period from a maximum of five years to ten years, and (2) reducing the holding period required to receive capital gains treatment to less than three years, preferably to six months.

4. CRITERIA FOR R&D DEDUCTIBILITY

a. Casual Inventors and Innovators Judicial decisions under Section 174, relating to the allowance of a current deduction for research and development expenses, *disallow* such a deduction to "casual" inventors and innovators who are not engaged in a trade or business at the time the expenditure is incurred. We cite, for example, the following cases:

—T. R. Ewart, Tax court Memo (1966) (deduction disallowed to a public relations executive who sought to promote a novel candy-dispensing toy);

—John F. Koons, 35 T.C. 1092 (1961) (deduction disallowed to advertising executive for payments to develop an invention unrelated to his advertising business);

—Charles H. Schafer, P–H T.C. Memo P64, 156 (1964) (deduction denied lumber salesman on the ground that his invention did not constitute a separate going trade or business);

—William S. Scull II, P–H T.C. Memo P64, 224 (1964) (deduction denied president of instant coffee corporation on the ground that he was not personally engaged in the coffee business).

We recognize that appropriate safeguards are necessary to protect against deductions for "hobby" expenditures, and feel that such safeguards can be erected without denying a deduction to bona fide inventors and innovators who incur out-of-pocket expenses for the *purpose of ultimately producing income*. Among the safeguarding factors which, in various combinations, may tend to show bona fide inventive activity, are the filing of an application for patent; diligent prosecution of the application; the borrowing of capital to finance the inventive activity in question; a contingent fee arrangement with the inventor's attorney; efforts to license, assign or otherwise exploit the patent or prospective patent.

We are aware of the Treasury Department's reluctance to draw a more generous line between the "casual inventor" and the "inventor-businessman," and are also aware that it is not easy to differentiate between a hobbyist and an inventor who intends to go into business. But the answer to this difficulty is not to draw the line at the point where the inventor is already in business before these expenses can qualify as deductible expenses, for to do so is to fail to take adequately into account the realities of the innovative process, with its very uncertain initial stages. Accordingly, we make the following recommendation.

RECOMMENDATION 3

The Internal Revenue Code should be amended so that a casual inventor or innovator can deduct out-of-pocket expenses legitimately incurred for the purpose of ultimately producing income.

Also, we see cases where the inventor-entrepreneur was indeed seriously intent upon going into business by the fact that he is *now* in business. At the time he was doing his research and development, he may not have declared his costs as a deduction. We need only recall the great uncertainty in the first (the "idea") stage of our small company example (see Chapter III). This failure to declare deductions frequently happens because the inventor-entrepreneur is usually not a sophisticated person in the tax aspects of his work and does not get adequate counsel *until he has an established business*. Accordingly, we make the following proposal.

RECOMMENDATION 4

The successful inventor who has a going business but did not declare his earlier development costs should receive a "generous backward look" by the Internal Revenue Service and be permitted to reconstruct his development costs and write them off over a period of five years.

b. New Lines of Business In a recent case before the United States Tax Court,[6] the Commissioner of Internal Revenue unsuccessfully argued that Section 174, allowing a current deduction for research and development expenditures, is not available in the case of such expenditures incurred to develop new products unrelated to the taxpayer's current products. This contention has an obviously adverse impact on a business that seeks to develop a new product. Accordingly, we urge the Internal Revenue Service to issue a ruling that it will no longer make this contention in litigation.

The Internal Revenue Service has indicated it will review this case and consider whether it needs to clarify the treatment of R&D outlays directed toward launching a new product line. That such a position was ever taken in litigation is in itself evidence of a point of view that, at least occasionally, puts the innovation process on the defensive. Almost by definition, the more significant the innovation, the more likely it is to be a "new product line." Accordingly, we make the following recommendation.

[6] Best Universal Lock Co., Inc. *45 T.C. No. 1 (1965).*

RECOMMENDATION 5

Research and development expenditures incurred to develop new products or processes should not be disallowed as a business deduction merely because they are unrelated to a taxpayer company's current products or processes.

5. THE PROFESSIONAL INVENTOR

Under present law, an individual patent owner receiving compensation for the sale or use of his patent may be entitled to capital gains treatment under two separate but overlapping provisions of the Internal Revenue Code. If he is an *"amateur"* inventor, he may be entitled to capital gains treatment under the general provisions of the Law (Internal Revenue Code Section 1222). These provisions are applicable to capital transactions in general and not just to patents. He is an "amateur" if he is not holding the patent for sale to customers in the ordinary course of his business. If he is a "professional" inventor, however, he must look to Section 1235 of the Internal Revenue Code, which permits the capital gains treatment to an inventor if he transfers substantially all of his rights in the patent.

Under the Treasury Regulations,[7] the requirements to qualify under Section 1235 are more stringent than the requirements developed by some courts with respect to the general provisions of the Code.[8] Thus, under these general provisions, an amateur inventor may realize a capital gain on a grant of rights in a patent limited to a specific field of use (for example, the field of radio and television), while retaining the rights to other fields (for example, computers or telephone equipment). Or he may limit a patent license to a particular geographical area of a country (for example, the West Coast), while retaining all rights in the remainder of the country. But a professional inventor loses his capital gains advantage if he imposes either of these limitations in a license of his patent, for Section 1235, as interpreted, does not permit such limitations.

These more stringent requirements imposed under Section 1235 can operate as a disincentive to the diffusion of technology. Requiring a professional inventor who seeks to comply with Section 1235 to forego, in affect, all possible applications of his invention is, it seems to us, against the public interest. For there are inventions which have diverse applications, and in these instances no *single* licensee or purchaser may be able to pursue all of the invention's possibilities.

In effect, we ask the inventor to make a complete commitment to a given company or person who will presumably exploit the invention. Because it is a complete commitment, it is no surprise the inventor's asking price is high. It is high because (1) he realizes that this is "his only chance" to receive the capital gains treatment and (2) he tries at the outset to be assured of a substantial

[7] *Treas. Reg. Sec. 1.1235–2(b)(1)(1965); Treas. Reg. Sec. 1.1235–2(c)(1957).*

[8] *See, for example,* Dairy Queen, Inc. v Commissioner, *250 F.2d 503(10th Cir. 1957);* Thornton G. Graham, *26 T.C. 730(1956);* Gowdey v. Commissioner, *307 F.2d 816(4th Cir. 1962);* Molberg v. Commissioner, *305 F.2d 800 (5th Cir. 1962).*

minimum advance payment, for he is uncertain as to how aggressively a given company will exploit his patent. In other words, he negotiates a final contract in an early atmosphere of very imperfect knowledge as to whom he is dealing with and the extent to which the other party will tap the potential uses of his invention.

From the *company's* standpoint, the value of the patent is not clear, because it often does not know its value until further development work is pursued, practical production or engineering problems solved, and market explorations conducted.

Thus, at this early point of *maximum ignorance* on both sides of the negotiation, the inventor and the company must make a commitment for "all substantial rights," if the inventor is to receive capital gains treatment. Several panel members have had personal experience on both sides of this kind of negotiation and are convinced it substantially deters the process of getting patents translated into commercial products.

For this reason, we believe that the two provisions of the Code should be reconciled to permit qualification under Section 1235 in the case of a transfer of substantially all the rights in a patent limited to a particular field of use, or to a particular geographical area within a country. This would afford to the professional inventor the same capital gains advantage available under present law to the amateur inventor. We believe there is ample evidence that much effective invention is done by inventors who are prolific—i.e., professionals. If we want to encourage these individuals who, by any study of history, have contributed so much to the innovative status of this country, we feel a positive incentive is warranted.

RECOMMENDATION 6

Professional inventors should be placed on the same tax footing as amateur inventors by interpreting or amending Section 1235 of the Internal Revenue Code so that a patent license qualifies as a transfer of "substantially all rights," even though the grant is legally limited to a particular field-of-use or a particular geographical area.

We recommend that the Treasury first consider whether it would be feasible to accomplish this by amendment of its Regulations, without legislation. If this cannot be accomplished, we recommend that appropriate legislation be sought.

6. TAXABLE PURCHASES OF TECHNOLOGICAL ASSETS

The Treasury Regulations issued under Section 174 of the Internal Revenue Code draw a distinction between research and experimental expenditures incurred by a business in its development of an invention or innovation and the cost of acquiring another's invention or innovation. While expenditures incurred for internal development are deductible against *current* income, the cost of acquiring another's patent or process must be *capitalized.* (U. S. Treasury Regulations, Section 1.174–2(a)(1)).

In the case of any capitalized expenditure, a deduction for the cost is written off over the estimated useful life of the asset acquired, provided that its useful life is determinable with reasonable accuracy. For example, in the case of a secret formula, generally no deduction is allowable for its cost against the income earned therefrom, until such time as the process becomes completely worthless. This result is premised on the assumption that a secret process has an indefinite life, an assumption made doubtful in many cases by the rapid changes in modern technology. Moreover, the advantage of the current deduction for self-developed innovations over purchased innovations tends to discourage the acquisition by purchase rather than development, especially in light of uncertainty as to the proper write-off period, and this may operate to the disadvantage of the small innovator seeking to sell his innovation.

The Treasury Department's concern over any step that might tend to erode the principle of no tax write-offs for "good will" is understandable. Yet, the equally legitimate concern over the rate of technological diffusion suggests serious consideration be given to that portion of "good will" that can logically be attributed to technological assets. The ability to write off patents but not technology creates a distinction that is neither logical nor meaningful.

We do not propose that a general assault be made on the "good will" principle. Rather, we seek to encourage the spread of innovation by permitting the depreciation of purchased technological assets in certain limited cases. Accordingly, we make the following recommendation.

RECOMMENDATION 7

Companies making taxable purchases of technological assets should be permitted some depreciation and tax write-off of these assets in excess of the value of tangible assets.

Such treatment could be limited in the following ways:

(1) Only taxable purchases (for example, in cash) would qualify; tax-free acquisitions in exchange for stock would not be entitled to such treatment.

(2) Purchasers would be required to distinguish the technological components of the intangible assets—e.g., know-how—from "good will" elements, such as trade names and marks.

(3) To remove some of the ambiguity, the purchaser of such qualifying technological assets could be assured that he could write off a certain minimum portion (say, 50%) of the excess of the purchase price over the value of the tangible assets (including cash and accounts receivable).

(4) The burden of proof would be on the purchaser to validate the values of technological assets above the level of tangible assets—for example, by estimating costs of duplicating know-how, if the company had developed it internally.

(5) Such values of technological assets could be written off over an interval of 17 years, which corresponds to the period over which the cost of an acquired patent can be amortized.

To further narrow the scope of the above recommendation, it may be desired to limit its applicability to purchases *from* individuals or companies that qualify as "small technologically based companies."[9] It should be noted, however, that the illogicality of retaining the tax distinction between internally developed technological assets and those externally acquired is not dissipated where the seller is a *large* company. The distinction is illogical and improper irrespective of the size and wherewithal of the seller.

7. A FINAL WORD ABOUT TAXES

Considerable effort and time will be required to review and act on the tax recommendations discussed here. *In the meantime,* while these tax recommendations are being considered, we urge an intensive effort:

(1) To acquaint responsible employees of such agencies as the Internal Revenue Service, the Small Business Administration, and the Department of Commerce with the importance and unique problems of small technological enterprises; and

(2) To apprise such firms of the *existing* governmental aids and incentives directed to them. There is good reason to believe that important, *existing* tax incentives are having far less than their maximum potential impact on the encouragement of innovation in this country.

