THE DETERMINANTS AND EFFECTS OF INDUSTRIAL RESEARCH AND DEVELOPMENT

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PREFACE

The phenomena of innovation and technical change are very much at the forefront of present research efforts in economics. However, despite the great attention currently being devoted to these subjects, our understanding of them remains slight. Undoubtedly this is due in large part to the fact that there is very little accumulated knowledge to aid research in these fields. Until very recently, these subjects were largely outside the domain of the economist.

The present thesis is undertaken with the objective of helping to close some of the current gaps of knowledge in these fields. It will concentrate on the role of the industrial firm in the inventive process. Various hypotheses concerning the determinants and effects of industrial research and development expenditures are formulated and tested on samples of firms in research-oriented industries. The implications for government anti-trust and fiscal policy are then considered. Some theoretical models which incorporate the main empirical finds are developed to analyze various policy questions. As the reader will see in going through the thesis, the study draws considerably on the recent work of Mansfield, Schmookler, Scherer, Minasian, and other economists working in this area. To these individuals, I owe my first debt of gratitude - both for piquing my interest in the subject matter, and also for providing some well-defined problems to investigate in this study.

The problems of data-collection encountered in this kind of empirical study are very great. These stem largely from the inherent difficulty of measuring input to inventive activity in a meaningful and consistent manner and also from the secrecy which surrounds this activity in many industrial firms. For making unpublished data available to me on R and D expenditures, I am especially indebted to Dennis C. Mueller. A number of industrial firms also deserve thanks for providing me with data and also for alerting me to the many problems associated with their use. In addition, data collected by McGraw-Hill, Inc. and compiled under the direction of Professor Robert Eisner of Northwestern University were very helpful in earlier stages of the work. Margaret Matulis of McGraw-Hill and Jon Joyce of Northwestern University deserve special thanks for their efforts in puting this data into a form appropriate for my use.

The research work for this study was done while I was a member of the Econometric Research Program of Princeton University. I am particularly grateful to Professor Oskar Morgenstern, its director, for his general encouragement throughout my years as a graduate student and generous financial support. A great debt of gratitude is also due to my thesis committee, Professors Richard Quandt and Burton Malkiel. Their many helpful suggestions and continual interest in the project have enhanced its content and exposition immeasurably. The present study also benefitted from numerous discussions with various members of the Department of Economics at Princeton, especially Professors Michael Scherer and

Philip Howrey. Finally, Regina Pasche and Betty Kaminski deserve a great deal of credit for competently typing the manuscript and providing editorial assistence in the different stages of preparation.

All of the computational work for this dissertation was performed on the IBM 7094 computer at the Princeton University Computer Center. These computer facilities are supported, in part, by National Science Foundation Grant NSF GP579. I am also grateful to the latter institution for providing funds in the form of an NSF Cooperative Fellowship during the academic year 1964-65 that helped support research work on this thesis.

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CHAPTER ONE

INTRODUCTION

I. The Underlying Background

The establishment of a high rate of growth has been one of the major policy objectives of the United States during the post-war period. There have been many factors contributing to this high social valuation of growth. Among the most important reasons for emphasizing growth over this period, however, has been the rapidly expanding needs of the public sector. Our newly acquired position of leadership among the free world countries has entailed steadily increasing expenditures for national defense, foreign aid, and space exploration. Likewise, the ambitious government programs in education, welfare, research and development, and other domestic areas have generated additional demands for increased public outlays. In order to satisfy these expanding needs of the public sector without diminishing the allocation of goods to the private sector, a high rate of GNP growth must be maintained. Thus, it is not surprising that policy-makers have been greatly concerned with our growth performance and have continually asked economists to provide them with methods capable of improving it.

Over these same post-war years in which our public policy has been so growth conscious, however, the nature and orientation of growth economics as a subject of study and research has undergone a marked change. For the purposes of our present discussion, we may define growth as growth in per-capita national income and dichtomize the methods of increasing growth so defined into two classes: 1) increases in the amount of physical capital per worker and 2) technical change. Until very recently, one may safely say that the growth economist's concern was almost primarily with the first category. Changes in technology were generally viewed as exogeneous to the economic system and not significantly influenced by normal economic variables such as sales, profits, wages, etc.[1] Technical change as such was an empty economic box and what economists had to say about growth, particularly that which was applicable to public policy, involved only the effects arising out of increasing investment per worker.

A pioneering empirical study by Solow[2] in the middle 1950's was instrumental in altering these traditional views concerning growth and technical change. In his empirical inquiry into the relative importance of the two effects in increasing U.S. per capita growth over the period 1909-1949, Solow found that only 12 percent could be attributed to increases in capital per-worker and thus the residual amount due to technical change or other unidentified factors normally excluded from economic analysis amounted to a startling 87 percent. This placed traditional analyses of growth in the quandry of being concerned with only a very small fraction of the actual growth process. It consequently led to a re-orientation of the views of many

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[1] An exception to this point of view has long been maintained by Jacob Schmookler. See his recent paper on this topic: "Technological Change and Economic Theory", American Economic Review, May 1965, pp. 333-341.