B. THE FINANCING OF INNOVATION

We turn now to the role of venture capital in the innovation process, its sources, some rough estimates as to the amount potentially available, and its significance with respect to the creation of jobs. We could summarize this subject by saying we have found an abundance of ignorance—in government, in business, and in the universities—on what the venture capital business is about. It should be apparent by now that the lack of knowledge, understanding and appreciation of the innovative process is the central theme of our report.

1. THE AVAILABILITY OF VENTURE CAPITAL

Quantitative information on the availability of venture capital is not readily obtained. We were unable to find any published data to support the widely stated notion that there is a lack of adequate *potential* venture capital in this country. Accordingly, we tried to develop our own rough estimates of potentially available venture capital through discussions with experienced individuals in the business and financial communities. Extensive conversations

[9] *See Page 33.*

were had with a number of Small Business Investment Companies (SBIC's), investment trust firms, wealthy individuals, and investment bankers engaged in organized venture capital investment activities. We heard testimony from a number of successful entrepreneurs and individual inventors who depend upon securing venture capital in their present business operations.

On the basis of these discussions we have made some rough estimates of the amounts of potentially available venture capital from various sources. Our estimates indicate that more than $3 billion of potentially available capital exists in this country. This by no means indicates that all of the holders of such capital are actively seeking investment opportunities or that the techniques and communication mechanisms for approaching capital sources are necessarily known to individuals with worthwhile projects requiring financial support. The potential availability of such an amount of money, however, indicates that factors other than money alone determine the rate of new-enterprise funding.

Let us discuss, for a moment, some of the sources of venture capital in the United States.

a. Personal Wealth—This country now has over 65,000 individuals each with a net worth in excess of $1,000,000. In addition, there are a large number of family fortunes which, in the aggregate, exceed several billions of dollars. We have also identified as a separate category, successful entrepreneurs who have prior experience in the field, and are in a position to assume the role of venture capitalists. For example, some twenty experienced and successful technical entrepreneurs in the Boston Route 128 complex alone, currently have a total *personal* net worth in excess of $500,000,000.

b. Insurance Companies, Investment Funds, Trusts—A number of less conservative insurance companies are engaged in financing speculative ventures—at least the "Second Stage" businesses we identified in our discussion of the small company environment (See Chapter III). In addition, publicly owned investment funds, such as American Research and Development, and organized, family-owned venture capital operations, represent a sizeable source of venture capital. These organizations have a high degree of sophistication and appraisal experience with respect to technological opportunities.

c. Corporate Sources—Within the past few years a number of large corporations have entered the venture capital business and have initiated the financing of new technological ventures. Although it is too early to appraise the impact of this development, the potential capital availability is obviously large. An important factor with respect to corporate sources of funds is that they may also provide knowledge of markets, management skills, and other aids that are, as we saw, essential to the success of a beginning firm. On the other hand, conflicts of interest and the frequent lack of knowledge on the part of the large corporation of the unique problems of small companies may present major difficulties.

d. Investment Bankers and Underwriters—The investing public becomes, through underwriters, a source of venture capital. For example, we found that in 1961 it was common to finance a wide variety of highly speculative electronic ventures through this public source of financing. Increased public interest in such schemes occurs from time to time, depending upon investment

attitudes. A large number of investment banking groups also operate in the venture capital field.

e. Small Business Investment Companies—Although less than 10% of the total amount of available SBIC capital is currently invested in technologically oriented businesses, the SBIC as an institution has undoubtedly created interest in the venture capital business, and some $500,000,000 is *potentially* available from this source.[10] Because of its relatively small size, however, the typical SBIC has had difficulty in developing a competent staff to tackle the formidable project appraisal problem and in carrying the necessary overhead to administer a complicated portfolio of new technical enterprise investments. It is doubtful, in our view, that an SBIC can be successful in a diversified program of financing technologically oriented ventures, if its size is less than 15 to 20 million dollars. Only a few SBIC's are currently of this size. Much can be learned from the developing experience of these few.

It is important to re-emphasize the project-appraisal problem which faces all sources of venture capital. Entrepreneurship is at best a risky business. Markets are rapidly changing, and the success of any venture is closely coupled to management ability. Capital requirements for new businesses are almost always in excess of initial estimates. The time required, particularly today, to reach the stage of profitability is usually several years longer than originally anticipated.

The more experienced and sophisticated venture capital sources compete with each other for the most attractive investment opportunities. Their decisions to invest are keyed to their judgments of the quality of the management, the quality and proprietary character of the product, and the timing with respect to the market. Experience shows that investments fail, primarily, because of *management* problems—the inadequacy of the key individual as a manager of people, or his lack of sensitivity to external conditions, which prevents him from developing a realistic time schedule for achieving goals with available capital.

In view of the above considerations, and our feeling that the alleged absence of potentially available venture capital is not really the problem, we see no basis for the establishment of any new federally supported programs for the furnishing of venture capital. Accordingly, we make the following recommendation.

RECOMMENDATION 8

In view of present information on the availability of venture capital, the Federal Government should take no action with respect to the establishment of new federally supported programs for the furnishing of venture capital. However, appropriate mechanisms should be developed to provide information on capital availability and the problems of new enterprise development at the regional level.

[10] *It is interesting to note that some 40% of the SBIC's (on a dollar basis) are located in three states, which already have large, well-organized and long-established venture capital sources.*

2. VENTURE CAPITAL AND JOBS

A recent study conducted by the Sloan School of Management at the Massachusetts Institute of Technology, examined the job-creating power of venture capital. We have tabulated the data developed in that study in the following chart.

CHART 19

VENTURE CAPITAL DOLLARS PER JOB: AN ILLUSTRATION

No. of Companies	21
Average Time Period	4.2 Years
Increase in Sales - Average	$ 3,657,000
Increase in Sales - Total	$76,806,000
Increase in Employment - Average	147
Increase in Employment - Total	3,096
Initial Venture Capital - Average	$ 225,000
Initial Venture Capital - Total	$ 4,720,000
Initial Venture Capital Requirement	$ 1,525 Per Job

This does not take into account the additional, derivative employment resulting from these primary jobs.

Source: Sloan School, Massachusetts Institute of Technology.

There were twenty-one companies in the survey. All were private, technological ventures. In an average period of a little over four years, the average increase in sales for these companies was approximately $3½ million; the total increase in sales was roughly $75 million. The average increase in employment over that period was 147 jobs; the total increase for all of the companies was 3,096 jobs. The average venture capital investment in these companies was $225,000, the total venture capital investment having been almost $5 million.

We note from the above data that roughly $1500 of venture-capital investment resulted in one primary job. We realize that there may be objections with respect to the adequacy of these data—for example, the sample was limited to the Boston area. Nevertheless, despite the deficiencies that purists may find in these data, they do illustrate the significant contribution of technological ventures to employment. For whether the amount of venture capital per job was $1500 or $2500 or, indeed, $3500 (which allows for a substantial margin of error), this still represents a very powerful job-creating capacity per risk-dollar utilized. Moreover, it should be understood that the data in Chart

19 concern primary employment only and do not account for the much greater secondary employment (in the food and service industries, etc.) that usually builds on the primary job base.

C. SOME ASPECTS OF FEDERAL RESPONSIBILITY

There are several areas in which the government bears a special responsibility with respect to various aspects of technological innovation, but in which, through action or inaction, this responsibility is being either ignored or frustrated. Perhaps this is because the areas in question are relatively less important than other, more noteworthy fields, such as antitrust and taxation. We considered three areas which have been neglected: studies of the innovation process, the adverse impact of government contracting on small technologically based firms, and the absence of an effective federal spokesman for such firms.

1. STUDIES OF THE INNOVATION PROCESS

This nation spends tens of billions of dollars every year on innovation—twenty billion on the research and development component of innovation alone. Yet we know very little about the processes of technological change and growth. As we have noted time and again throughout our analysis, insufficient effort is being devoted to the development and expansion of our knowledge of these processes. Until adequate data and better insights are developed, we will have to continue to rely on inappropriate information, educated guesses and, unwittingly at times, on lore. It is inexcusable that decisions, both in and out of government, as to the probable impact of proposed policy changes on technological innovation, have to be made on the basis of such information.

Additional research on the processes of technological change is therefore badly needed. The initial studies being worked on in the Commerce Department's National Bureau of Standards, should be expanded and made more comprehensive. These studies, concerning the processes of invention and innovation and the social, economic and legal forces with which they interact, should be undertaken in close cooperation with the universities, industry, and other students of the subject.

Accordingly, we make the following recommendation.

RECOMMENDATION 9

The Department of Commerce should broaden and complement its studies of the innovative and entrepreneurial processes by initiating an integrated program, in cooperation with the universities, including the preparation of empirical data and case materials on these processes, studies of the venture capital system, and experimentation with teaching methods to develop innovative and entrepreneurial talents.

2. GOVERNMENT CONTRACTING AND THE SMALL FIRM

In the past, government contracts have been one of the most important sources of business for the initiation of new technologically based enterprises. Nevertheless, the small business "set-aside" program, which purports to set aside contracting opportunities for small businesses, does not provide them with any real hope for success in the highly competitive research and development business associated with today's defense and space programs. It should be noted, also, that the total percentage of Federal work performed by small companies has decreased in the last five years.

Current Department of Defense (DOD) and National Aeronautics and Space Administration (NASA) contracting trends, the rapidly increasing costs of doing R&D, and the increased critical size required for a successful business operation, all work against the interests of small technologically oriented ventures. In addition, increasing competition from in-house government laboratories and "nonprofit" firms that are DOD and NASA captives, and the greatly increased costs of preparing proposals for government R&D contracts and of private representation in Washington, have all substantially reduced the prospects for success by the small company.

The large technologically based company (which, as we have noted, probably had small beginnings itself) can bid a fixed price under the current fixed-price R&D contracting procedures that may clearly be a losing proposition—in the short term. In the long term, however, the bid may be a winner in terms of lodgement in the technological field involved. For example, assume a large company bids $300,000 below the estimated cost of a contract. Generally, a small firm cannot compete in this way. If it loses $300,000, it has probably committed suicide; it is out of business. As Professor Corwin Edwards of the University of Oregon expresses the problem, a large economically powerful firm ". . . can outbid, outspend, and *outlose* a small firm. . . . If it overdoes its expenditures, it can absorb losses that would bankrupt a small rival." [11]

As an important first step in bringing these problems to the attention of government contracting agencies, we make the following recommendation.

RECOMMENDATION 10

An interdepartmental ad hoc review of current contracting policies and procedures of such agencies as the Department of Defense, the National Aeronautics and Space Administration, the Atomic Energy Commission, and the National Institutes of Health, to ensure that these policies are conducive to the long-range growth of small enterprises.

[11] *Testimony in hearings on Economic Concentration before U.S. Senate Antitrust Subcommittee, 88th Cong., Part I* Overall and Conglomerate Aspects *(Government Printing Office, 1964), p. 42.*

3. A FEDERAL SPOKESMAN

The above recommendation can at best be only a palliative. For it does not go to the heart of the problem. It merely treats one of the symptoms. The basic problem is that the small technologically based companies, despite all they have contributed to American progress, really have no effective representation in Washington.

There is *no Federal spokesman* for them. Within the Federal Government there is no single place which is specifically concerned with the generation of new technological enterprises and the problems of these unique organizations.

The Small Business Administration cannot deal effectively with these inherently *high-risk* enterprises because its enabling statute prevents it from doing so. In any event, there is very little understanding in the SBA or elsewhere in the government (indeed, as we have noted, in society at large) of the special problems and needs of these businesses. We therefore make the following recommendation.

RECOMMENDATION 11

The Department of Commerce should serve as the Federal spokesman representing the interests of new technologically based enterprises and should develop the necessary competence and organization to deal effectively with problems associated with venture capital availability and the generation of such enterprises.

This recommendation is closely related to the program of studies proposed in Recommendation 9. For only through greater understanding of the processes of invention and innovation will the Department of Commerce be able to perform the role we urge.

D. ANTITRUST AND THE REGULATION OF INDUSTRY

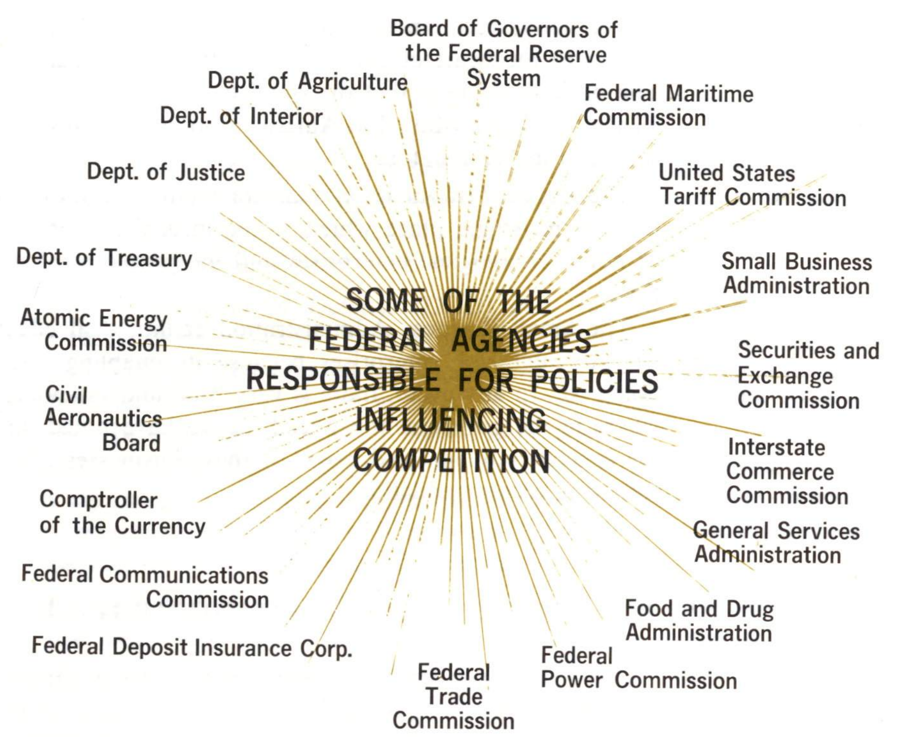
It is probably fair to say that most well-informed individuals, who are not directly concerned with the fields of antitrust and regulation, are unaware of the numerous Federal agencies that are active in these fields.[12]

Chart 20 is a partial tabulation, not intended to be comprehensive, which illustrates the magnitude of the government's involvement in what we loosely call a "free enterprise economy." Of course, our economic system is not literally free; it is much too complex for that.[13]

[12] *An excellent discussion of government activities in these fields appears in Massel,* Competition and Monopoly, *Brookings Institution, 1962.*

[13] *See Appendix B for some of the relevant statutory provisions affecting competition in the American economy.*

CHART 20



The purpose of this chapter is to examine an important facet of this complex system. What we hope to do is clarify some of the issues concerning the interfaces between competition, antitrust, regulation and technological innovation.

1. THE NEED FOR CLARIFICATION

The necessity for our examination is perhaps obvious: Our central concern is innovation and its stimulus and promotion. Such promotion requires appropriate attention and adjustment to *other* public policies—among them, antitrust and regulatory policies, which we lump, for convenience, into what we call "competitive policy." Hence, it becomes necessary to examine the interrelationship between innovation and competition, understand their interaction, lay bare the apparent or hidden conflicts between them, and suggest means for resolving or minimizing these conflicts.

We subscribe to both of the public policies involved here: (1) the preservation of a satisfactorily balanced, competitive enterprise system, and (2) the promotion of invention and innovation. The former is reflected in our laws on restraint of trade, monopolization, regulation and unfair methods of competition. The latter includes both technological and commercial activities, and both private and governmental actions.

Sometimes, a given practice furthers both of these objectives. Sometimes it does not. If it does, problems of concern to us are unlikely to arise. Practices that promote both competitive and innovative objectives or that promote one and are neutral as to the other, are acceptable in terms of our mission. Practices that impede both or impede one without promoting the other, are unacceptable. A practice that promotes one of the objectives and impedes the other, however, is another matter. In this event, we must try to find an accommodation that minimizes the conflict between the two, and decide which objective shall prevail in those circumstances where the conflict cannot be resolved or reduced.

Past judicial, legislative or administrative efforts to resolve this conflict disclose no clear-cut, uniform pattern. *Nor do we have satisfactory empirical analyses of actual situations to serve as the basis for such resolution.* Sometimes, competitive objectives seem to be the dominant concern in the consideration of competitive problems; sometimes, innovative objectives prevail. Often, the objective fastened upon is pursued without apparent concern for the possible adverse effects upon other objectives.

Neither objective can safely be disregarded in our present social, economic and political circumstances. The support and furtherance of *both* are too important in terms of public interest for either to be heedlessly pushed aside in the interests of promoting the other. Fortunately, only minimal conflicts seem likely to arise in the areas under discussion, since it appears that *on the whole, a well-balanced and healthful, competitive economy stimulates, rather than frustrates, innovation.*

Let us turn now to an examination of those areas in which *conflicts* are most likely to arise—since it is conflict, not complementary action, that poses the problems we are concerned about.

2. AREAS OF POSSIBLE CONFLICT

The thrust of the antitrust laws is against (1) commercial or industrial combinations which prevent or limit the competition upon which our free enterprise system depends, (2) the creation of monopolies that destroy or impede such competition, and (3) unfair competitive and business practices that hinder competition and contribute to monopoly. Our concern, therefore, is directed to those structural characteristics of the innovative process and specific practices involving innovation that may result in monopoly, restraint of trade, or unfair trade practices of the kind mentioned.[14]

Technological innovation may be undertaken by (1) individuals or other single entities, or (2) two or more entities (of an industrial, governmental, educational or other nature) acting cooperatively. Neither of these ordinarily need give us concern, *as such,* in dealing with the competitive-innovative relationship.

The conduct of innovation by individual, independent entities is not only

[14] *See Appendix C for some hypothetical situations that illustrate possible conflicts between Federal policies on competition and various practices involving innovation.*

condoned, but affirmatively encouraged in the public interest. Such activity poses no antitrust problem in the restraint-of-trade sense. Monopoly problems can arise, but they rarely do. Even if they do, both judicial and statutory law tend to accept this in the interests of encouraging individual effort. The policy seems to have worked reasonably well.

Similarly, there is no problem with respect to cooperative innovative activities, *as such*. The attack upon a given problem by two or more minds, instead of one, or through two or more sets of resources (know-how, assets, managerial skills, equipment, and the like) instead of one, seems as likely in most instances to produce beneficial results in this as it does in other fields of cooperative endeavor. The same is generally true of cooperation in removing legal and other impediments to innovation through the licensing of patents, the release of secret processes and know-how, and other transfers of technological property.

Restrictive agreements involving the use or non-use of technological property are more of a problem. Here, conflicts between our innovative and competitive goals do arise. Such agreements may restrain trade, create monopolies or otherwise distort the competitive balance.

These restrictive agreements may take various forms:

—Parties may agree not to compete with each other or with third parties. They may do this directly by means of patent licenses and other agreements containing price, geographic, field-of-use or other restrictions, or indirectly by royalty arrangements that impede or discourage competition.

—They may boycott or otherwise injure third persons, or obstruct channels of distribution, and at the same time adversely affect innovation by means of closed pools, tie-in arrangements, discriminatory conditions as between different licensees, and so on.

—They may lessen the incentive to engage in competitive innovation by imposing limitations upon the use of new technology developed or acquired by the licensee or upon methods of distribution.

—They may cause competitive imbalance through excessive acquisition of technological property by purchase, merger or grant-back.

Arrangements such as those we have noted above may be quite ambivalent from the standpoint of both innovation and competition. They may stimulate innovation or they may retard it. They may strengthen competition or weaken it. It may be extraordinarily difficult, in short, to reach firm conclusions as to the extent to which a given practice promotes or retards innovation, on the one hand, and competition on the other.

It may be even more difficult to assess the *relative* merits or demerits of such arrangements in terms of the respective objectives, or to determine where, on balance, the public interest lies. In the formulation of policy, the difficulties in defining and measuring the nature and extent of benefit or detriment in terms of innovative and competitive effects are compounded when one attempts to balance the one against the other. This is so whether the policy in question is determined at the legislative, administrative or judicial level.[15]

Beyond this, in the vast area of *private* action and policy making—where the businesman, the entrepreneur, the inventor and the innovator operate—decision and conduct, and the effect thereof, may be even less well defined and more haphazard. Here, it not only becomes increasingly difficult for the decision-makers to evaluate and properly balance the effects flowing from their conduct and the public policy considerations involved, but they may also be influenced by *mistaken notions* of what the law permits and what it prohibits.[16]

In terms of influencing their conduct, it is not what the law really is that matters. It is what the decision-makers *think* it is.

We want to emphasize that what we are saying is not limited to *technological* innovation. The problems go deeper, and so must our inquiry into them. Innovation occurs in finance, marketing, methods of distribution, business structure, business administration, labor relations—indeed, in virtually every area of activity that the processes of business touch upon.

In methods of distribution, for example, it may show up in brand selling, introduction of new products, price discounts, offer of side inducements and collateral attractions, advertising, dealer relationships and development, service and advisory activities, extension of credit, and so on. Here, as in technological innovation, the activities may run afoul of the antitrust laws, including the Robinson-Patman Act. They may also come into conflict with other trade regulation laws, such as fair trade laws, trademark laws, labeling laws, the Shipping Act, the Food, Drug and Cosmetic Act. These interrelationships have been a part of our inquiry.

The problems, described generally in the foregoing discussion, may be summarized as follows:

(1) Long-standing and settled public policy supports and demands the promotion of competitive objectives.
(2) Public policy also supports and demands the promotion of innovation.
(3) These two public policies, while usually compatible, may at times comes into conflict with each other.
(4) It is often difficult to detect, define and evaluate these conflicts. We have not, on the whole, developed satisfactory procedures for achieving an understanding of their relationship and their accommodation to each other. This is true at all levels of decision and policy-making: private, legislative, administrative and judicial.

3. RESOLUTION OF CONFLICTS

Our investigation has helped us to see what some of the problems are. It has not enlightened us on how to solve them. We must promote *both* com-

[15] *See, for example, a current study by the Office of Invention and Innovation, National Bureau of Standards, entitled* Judicial Consideration of Technological Factors in Antitrust Actions. *The study will be published in early 1967.*

[16] *For a lucid discussion, aimed at providing a better understanding of the field of antitrust to business executives and others who are not expert in the field, see Kintner,* An Antitrust Primer, *MacMillan, 1964.*

petition and innovation to the extent that this can be done, by minimizing or eliminating the conflicts to the extent possible. Where this cannot be done, we must decide under what circumstances the one or the other shall prevail.

The formulation of procedures in this area poses a dilemma: The desirability, and hence the ultimate legality, of a given restriction may turn upon the nature of the transaction, its subject matter and the economic and technological status of the parties affected. This suggests a case-by-case, *rule-of-reason* approach, guided by the sometimes conflicting objectives of promoting innovation and of preserving a satisfactory competitive structure. At the same time, it is important to formulate relatively *certain* rules in order to tell businessmen what they can and cannot do and to preserve the effectiveness and administrability of the antitrust and related laws. This suggests the development of *per se* doctrines, trade regulation rules, and the like.

We cannot have it both ways. It may, however, be possible to resolve the dilemma, partially at least, by two means. First, by defining those circumstances and practices that push so *predominantly* toward a given result as to justify a conclusion that they should be deemed, at least presumptively, permissible or prohibited. Second, by suggesting criteria and procedures (within existing procedural frameworks, to the extent possible) for resolving the more uncertain and debatable issues in a manner that promotes the public interest and is reasonably satisfactory to the affected parties.

The achievement of these goals will be no easy task. In few, if any, of the gray areas under discussion does our present knowledge and understanding provide a basis for firm answers. *To suggest significant judgmentive changes of policy in the absence of the empirical data and analysis needed to support such changes, would therefore be irresponsible.*

RECOMMENDATION 12

We recommend, at this time, no legislative changes in the antitrust and regulatory laws. However, we do recommend that in the interpretation and administration of these laws, the effect on innovation, as well as on competition, be taken into account.

4. AN ANALYTICAL AND ADVISORY RESOURCE FOR THE ANTITRUST AND REGULATORY AGENCIES

We need empirical data. How are we to get them? How are we then to arrive at sound interpretations of the facts? While there can be no assurances of certain success, we suggest certain premises and considerations for the satisfactory performance of these tasks:

(1) To avoid unnecessary injury to either competition or innovation, those responsible for making and carrying out policy in these fields must have access to information concerning the effect of their policies upon both competition and innovation, and should be in a position to evaluate such information in order to achieve a proper balance and coordination between these policies. In today's fast-evolving economy, both the necessary information and the means for evaluating it are often seriously lacking.

(2) While the ultimate formulation of specific "black-and-white" rules or guidelines for determining the legality or illegality of given practice seems desirable, this cannot be done, except in a few small areas, until more extensive studies have been made of the many ramifications of the relationships between competition and innovation.

(3) Antitrust, regulation and innovation have all demanded increasing attention in recent years. As a result, agencies operating in all three areas have proliferated. Inevitably, conflict and lack of mutual assistance among them have resulted. This condition is a matter of concern to many, including the agencies themselves. Unfortunately, the independent and separate status of those affected has made it difficult to resolve or lessen this conflict. Moreover, the formulation of the rules and guides referred to in the preceding paragraph becomes the most difficult at the very time that their need becomes the greatest.

In these circumstances, we believe that the ultimate development of such rules and guides, as well as the day-to-day administration of policies concerning competition and innovation, would be furthered if a group existed, *independent of the agencies charged with the administration and enforcement* of the antitrust and regulatory laws, to whom these agencies could turn for expert and unbiased advice and assistance. The creation of such a group, we emphasize, is a response to recognized needs for coordination and mutual accommodation. It does not infer any unreasonableness or known remediable deficiencies in existing policies and administration.

Hence, the function of such a group would be to offer advice and assistance rather than exercise authority of any sort over its "clients." It should be a continuing staff, designed to service the administering agencies and the policymakers by conducting studies and providing information, data, and suggestions for modifying policy and procedure.

Greater understanding and judgment should also accrue to the affected public, thus lessening the likelihood of conduct based upon misunderstanding and misinformation. The group could, for example, provide information, analysis and advice concerning the competitive and innovative aspects of various types of joint R&D programs, foreign trade and technology transactions, patent pools, mergers and acquisitions, restrictive or limited licenses relating to patents or know-how, government policies in awarding and framing R&D contracts, and so on.

Such a group should operate subject to the following conditions:

—It should concentrate on empirical analyses.

—It should be an advisory rather than a supervisory unit, maintaining continuous communication with the pertinent agencies and departments and with the Congress.

—Since the conditions to which it addresses itself are dynamic, not static, and also massive and complex, it should be a permanent entity.

—It should give appropriate attention to the need for clarity and administrability and to the importance of accommodation, insofar as possible, to existing procedures and structures of authority.

—Although its responsibilities should be primarily to the appropriate governmental agencies, its operations should be conducted with full attention to the need for informing and generally advising interested parties and the public, as well.

With these considerations in mind, we urge that such a group be formed.

RECOMMENDATION 13

A group should be established within the Federal Government to aid and advise the regulatory and antitrust agencies by performing such activities as:

(1) Developing criteria for helping these agencies judge the impact of antitrust and regulatory policies on invention and innovation.

(2) Systematically analyzing the consequences of past antitrust and regulatory activities in light of these criteria.

(3) Advising the responsible agencies on the probable consequences of proposed policy changes affecting invention and innovation.

(4) Providing technological forecasts as an additional factor for antitrust and regulatory planners to weigh in their policy formulations.

We would be remiss if we did not point out that we had much difficulty on the question of where this group should be located in the Federal Government. We have already explained that the objectivity it must rigorously pursue requires that it not be a part of any of the agencies responsible for *administering and enforcing* the antitrust and regulatory laws.

If we consider again the large number of independent agencies affecting competition (See Chart 20), it is not difficult to understand the need for some *central* location of the group we propose. The issues with which it would deal stretch from one end of Washington to the other. The most logical housing for such a group would therefore be in the Executive Office of the President, but we are aware of the reluctance to add "appendages" to that Office.

In any event, we have chosen *not* to make any specific recommendation as to the location of the proposed group. We would only urge that its initial structure and operation be kept as *flexible* as possible in order to permit experimentation and adjustment in the light of experience.

Pending the establishment of the central group we urge be formed, we believe that much could be done in the legislative, executive and judicial branches to broaden understanding of the problems under discussion. In particular, we make the following recommendations.

RECOMMENDATION 14

To enable the antitrust and regulatory agencies to give greater attention to questions concerning technological innovation, their staffs should be strengthened by increasing the number of personnel who have a deep understanding of economic and technological development.

RECOMMENDATION 15

In the legislative and judicial processes involving antitrust and regulation, more consideration should be given to the interaction of technological change and competition.

We should note in this regard the continuing efforts of the Senate Antitrust and Monopoly Subcommittee to explore the interrelationships between competition, invention and innovation. We have referred to their work elsewhere in this report.

RECOMMENDATION 16

(a) The antitrust and regulatory agencies should provide guidelines clarifying the legality or illegality of business conduct affecting competition and technological innovation.

(b) The agencies should also devote more attention to the effect of remedies, orders, and decrees on innovation in relation to competition.

During the past year, the Antitrust Division of the Department of Justice, with whom we have had a very rewarding relationship, has been developing guidelines to help clear away some of the inevitable uncertainties that emerge as antitrust policies evolve. We are hopeful that these guidelines will help resolve some of the issues we have discussed in our analysis of the policies affecting competition *and* innovation.

VI

CONCLUSIONS AND OVER-ALL RECOMMENDATION

One môre recommendation remains and it is, in our view, of key importance. We have stressed the reason for it throughout this report. It has to do with the abundance of ignorance about the processes of invention, innovation and entrepreneurship.

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.

We therefore propose a high-level conference on technological innovation, to dramatize the importance of this vital process, and urge that this conference be followed by a nationwide program for broadening recognition, understanding and appreciation of the problems and opportunities associated with technological change.

RECOMMENDATION 17

(a) A White House conference on "Understanding and Improving the Environment for Technological Innovation."

(b) Soon thereafter, a series of regional innovation conferences, composed of governors, mayors, bankers, academicians, scientists, engineers, entrepreneurs, and others—aimed at removing barriers to the development of new technological enterprises, jobs, and community prosperity in the respective regions.

Summing up, we find that the concepts, uncertainties, and other realities of technological innovation are like a foreign language, indeed a strange world, to too many of us. Because of this, we believe the most important initial task before us is to become more widely acquainted with the "language" and "world" of innovation.

Understanding, as Alexander Pope might have put it, is the key to a drawer wherein lie other keys. When we come to appreciate and understand the problems and the opportunities associated with innovation, we can more effectively act on programs that will best encourage beneficial change and the continued renewal of our society.

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Appendix A

PANEL MEMBERS AND THEIR ASSOCIATES

The Panel

Lawrence S. Apsey is General Counsel, Celanese Corporation of America.

Robert A. Charpie (*Chairman*) is President, Electronics Division, Union Carbide Corporation.

John F. Costelloe is an attorney and member of the firm of Chadbourne, Parke, Whiteside and Wolff.

Daniel V. De Simone (*Executive Secretary*) is Director of the Office of Invention and Innovation in the National Bureau of Standards.

John F. Dessauer is Executive Vice President for Research and Engineering, Xerox Corporation.

John McK. Fisher is a consultant, Schenley Industries, Inc.

Aaron J. Gellman is Vice President, North American Car Corporation.

Peter G. Goldmark is President, CBS Laboratories.

Earl W. Kintner, former Chairman of the Federal Trade Commission, is a member of the firm of Arent, Fox, Kintner, Plotkin and Kahn.

Mark S. Massel is a member of the Senior Staff, Brookings Institution.

Richard S. Morse is a senior lecturer, Sloan School of Management, Massachusetts Institute of Technology, and former Assistant Secretary of the Army for Research and Development.

Peter G. Peterson is President, Bell and Howell Company.

Sidney I. Roberts is an attorney and member of the firm of Roberts and Holland.

Dan Throop Smith is Professor of Finance, Graduate School of Business Administration, Harvard University.

John C. Stedman is Professor of Law, University of Wisconsin School of Law.

William R. Woodward is General Patent Attorney, Western Electric Company.

Government Liaison With the Panel

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Appendix B

MAJOR FEDERAL POLICIES THAT REGULATE COMPETITIVE ACTIVITIES AND PRACTICES

Name of Agency	Nature and Scope of Regulation	Statute
A. *General Provisions* (NOT LIMITED TO A SPECIFIC AGENCY)	Declares unlawful (1) contracts, combinations, and conspiracies in restraint of trade, and (2) the monopolization or attempt to monopolize trade.	Sherman Act, 26 Stat. 209; 15 U.S.C. 1–7; Public Law No. 190, 51st Cong. (1890).
	Declares unlawful, price discrimination, exclusive dealing arrangements, and mergers and acquisitions by corporations that may lessen competition or tend to create a monopoly. It also places restrictions on interlocking directorates among banks and among corporations.	Clayton Act, 38 Stat. 730; 15 U.S.C. 12ff.; P.L. 212, 63rd Cong. (1914).
	Declares unlawful, any contracts, combinations and conspiracies by persons or corporations engaged in importing articles from a foreign country into the U.S. which restrain trade or are intended to increase the price of articles imported into the U.S.	Wilson Tariff Act, 28 Stat. 570; 150 U.S.C. 8–11; P.L. 227, 53rd Cong. (1894).
	Declares unlawful, the importation and sale, by persons engaged in importing articles from a foreign country into the U.S., of articles within the U.S. at a price substantially less than the actual market value or wholesale price of such articles in the principle markets of the country of their production, or other foreign countries where they are exported, after allowance for freight, duty, and similar expense.	Revenue Act, 1916, 39 Stat. 798; 15 U.S.C. 71–77; P.L. 271, 64th Cong. (1916).
	Declares unlawful, the disclosure of the amount or terms of a bid, or any combination or agreement that would deprive the U.S. of the benefit of full, free and secret competition in the awarding of a contract or charter under the Merchant Marine Act of 1936. It declares unlawful any agreement or concerted action by any contractor or charterer of vessels under the Act which is unjustly discriminatory or unfair to any citizen who operates a common carrier by water.	Merchant Marine Act, 1936; 49 Stat. 2014; 46 U.S.C. 1224, 1227 and 1228; P.L. 835, 74th Cong.

Name of Agency	Nature and Scope of Regulation	Statute
	Prohibits any vessel engaged in foreign trade of the U.S. from entering or passing through the Panama Canal if such vessel is owned, chartered, operated or controlled by a person or corporation doing business in violation of the antitrust laws.	Panama Canal Act, 37 Stat. 567; 15 U.S.C. 31; P.L. 337; 62nd Cong.
	Prohibits contracting with any person who has entered or proposed to enter into a combination to fix the price of bids, or to induce others not to bid, for postal supply contracts.	62 Stat. 704; 18 U.S.C. 441 (1948).
B. *Supplemental Enforcement of the Antitrust Laws*		
Federal Trade Commission	Created the Federal Trade Commission (FTC) and declared unfair methods of competition and unfair or deceptive acts or practices in commerce unlawful, including the dissemination of false advertisement. The FTC was also given the power to investigate and require annual reports providing information on organization, business conduct and practices.	Federal Trade Commission Act, 38 Stat. 717; 15 U.S.C. 41ff; P.L. 203; 62nd Cong. (1914).
Federal Trade Commission	Declares the manufacture fcr sale and sale of any wool product, which is misbranded, unlawful and a violation of the Federal Trade Commission Act (FTCA).	Wool Products Labeling Act of 1939, 54 Stat. 1129; 15 U.S.C. 68a; P.L. 850; 76th Cong. (1940).
Federal Trade Commission	Declares the manufacture for sale, sale, or advertising of any fur product, which is misbranded or falsely or deceptively advertised or invoiced, unlawful and a violation of the FTCA.	Fur Products Labeling Act, 65 Stat. 175; P.L. 110; 82nd Cong. (1951).
Federal Trade Commission	Declares the manufacture for sale, sale, importation into the U.S., or transportation in commerce of any article of wearing apparel which is defined under the Act as highly inflammable, as to be dangerous when worn by individuals, unlawful and a violation of the FTCA.	Flammable Fabrics Act, 67 Stat. 111; 15 U.S.C. 1191–1200; P.L. 88, 83rd Cong. (1953).
Federal Trade Commission	Declares the manufacture for sale, sale, advertising, transportation in commerce, or importation into the U.S. of any textile fiber product, which is misbranded or false or deceptively advertised, unlawful and a violation of the FTCA.	Textile Fiber Products Identification Act, 72 Stat. 1718; 15 U.S.C. 70a; P.L. 85–897 (1958).

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Name of Agency	Nature and Scope of Regulation	Statute
Federal Trade Commission	Amended Section 2 of the Clayton Act. In addition, it forbids the payment of a broker's commission in cases where an independent broker is not employed. It forbids sellers to provide supplementary services rendered them by buyers unless available to all buyers on proportionally equal terms. It forbids the establishment, in one locality of prices lower than those charged elsewhere, and prohibits the sale of goods at unreasonably low prices for the purpose of destroying or eliminating a competitor.	Robinson-Patman Act, 49 Stat. 1526; 15 U.S.C. 13, 13a, 13b, 21a; P.L. 692; 74th Cong. (1936).
Secretary of Treasury	Imposes a double duty on any article imported into the U.S. under an exclusive dealing or selling agreement, but does not apply to the establishment of an exclusive agency in the U.S. by the foreign producer.	Revenue Act 1916, 39 Stat. 798; 15 U.S.C. 71–77; P.L. 271; 64th Cong. (1916).
Secretary of Agriculture	Declares unlawful, the manipulation or attempt to manipulate the price of any commodity in commerce or for the future delivery on any board of trade. It also prohibits the cornering or attempt to corner any commodity, or knowingly or carelessly delivering or causing to be delivered for transmission through mails or otherwise in interstate commerce, false and misleading reports concerning crops or market information or conditions that affect the price of grain in commerce.	Commodity Exchange Act, as amended by 49 Stat. 1491; 7 U.S.C. 13; P.L. 675, 74th Cong. (1936).
Secretary of Agriculture	Authorizes the Secretary of Agriculture to require all contract markets to suspend all trading privileges and to suspend or revoke the registration, as a future merchant or floor broker, of any person who is found, after a hearing, to have violated any provision of the Commodity Exchange Act, rules and regulations issued pursuant thereto, or has manipulated or attempted to manipulate the market price of any commodity in interstate commerce.	Commodity Exchange Act, as amended by 49 Stat. 1498; 7 U.S.C. 9; P.L. 675, 74th Cong. (1936).
Secretary of Interior	Provides that any lease, option or permit used under the Mineral Leasing Act of February 25, 1920, shall be forfeited by appropriate court proceedings if any lands or deposits shall be subleased, trusteed, or controlled so that they form an unlawful	Mineral Leasing Act of Feb. 25, 1920, 41 Stat. 488; 30 U.S.C. 184; P.L. 1461, 66th Cong.; as amended, 74 Stat. 789; P.L. 86–704, Sec. 3(k).

Name of Agency	Nature and Scope of Regulation	Statute
	trust, or form the subject of any contract or conspiracy in restraint of trade in the mining or selling of specified minerals.	
Secretary of Agriculture	Declares unlawful, certain practices in the sale or transfer of meats, livestock, poultry or poultry products, such as apportioning their supply if it has the tendency or effect of restraining commerce or creating a monopoly, manipulating or controlling prices in commerce, creating a monopoly in the acquisition of any article in commerce, or conspiring or combining to apportion territories. It also prohibits any unfair, unjustly discriminatory, or deceptive practice or device in commerce.	Packers and Stockyard Act, 42 Stat. 159; 7 U.S.C. 181ff, P.L. 51, 67th Cong. (1921).
Securities Exchange Commission	Declares unlawful, unless approved by the Chairman of the SEC, the acquisition of any securities, utility assets, or any other interest in any business, or the acquisition of any security of any public utility by a registered holding company or its subsidiary. The Commission is authorized to examine and review the corporate structure of any registered holding company for purpose of simplifying the structure, eliminating complexities, distributing voting power among shareholders, and confining properties and business to the operations of an integrated public utility system.	Public Utility Act of 1935, 49 Stat. 817; 15 U.S.C. 791; P.L. 333, 74th Cong.
Secretary of the Treasury	Declares unlawful certain practices or conduct by persons engaged in business as a distiller, brewer, rectifer, blender or bottler of distilled spirits, wine or malt beverages. Such practices declared unlawful are exclusive retailing arrangements; acquiring an interest in any retailer's license or real or personal property; furnishing or renting equipment or fixtures, etc. to retailer; paying or crediting the retailer for advertising; guaranteeing or repayment of retailer's financial obligation or providing other similar benefits; inducing any trade buyer to purchase such products by commercial bribery or offering of a bonus or compensation to said buyer; and to sell or to purchase	Federal Alcohol Administration Act, 49 Stat. 977; 27 U.S.C. 202ff.; P.L. 401, 74th Cong. (1935).

Name of Agency	Nature and Scope of Regulation	Statute
	such products on consignment or on any basis other than a bona fide sale. It also prohibits interlocking directorates in companies engaged in business as a distiller, rectifier or blender of distilled spirits.	
Secretary of Commerce	The Secretary of Commerce at his discretion may declare any person or corporation, convicted of a violation of that section of the Merchant Marine Act, 1936, listed above, ineligible to receive any benefits or a charter under the provisions of that Act.	Merchant Marine Act, 1936; 49 Stat. 2014, Sec. 806(C); 46 U.S.C. 1228; P.L. 835; 74th Cong.
Postmaster General	The Postmaster General is authorized to employ any means to provide for the inland transportation of mail by star routes, without reference to laws concerning the employment of personal services or the procurement of conveyances, materials, or supplies, whenever he has reason to believe that a combination of bidders has been entered into to fix the rate for star-route service or the bids are exorbitant or unreasonable.	39 Stat. 161; 39 U.S.C. 433 (1916).
The President	The President may direct the manufacture of naval aircraft engines, parts and equipment at any Government Plant if it reasonably appears that persons or firms bidding on the construction of these items have entered into agreements to restrict competition in the letting of the contracts for such work.	70A Stat. 454; 10 U.S.C. 7343; P.L. 1028, 84th Cong. (1956).
Administrator of General Services	All executive agencies are required to obtain clearance from the Attorney General on the question of whether the disposal of plant, plants, or other property would tend to create or maintain a situation inconsistent with the antitrust laws. In addition, the Administrator of General Services is required to furnish the Attorney General such information as is necessary for the latter to determine whether any disposition of surplus property violates or would violate any of the antitrust laws.	Federal Property and Administrative Services Act of 1949, 63 Stat. 391; Title II, Sec. 207; 40 U.S.C. 488; P.L. 152, 81st Cong.
Department of Defense	The head of an agency is authorized to negotiate contracts for the purchase of property or services which are required to be made by formal advertising, where he determines that the bid prices received after	Armed Services Procurement Act, 70A Stat. 127; 10 U.S.C. 2304–2305; P.L. 1028, 84th Cong.; 78 Stat. 341; P.L. 88–390 (1964).

Name of Agency	Nature and Scope of Regulation	Statute
	formal advertising were not independently reached in open competition. He is required to refer any bid he considers to be evidence of an antitrust violation to the Attorney General.	
Atomic Energy Commission	Declares that nothing contained in the Atomic Energy Act of 1954 shall relieve any person from the operation of the antitrust laws, and in the event a licensee is found by a court to have violated the antitrust laws in the conduct of the licensed activity, the AEC may suspend, revoke, or take such other action deemed necessary with respect to any license issued by the AEC. In addition, the Commission is required to report to the Attorney General any activity concerning nuclear material or atomic energy which appears to violate or tends toward the violation of the antitrust laws.	Atomic Energy Act of 1954, 68 Stat. 938; 42 U.S.C. 2135; P.L. 703, 83rd Cong. (1954).
Federal Power Commission	Provides that, in addition to bringing suits in the Federal Courts to enforce compliance with the Natural Gas Act and to enjoin acts or practices which constitute violations of this Act, the FPC may transmit evidence concerning apparent violations of the antitrust laws to the Attorney General who may institute the necessary criminal proceedings.	Natural Gas Act, 52 Stat. 832; 15 U.S.C. 717; P.L. 688, 75th Cong. (1938).
Federal Power Commission	Declares that combinations, agreements, arrangements, or understandings, expressed or implied, to limit the output of electrical energy, to restrain trade, or to fix, maintain, or increase prices for electrical energy or service are prohibited.	Federal Power Act, 41 Stat. 1070; 16 U.S.C. 803(h); P.L. 280, 66th Cong. (1920); as amended, 49 Stat. 844; 16 U.S.C. 803(h); P.L. 333, 74 Cong. (1935).
Board of Governors of the Federal Reserve System	Provides that corporations organized under the Federal Reserve Act may purchase or acquire stock in another corporation, and sets forth the conditions under which such mergers or acquisitions are permissible, including the consent of the Board of Governors. It prohibits any corporation or its agents and employees organized under the Act from directly or indirectly controlling or fixing the price of commodities in commerce which subjects the corporation's charter to forfeiture.	Federal Reserve Act, 41 Stat. 379, 380, 381, Sec. 25(a); 12 U.S.C. 615 and 617; P.L. 106; 66th Cong. (1919).

Name of Agency	Nature and Scope of Regulation	Statute
Federal Deposit Insurance Corporation Comptroller of the Currency Board of Governors of the Federal Reserve System	Prohibits the merger, acquisition, or consolidation of an insured bank with any other insured or non-insured bank without the consent of one of the listed agencies, depending upon whether the bank involved in the merger is a National Bank, State Bank (member of FRS), or a non-insured bank. The Act sets forth the criteria upon which the agency shall determine its approval or disapproval of a proposed merger.	Federal Deposit Insurance Act, 64 Stat. 873; 12 U.S.C. 1828(c), as amended by the Bank Merger Act; P.L. 89-356, 89 Cong. (1966).
Federal Communications Commission	Prohibits interlocking directorates between or among carriers subject to this Act, unless holding the position of director or officer in more than one carrier is authorized by the Commission upon the finding that neither public nor private interests will be adversely affected thereby.	Communications Act of 1934, 49 Stat. 1087; 47 U.S.C. 314; P.L. 416, 73rd Cong.; as amended, 70 Stat. 931, Sec. 1; 47 U.S.C. 212; P.L. 899, 81st Cong. (1956).
Federal Communications Commission	Provides that no person engaged in the business of transmitting and/or receiving for hire, energy, communications, or signals by radio shall purchase, lease, or otherwise acquire control or operate any cable or wire telegraph or telephone line system if the purpose or effect thereof may be to substantially lessen competition or restrain commerce, or unlawfully to create a monopoly in any line of commerce. The same prohibition applies to a telegraph or telephone line system acquiring or merging with a business engaged in transmitting and/or receiving communications by radio.	Communications Act of 1934, 41 Stat. 1087; 47 U.S.C. 314; P.L. 416, 73th Cong.
Federal Communications Commission	Specifically provides that Sherman Act prohibitions apply to the manufacture, sale of and trade in radio apparatus and devices affecting interstate commerce. In addition, a license issued under the provisions of this Act shall be revoked when any licensee is found guilty of violating the provisions of the antitrust laws.	Communications Act of 1934, as amended by 74 Stat. 893, Sec. 5(b); 47 U.S.C. 313; P.L. 86–752 (1960).

C. *Exemption from Antitrust Laws*

Name of Agency	Nature and Scope of Regulation	Statute
Federal Trade Commission	Provides that an association, entered into for the sole purpose of engaging in export trade and actually engaged solely in export trade, is exempt from Sherman Act violations pro-	Webb-Pomerene Act, 40 Stat. 516; 15 U.S.C. 61–65; P.L. 126, 65th Cong. (1918).

Name of Agency	Nature and Scope of Regulation	Statute
	vided such association is not restraining trade within the U.S., or in restraint of a domestic competitor in export trade. In addition, mergers or acquisitions of corporations engaging solely in export trade are exempt, unless the effect of the acquisition substantially lessens competition within the U.S. Unfair methods of competition prohibited under the FTCA do apply to competition in export trade.	
Federal Maritime Commission	Prohibits certain anticompetitive practices on the part of a common carrier by water and gives the Commission the authority to refer any violation to the Commissioner of Customs who shall refuse a violating carrier entry in any port of the U.S. Notwithstanding these prohibitions, the Commission shall, upon application, permit the use, provided criteria is met by carriers, in foreign commerce of any contract, which is available to all shippers and consignees on equal terms and which provides lower rates to a shipper who agrees to give all or any fixed portion of his patronage to such carrier or conference of carriers.	Shipping Act, 1916, 39 Stat. 733; 46 U.S.C. 812; P.L. 260, 64th Cong. (1916).
Civil Aeronautics Board	Prohibits consolidations, mergers and certain interlocking relationships between common carriers by air without the approval of the CAB, and requires the CAB to disapprove agreements between carriers which are adverse to the public interest. However, any person or corporation affected by any order of the CAB, under the sections prohibiting the practices listed above, is relieved from the operations of the antitrust laws.	Federal Aviation Act of 1958, 72 Stat. 770; 49 U.S.C. 1384; P.L. 85–726 (1958).
Interstate Commerce Commission	Prohibits any common carrier subject to the provisions of the Act from pooling or dividing traffic unless the Commission finds that such practice will be in the interest of better service to the public or of economy in operation, and will not unduly restrain competition. It permits two or more carriers to consolidate or merge with the approval and authorization of the Commission upon its finding that such action will be consistent with the public interest after weighing certain stipulated factors.	Interstate Commerce Act, as amended, 63 Stat. 486; 49 U.S.C. 5; P.L. 197, 81st Cong. (1949).

Name of Agency	Nature and Scope of Regulation	Statute
Interstate Commerce Commission	Provides that the ICC shall approve any agreement between two or more carriers of the same class (except under certain situations) relating to rates, fares, classifications, divisions, allowances, or charges, if it finds such agreements will further the national transportation policy declared in the Act, and if so, the parties to the agreement shall be relieved from the operation of the antitrust laws.	Reed-Bulwinkle Act, amended the Interstate Commerce Act by adding this provision to it; 62 Stat. 472; 49 U.S.C. 5(b); P.L. 662, 80th Cong. (1948).
Federal Communications Commission	Permits telephone companies to consolidate or acquire the whole or any part of another telephone company and domestic telegraph carriers to consolidate or acquire all or any part of another domestic telegraph carrier, upon the approval of the FCC and its finding that such action will be of advantage to the persons to whom service is to be rendered and in the public interest. Upon such approval such consolidations or mergers shall be exempt from any laws making consolidations and mergers unlawful.	Communications Act of 1934, 48 Stat. 1064; 46 U.S.C. 151 ff; P.L. 416, 73rd Cong.; as amended, 70 Stat. 932, Sec. 3; 47 U.S.C. 221(a); P.L. 915, 84th Cong. (1956).
Secretary of Agriculture	Permits the Secretary to enter into agreements with manufacturers and others engaged in the handling of anti-hog-cholera serum and hog-cholera virus for the purpose of regulating the marketing of such serum and virus in order to maintain an adequate supply. Such agreements are specifically exempt from the antitrust laws.	Anti-Hog-Cholera Serum and Hog Cholera Virus Act, 49 Stat. 781; 7 U.S.C. 851 ff; P.L. 320, 74th Cong. (1935).
Secretary of Agriculture	Permits persons engaged in the production of agricultural products to act together in associations, corporate or otherwise, in collectively processing, preparing for market, handling, and marketing in commerce such products. The Secretary is authorized to issue a complaint and hold a hearing to determine whether any such association monopolizes or restrains trade to such an extent that the price of any agricultural product is unduly enhanced. He also has the authority to issue a cease and desist order.	Capper-Volstead Act, 42 Stat. 388; 70 U.S.C. 291 and 292; P.L. 146, 67th Cong. (1922).

Name of Agency	Nature and Scope of Regulation	Statute
Secretary of Agriculture	Permits original producers of agricultural products to acquire, exchange, and disseminate past, present, and prospective crop, market, statistical, economic and other similar information by direct exchange between such persons and/or such associations thereof.	Cooperative Marketing Act, 44 Stat. 802; 7 U.S.C. 451 ff. at 455; P.L. 450, 69th Cong. (1962).
Secretary of Agriculture	Secretary is authorized, after notice and hearing, to enter into marketing agreements with processors, producers, associations of producers, and others engaged in the handling of any agricultural commodity, only with respect to such handling which directly burdens, obstructs, or affects interstate commerce. Such agreements are exempt from the antitrust laws.	Agricultural Adjustment Act, as amended, 61 Stat. 208, Title II, Sec. 206(d); 7 U.S.C. 608(b); P.L. 132, 80th Cong. (1947).
Secretary of Agriculture	Exempts from the operation of the antitrust laws awards or agreements resulting from the arbitration of bona fide disputes between cooperative associations of milk producers and the purchasers, handlers, processors, or distributors of milk or its products, as to the terms and conditions of the sale of milk or its products.	Agricultural Marketing Agreement Act of 1938, 62 Stat. 1258; 7 U.S.C. 671 ff; P.L. 897, 80th Cong. (1948).
Secretary of Interior	Permits persons engaged in the fishing industry, as fishermen or as planters of aquatic products to act together in associations in collectively catching, producing, preparing for market, processing, and marketing in commerce, such products. The Secretary of the Interior is authorized to issue a complaint and an order to cease and desist any activity which he believes monopolizes or restrains trade to such an extent that the price of an aquatic product is unduly enhanced.	Fisherman's Collective Marketing Act, 48 Stat. 1213; 15 U.S.C. 521, 522; P.L. 464; 73rd Cong. (1934).
Securities and Exchange Commission	Provides that the provisions of this Act, permitting the association of brokers and dealers in securities, shall prevail where any provision conflicts with any law of the U.S.	Maloney Act, 52 Stat. 1070; 15 U.S.C. 780–3; P.L. 719; 75th Cong. (1938).
State Insurance Commission	Provides for the regulation by the states of companies in the insurance business. It provides that the antitrust laws shall not apply to the business of insurance or to acts in	McCarran Act, as amended; 61 Stat. 448; 15 U.S.C. 1011 ff; P.L. 238, 80th Cong. (1947).

Name of Agency	Nature and Scope of Regulation	Statute
	conduct thereof, except to the extent that such business is not regulated by state law. It does not exempt Sherman Act application to any agreement to boycott, coerce, or intimidate or act of boycott, coercion, or intimidation.	
Small Business Administration	Provides that no act or omission to act in the formation of corporations provided for in this Act, if approved and found by the SBA as contributing to the needs of small business, shall be within the prohibitions of the antitrust laws. It also exempts, from the operation of the antitrust laws, any act or omission to act pursuant to and within the scope of any joint program for research and development under any agreement approved by the Administrator.	Small Business Act, 72 Stat. 388; 15 U.S.C. 636(a)(6); P.L. 85–536 (1958).
The President	Authorizes the President to encourage the making by representatives of industry, business, finance, agriculture, labor and other interests, of voluntary agreements and programs to further the objectives of the Defense Production Act of 1950. It exempts from the operation of the antitrust laws any act or omission to act pursuant to this act, if requested by the President pursuant to a voluntary agreement or program approved under the provisions of the Act and found by the President to be in the public interest as contributing to the national defense.	Defense Production Act of 1950, as amended, 69 Stat. 581, Sec. 6; 50 U.S.C. App. 2158; P.L. 295 (1955).
	Exempts from the operation of the antitrust laws any joint agreement, by or among persons engaged in the organized professional team sports of football, baseball, basketball, or hockey, by which any league or clubs participating in these sports sells the rights of such league's member clubs in the sponsored telecasting of the games engaged in by such clubs. The exemption is limited to this specific type of agreement only.	Telecasting of Professional Sports Contests, 75 Stat. 732, Sec. 1; 15 U.S.C. 1291–95; P.L. 87–331, 87th Cong. (1961).
	Provides that nothing in the antitrust laws shall be construed to forbid the existence and operation of labor, agricultural, or hor-	Clayton Act, 38 Stat. 731; 15 U.S.C. 17; P.L. 212, 63rd Cong. (1914).

Name of Agency	Nature and Scope of Regulation	Statute
	ticultural organizations, instituted for purposes of mutual help, and not having capital stock or conducted for profit . . . ; nor shall such organizations or their members be held or construed to be illegal combinations or conspiracies in restrain of trade under the antitrust laws.	
	Exempts from the operation of the antitrust laws an association entered into by marine insurance companies to transact a marine insurance and reinsurance business in the U.S. and in foreign countries.	Ship Mortgage Act, 1920; 41 Stat. 1000; 46 U.S.C. 885; P.L. 261; 66th Cong. (1920).
	Provides that the Robinson-Patman Act shall not apply to purchase of supplies for their own use by schools, colleges, universities, public libraries, churches, hospitals, and charitable institutions not operated for profit.	Exemption of Nonprofit Institution from Price Discrimination Provisions, 52 U.S.C. 13C; P.L. 550; 75th Cong. (1938).
	Exempts from the operation of the antitrust laws any agreements or contracts prescribing minimum or stipulated prices for the resale of a commodity which bears the trademark or trade name of the producer or distributor, when such contracts or agreements are lawful as applied to intrastate transactions under any *state law*. It does not exempt contracts or agreements providing for minimum resale price on any commodity, between manufacturers, or between producers, or between wholesalers, or between brokers, or between retailers, or between persons or corporations in competition with each other.	Miller-Tydings Act, 50 Stat. 693; 15 U.S.C. 1; P.L. 314; 75th Cong. (1937). Amended the Sherman Act.
	Cooperative associations or method or act thereof which comply with and are bound by the District of Columbia Cooperative Association Act are not deemed a conspiracy or combination in restraint of trade or an illegal monopoly, or an attempt to lessen competition or fix prices arbitrarily.	District of Columbia Cooperative Association Act, 54 Stat. 490; 29DC Code 840 ff (1940 ed); P.L. 642; 76th Cong. (1940).
	Exempts from the operation of antitrust laws the enforcement of the right of action created by *state law* to obtain damages for advertising, offering for sale, or selling any commodity at less than the price or prices	McGuire Act, 66 Stat. 632; 15 U.S.C. 45(a); P.L. 542, 82nd Cong. Amendment included in Sec. 5(a) of the Federal Trade Comm. Act.

Name of Agency	Nature and Scope of Regulation	Statute
	prescribed in resale price maintenance agreements or contracts, whether or not the person so advertising, offering for sale, or selling is or is not a party to such an agreement or contract.	
D. *Unfair Methods of Competition*		
The President	Declares unlawful, unfair methods of competition and unfair acts in the importation or sale of articles into the United States with the effect or tendency of destroying or substantially injuring an industry, efficiently and economically operated, in the U.S., or to prevent the establishment of such an industry, or to restrain or monopolize trade and commerce in the U.S. The FTC is authorized to investigate possible violations, hold hearings, and report its findings to the President.	Unfair Practices in Imports Act, 46 Stat. 703; 19 U.S.C. 1337; P.L. 361, 71st Cong. (1930).
Federal Trade Commission	Specific practices declared to be unfair methods of competition are contained in the Federal Trade Commission Act (dissemination of or causing to be disseminated any false advertisement); Wool Products Labeling Act of 1939 (misbranding of wool products); Fur Products Labeling Act (misbranding of fur products); Flammable Farbics Act (manufacture, sale transportation, etc. of highly flammable wearing apparel); and Textile Fiber Products Identification Act (misbranding and false advertising of any textile fiber product), all of which are described in Part B of this compilation of laws.	
E. *Miscellaneous*		
Food and Drug Administration	Prohibits the adulteration or misbranding of any food, drug, device, or cosmetic and the introduction or delivery for introduction of any adulterated or misbranded food, drug, device or cosmetic in interstate commerce. Prohibits any act which causes a drug to be a counterfeit drug; or the sale or dispensing, or the holding for sale or dispensing, of a counterfeit drug.	Federal Food, Drug and Cosmetic Act, June 25, 1938, Ch. 675, Sec. 301; 52 Stat. 1042; 21 U.S.C. 331.

Appendix C

EXAMPLES OF POSSIBLE CONFLICTS BETWEEN POLICIES ON COMPETITION AND VARIOUS PRACTICES INVOLVING INNOVATION

The following hypothetical situations illustrate various business practices concerning technological matters which could possibly conflict with national policies concerning antitrust and competition. These examples also illustrate the kinds of questions with respect to which the group, proposed in Recommendation #13, would conduct research and provide advice based upon the results of its investigations.

Situation 1: The owner of a small manufacturing corporation, invents and patents an invention highly important in its field, and useful in other fields as well. He is willing to grant licenses under his patent but only if he can impose what he regards as appropriate conditions on his licensee in order to protect his own best interests. Such conditions might include restrictions with respect to some or all of the following: price, quality, quantity of production, geographic area in which the licensee manufactures and sells, field of use, and grant-back of nonexclusive rights under improvement patents.

Situation 2: In order to strengthen its position vis-a-vis competitors, a company which dominates its industry, engages in the following practices:

(a) imposes stringent contract conditions on its employees which preclude divulgence or use of inventions made or learned of while in its employ and for two years following termination of employment with the company;

(b) bars employees from working for competitors for two years after leaving its employ;

(c) hires away competitor's key research personnel and follows a practice of outbidding competitors for promising new personnel;

(d) deliberately delays by lawful means the issuance of an important patent covering a product that is unlikely to become commercially significant for 20 years.

Situation 3: A corporation owns a number of patents under which it licenses other corporations to manufacture articles covered by its patents. The licensing agreement includes a provision which requires the licensee to grant-back exclusively to the licensor any patentable invention or improvement relating to the field of the licensed patent.

Situation 4: A group of companies within a specified industry forms a restrictive or closed patent and know-how pool.

Situation 5: A number of companies form patent and know-how pools by which:

(a) Parties cross-license conflicting and competing patents on a nonexclusive basis and grant one licensee the right to sub-license under all the patents. Licenses are granted to all applicants on condition of a grant-back of inventions in the licensed field. Licenses are granted only by acceptance of the entire package. Only one licensee can grant licenses under the whole package. Licenses are on standard terms and royalties.

(b) The licensing party grants a license under the package to a foreign licensee, which is exclusive outside the U.S. The foreign licensee grants a return license under its patents, exclusive for the U.S., with rights to sub-license.

Situation 6: Company A licenses Company B under Company A's foreign patents in exchange for a license from Company B under Company B's U. S. patents.

Situation 7: A foreign company wants to get the benefit of the American market for a product involving technology not known in the U. S. It is unwilling to license a U. S. company for fear the latter will compete with it in its own markets, using its know-how. It introduces the new product into the U. S. market through a *joint venture* agreement with a U. S. company under which it retains a share of the profits and management authority. The new company created by the venture receives exclusive rights for the U. S. but no rights elsewhere. This is the only way that the technology is likely to get into the U. S. within a reasonable time, for the U. S. partner cannot itself develop the technology in a timely manner. Another U. S. company is the sole U. S. producer of the product, under a different, patented process. This U. S. company now dominates the field which the joint venture seeks to enter. Barring the joint venture, the parties to it might each have gone into the market separately, but this would have delayed the introduction of the product approximately eight years.

Situation 8: Two companies engage in a joint research activity, but exclude others from participating or obtaining licenses.

Situation 9: Several companies ask an independent R&D laboratory to do R&D for them, for the purpose of developing new processes in a certain industrial field. It is agreed that each must pay a certain amount per annum for this R&D, and each will have nonexclusive rights in the results. However, the final agreement to undertake the project is deferred pending the parties agreement on the legal implications of issues such as: (a) Must the project be open to all applicants on the same terms? (b) Since applicants in later years will not have paid as much as those in earlier years and will thus get the benefits of the R&D done with money contributed by the others in earlier years, can the later applicants be required to pay the assessments for prior years?

Situation 10: Corporation A acquires Corporation B, a research-oriented concern and a potential competitor of Corporation A, with the objective of expanding and enlarging Corporation B's research activities to cover as well the areas in which Corporation A has been operating.

Situation 11: An independent inventor sells his invention to the highest bidder, which is the dominant company in the field to which the invention relates.

Situation 12: Similarly, a technically-oriented entrepreneur (individual or corporate) seeks to sell out to the highest bidder, who is dominant in the field. The adverse effect upon competition if the sale is permitted, and adverse effect on innovation stimulus if prohibited, present conflicting considerations.

Situation 13: A machinery company, the dominant firm in its industry, invents an attachment that will make its machine so much more effective than those of its competitors as to reduce seriously the effectiveness of their competition. However, fear of antitrust vulnerability causes it to:

(a) refrain from incorporating the device in its machine;

(b) sell machines containing the device at a higher price than it otherwise would; or

(c) refrain from the vigorous sales efforts that the improved machine would justify.

Situation 14: In the interests of more effective and economical merchandising, a company considers undertaking the following:

(a) forming, with other concerns, a buying cooperative to take advantage of quantity discounts;

(b) forming, with other concerns, a cooperative merchandising program, including such features as joint advertising and common use of a collective symbol; or

(c) forming, with others in the industry, a quality control program to improve the industry's performance and reputation.

However, it decides against these because of possible antitrust and Robinson-Patman complications.

Situation 15: A company, in order to introduce a new product:

(a) Gives a distributor a long-term exclusive distributorship within a limited territory.

(b) Offers the product at a price below the cost of producing it.

Situation 16: A corporation, attempting to break into a new market, reduces its selling price in that market below its price in other areas.

Situation 17: A corporation, introducing a complex and experimental product into the market, requires that purchasers buy their supplies and replacements, and obtain their servicing, from the corporation.

Situation 18: Building contractors and their labor union enter into an agreement (in the face of a strike threat) not to use certain new materials and methods of construction. The new methods and materials will improve the quality of building and reduce its cost, but will also sharply reduce the amount of manual labor required.

Appendix D

RELEVANT TAX PROVISIONS

Sec. 172 IRC

Net operating loss deduction. This Section permits a deduction, in the taxable year, for net operating loss carry-overs and carry-backs to the taxable year. Net operating loss means the excess of allowable deductions over the gross income. A net operating loss can be carried over to each of the FIVE taxable years following the taxable year of such loss, and deducted from income.

Sec. 174 IRC

Research and experimental expenditures. This section permits a taxpayer to treat research and experimental expenditures, which are paid or incurred by him in connection with his trade or business, as current deductible expenses. It also contains the option to treat these expenditures as deferred expense which the taxpayer may amortize over a period not less than five years, beginning with the month in which he first realizes benefits from the expenditures.

Research and development experimental expenditures do not include expenditures made for depreciable research equipment nor for the cost of constructing depreciable property designed for production as distinguished from pilot model purposes.

Sec. 421 and 422 IRC

Stock options. Section 421 provides that no taxable income shall result from the transfer of a share of stock to an individual who has exercised an option that meets the requirements of Section 422. (Note: this section also applies to other stock option plans which are covered under Sections 423 and 424, but which are not applicable to the subject being considered here).

Section 422 defines a qualified stock option and lists two conditions which must be met before the exercise of such option will be accorded the treatment provided under Section 421, as described above. A qualified option

is an option granted by a corporation to an individual, for any reason connected with his employment, to purchase stock in the corporation. The two conditions are: (1) the individual must hold the stock for three years, after the transfer pursuant to the exercise of the option, before he makes a disposition, and (2) if the individual ceases to be employed by the corporation granting the option, he must exercise the option within three months following the termination of the employment.

The option must also meet a number of criteria, the two most pertinent for present purposes being: (1) "the option by its terms, must be exercised within five years after the date the option is granted" and (2) the optionee cannot own stock possessing more than 5% of the total combined voting power or value of all classes of stock of the employer corporation, except where the equity capital of the corporation is less than $2,000,000 (where this exception applies, a formula is used to determine the permissible percentage of voting powers, which may range from 10%, the maximum, down to 5%).

Sec. 1235 IRC

Sale or exchange of patents. This section permits long term capital gains treatment for payments received by a holder from the "transfer of property consisting of all substantial rights to a patent". The payments qualify for this treatment even though they are "payable periodically over the time of the transferee's use of the patent," or they are "contingent on the productivity, use or disposition of the property transferred." A "holder" is defined as "any *individual* whose efforts created the property, or who has acquired his interest in the property . . . from the creator prior to actual reduction to practice of the invention covered by the patent, if such individual is neither the employer of nor related to the creator."

Sec. 1244 IRC *Losses on small business stock.* This section provides that "a loss on Section 1244 stock issued to an individual or to a partnership . . . shall be treated as a loss from the sale or exchange of an asset which is not a capital asset," and therefore, deductible from ordinary income. The loss on the sale or exchange of 1244 stock may not exceed $25,000, or $50,000 in the case of a joint return by a husband and wife for any taxable year.

1244 stock is defined as stock in a domestic corporation if (1) the corporation adopted a plan to offer the stock for a period specified in the plan, not exceeding two years after the date such plan is adopted; (2) the corporation was a small business when the plan was adopted (a corporation is a small business if "the sum of the aggregate amount which may be offered under the plan, plus the aggregate amount of money and other property received by the corporation, for stock, as a contribution to capital, and as paid-in surplus does not exceed $500,000; and the sum of the aggregate amount which may be offered under the plan, plus the equity capital of the corporation does not exceed $1,000,000"); (3) at the time the plan was adopted, no portion of a prior offering was outstanding; (4) the stock was issued, pursuant to such a plan, for money or other property, excluding stock and securities; and (5) the corporation, "during the period of its five most recent taxable years ending before the date of the loss on the stock is sustained . . ., derived more than 50% of its aggregate gross receipts from sources other than royalties, rents, dividends, interest, annuities, and sales of stock or securities."

Appendix E

THE RECOMMENDATIONS RECAPITULATED

	Page
RECOMMENDATION 1	
We recommend that losses of small, technologically based companies, meeting criteria along the lines we have suggested, be allowed as a carry-forward against profits of the succeeding ten years instead of only five years.	34
RECOMMENDATION 2	
We recommend a liberalization of the stock option rules for small technologically based companies by (1) extending the permissible option period from a maximum of five years to ten years, and (2) reducing the holding period required to receive capital gains treatment to less than three years, preferably to six months.	36
RECOMMENDATION 3	
The Internal Revenue Code should be amended so that a "casual" inventor or innovator can deduct out-of-pocket expenses legitimately incurred for the purpose of ultimately producing income.	37
RECOMMENDATION 4	
The successful inventor who has a going business but did not declare his earlier development costs should receive a "generous backward look" by the Internal Revenue Service and be permitted to reconstruct his development costs and write them off over a period of five years.	37

RECOMMENDATION 5

Page

Research and development expenditures incurred to develop new products or processes should not be disallowed as a business deduction merely because they are unrelated to a taxpayer company's current products or processes. 38

RECOMMENDATION 6

Professional inventors should be placed on the same tax footing as amateur inventors by permitting qualification under Section 1235 of the Internal Revenue Code so that a patent license qualifies as a transfer of "substantially all rights," even though the grant is limited to a particular field-of-use or a particular geographical area. 39

RECOMMENDATION 7

Companies making taxable purchases of technological assets should be permitted some depreciation and tax write-off of these assets in excess of the value of tangible assets. 40

RECOMMENDATION 8

In view of present information on the potential availability of venture capital, the Federal Government should take no action with respect to the establishment of new federally supported programs for the furnishing of venture capital. However, appropriate mechanisms should be developed to provide information on capital availability and the problems of new enterprise development at the regional level. 43

RECOMMENDATION 9

Page

The Department of Commerce should broaden and complement its studies of the innovative and entrepreneurial processes by initiating an integrated program, in cooperation with the universities, including the preparation of empirical data and case materials on these processes, studies of the venture capital system, and experimentation with teaching methods to develop innovative and entrepreneurial talents. 45

RECOMMENDATION 10

An interdepartmental ad hoc review of current contracting policies and procedures of such agencies as the Department of Defense, the National Aeronautics and Space Administration, the Atomic Energy Commission, and the National Institutes of Health, to ensure that these policies are conducive to the long-range growth of small enterprises. 46

RECOMMENDATION 11

The Department of Commerce should serve as the Federal spokesman representing the interests of new technologically-based enterprises and should develop the necessary competence and organization to deal with problems associated with venture capital availability and the generation of such enterprises. 47

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RECOMMENDATION 12

We recommend, at this time, no legislative changes in the antitrust and regulatory laws. However, we do recommend that in the interpretation and administration of these laws, the effect on innovation, as well as on competition, be taken into account. 52

RECOMMENDATION 13

A group should be established within the Federal Government to aid and advise the regulatory and antitrust agencies by performing such activities as:

(1) Developing criteria for helping these agencies judge the impact of antitrust and regulatory policies on invention and innovation.

(2) Systematically analyzing the consequences of past antitrust and regulatory activities in light of these criteria. 54

(3) Advising the responsible agencies on the probable consequences of proposed policy changes affecting invention and innovation.

(4) Providing technological forecasts as an additional factor for antitrust and regulatory planners to weigh in their policy formulations.

Page

RECOMMENDATION 14

To enable the antitrust and regulatory agencies to give greater attention to questions concerning technological innovation, their staffs should be strengthened by increasing the number of personnel who have a deep understanding of economic and technological development. 55

RECOMMENDATION 15

In the legislative and judicial processes involving antitrust and regulation, more consideration should be given to the interaction of technological change and competition. 55

RECOMMENDATION 16

(a) The antitrust and regulatory agencies should provide guidelines clarifying the legality or illegality of business conduct affecting competition and technological innovation. 55

(b) These agencies should also devote more attention to the effect of remedies, orders, and decrees on innovation in relation to competition.

RECOMMENDATION 17

(a) A White House conference on "understanding and improving the environment for technological innovation."

(b) Soon thereafter, a series of regional innovation conferences, composed of governors, mayors, bankers, academicians, scientists, engineers, entrepreneurs, and others —aimed at removing barriers to the development of new technological enterprises, jobs, and community prosperity in the respective regions. 57

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Reading for Business

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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

THE WALL STREET JOURNAL,

MONDAY, MAY 1, 1967

Invention's Mothers

Can the rate of invention and innovation be accelerated?

An affirmative answer would have important implications for economic growth—and corporate success. This may explain why President Johnson directed the Secretary of Commerce to explore new ways of "speeding the development and spread of new technology." Hence the Secretary's ad hoc Panel on Invention and Innovation made up of businessmen, academicians and attorneys.

The panel's provocative report, **Technological Innovation: Its Environment and Management** (U.S. Government Printing Office, Washington, D.C., 90 pages, $1.25), was prepared by Daniel V. De Simone, director of the U.S. Office of Invention and Innovation. A companion work, equally provocative but more theoretical and extensive, is **Invention and Economic Growth** (Harvard University Press, 347 pages, $9.95) by Jacob Schmookler, professor of economics at the University of Minnesota.

It is Professor Schmookler who really comes to grips with the role of intellectual stimuli in influencing technology. So, while necessity may be the mother of invention, Professor Schmookler wonders just what makes inventors invent and innovators innovate.

What, for example, motivated John Rust to invent the mechanical cotton picker, Willis Carrier the air conditioner, Samuel Ruben the mercury dry cell, John Harwood the self-winding wristwatch, Eugene Houdry the catalytic cracking of petroleum and John Tytus the continuous hot-strip rolling of steel?

* * *

Before serving up an answer Professor Schmookler provides a brilliant overview of the inventive process. He notes technology is a seamless web, stretching all the way back to the unknown Bronze Age inventor of the wheel, with the result that invention breeds invention, that technological advances in one field can hasten technological advances in another, that the climate for invention is terribly important to the rate of invention.

He also notes that the trend of invention correlates closely with the trend of investment—that, in other words, the amount of invention is largely a function of the extent of the market. On this point, he draws persuasive comparisons over time between railroad patents and railroad investment and between petroleum patents and petroleum investment.

This brings up the Schmookler answer to why inventors invent. He says they do so, in the main, in the pursuit of profit, in response to specific market demand and, yes, to Mother Necessity.

Profit motivation is also explored by the Commerce Secretary's panelists, who include Lawrence S. Apsey, general counsel of Celanese; Robert A. Charpie, president of Union Carbide Electronics; John F. Dessauer, executive vice president, research and engineering, of Xerox; Peter G. Peterson, president of Bell & Howell, and Dan Throop Smith, professor of finance at the Harvard Business School.

The panelists observe the hard truth that nothing productive happens to a technological idea—sometimes a "garage" or "cellar" operation—until it gets financial backing: Venture capital. Venture capital is high-risk money, they hold, and high-risk money requires high potential returns.

Financing, then, is a classic bugaboo of the small technologically based business. Its losses, the panelists recommend, should be allowed as a carry-forward against profits for ten instead of only five years, and its stock option rules liberalized by reducing the holding period required to receive capital gains treatment to as little as six months.

* * *

Clearly the panelists, notwithstanding quite a few big business connections, are sympathetic to the problems of small technologically based business. A good reason for their sympathy is seen in their data that although a relative handful of large companies account for around 85% of research and development expenditures, it is the independent inventors and small businesses that have often outperformed their big brothers in coming up with important inventions and innovations.

Why is this? The panelists say that big business is sometimes given to flabbiness, to complacency, to in-breeding, to an over-concern with the time value of money—with the upshot of a preference for less ambitious short-run technological opportunities over long-run possibilities of greater potential.

Still, this is, to an extent, a problem of organization. For, big or small, business, like invention, needs incentives. And, apparently, the greater the incentives the greater the volume of business—and the greater the rate of invention and innovation.

As Jacob Schmookler quotes John Stuart Mill: "The labour of Watt in contriving the steam-engine was as essential a part of production as that of the mechanics who build or the engineers who work the instrument; and was undergone, no less than theirs, in the prospect of remuneration from the produce."

—MARY JEAN BENNETT

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