[2] Robert M. Solow, "Technical Change and the Aggregate Production Function", Review of Economics and Statistics, August 1957, pp. 312-320.

economists concerning the need to seriously study the empty box called technical change in order to obtain a satisfactory understanding of economic growth.

In the decade that has followed Solow's path-breaking work, growth economics has developed in a variety of directions. Dennison,[3] for one, has chosen to work with a dozen or so variables as important sources of growth and has personally estimated the percentage contribution to growth of each of these variables. To complement the traditional policy tools for growth, he advocates several new policies designed to increase investment in human capital and inventive activity and also remove various institutional constraints to growth. On the other hand, a number of economists,[4] Solow again leading the way, have brought capital investment back into central consideration by setting forth and testing models of embodied technical change. Formerly, growth models had treated technical change as organizational in nature, and its effect on GNP was independent of other economic stock and flow variables. The new models, however, rest on the premise that technical change to become effective must be embodied into new additions of the capital stock, and therefore gross investment plays a central part in the adaption of new techniques and methods. In the midst of these developments typified by the work of Dennison and Solow, more extensive empirical

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[3] Edward F. Dennison, The Sources of Economic Growth in the United States and the Alternatives Before Us, Committee on Economic Development, 1962.

[4] See, for example, Robert M. Solow, "Investment and Technical Progress", in Mathematical Methods in the Social Sciences, Kenneth J. Arrow, Samuel Karlin, and Patrick Suppes, Eds.; Leif Johansen, "Substitution versus Fixed Coefficients in the Theory of Economic Growth: A Synthesis; Econometrica,

investigations than Solow's 1957 study have pointed up the difficulty in apportioning growth to various causes.[5]

While there is thus considerable flux in growth economics at the present time, economists have in general changed their basic attitudes toward the place of technical change in economics. A number of studies have been undertaken in recent years with the specific aim of inquiring into the nature and sources of technical change. A great deal of this work has centered around the role of organized inventive activity in the innovative process, and the possibility of evolving government policies which could affect technical change and growth by influencing the level and character of this activity. While all of this work is still in a pioneering stage, the situation has radically changed from a decade ago when technical change was basically treated as an exogeneous variable incapable of being influenced by normal policy tools.

II. The Scope of the Present Study

The present thesis will focus its attention on one aspect of organized inventive activity -- industrial research and development. Since over one-third of our total national research and development effort is currently

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April 1959, pp. 157-176; and Edmund S. Phelps, "The New View of Investment: A Neoclassical Analysis", Quarterly Journal of Economics, November 1962, pp. 548-567.

[5] See in particular the studies by Benton F. Massell, "Capital Formation and Technoligcal Change in United States Manufacturing", Review of Economics and Statistics, May 1960, pp. 182-188; "Is Investment Really Unimportant?", Metroeconomica, April 1962, pp. 65-85.

being performed and financed by private industry, the activities of this sector constitute one of the important elements in the overall innovative process. Indeed, the expansion of private industry's activities for this purpose has been so rapid and manifest in recent years as to popularize the phase "research revolution" by those describing it. This significant development together with the greater availability of data in this sector are our chief reasons for selecting it for study here.

Within the industrial community itself there are, of course, substantial differences in the level and character of research[6] performed among industries owing to differences in their scientific base, market structure, estabished patterns of competition, and other relevant factors. The models we shall develop and test in this thesis will be specifically aimed toward an understanding of the research process in the most technically oriented industries. It is this group that has the most important effect on economy-wide technical change and is therefore also most relevant for any policy measures designed to stimulate economic growth.

Our analysis of industrial research will be principally in the micro-economic level. The subject matter is essentially twofold. First, we will investigate R and D activity within the context of the normal firm decision-making processes and concentrate on the factors that determine how much is spent for R and D. Our hypothesis in this regard will be based mainly

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[6] We shall use the terms "research and development" and "research" synonymously in the text of this thesis unless a specific distinction is denoted. The abbreviated form R and D also will frequently be employed.

on the observations and empirical work of others studying related aspects of corporate bahavior and also on personal interviews. A model is eventually constructed and tested which relates the firm's R and D expenditures to various technological, financial, and marketing variables. In addition some alternative hypotheses are also tested and compared to those embodied in our model.

The second major question analyzed is the effect of a firm's level of research and development activity on its rate of growth of output. This relationship is singled out for particular attention because of the predominantly new-product orientation of most industrial research and development. Some empirical work on this question is performed on a cross-sectional sample of firms in the chemical and drug industries spanning the period 1950-1964. The evidence for a positive link between a firm's research and development activity and its rate of growth is then evaluated against the background of econometric problems that beset a study of this type.

On the basis of this empirical work on the determinants and effects of industrial research and development, some first level policy implications are also drawn. The main considerations here are the possible effects of different fiscal incentive schemes on the level of research and development expenditures by the firm. Another topic that is investigated is the relation between firm size and research and development activity. This is obviously an important issue for government anti-trust policy.

If it can be shown, as some noted observers maintain,[7] that large size has a significantly positive effect on the level of a firm's research intensity, then the case for anti-trust policy is obviously weakened. The question however poses some very complex conceptual and empirical considerations, and the results presented here only offer some quantitative information of a preliminary nature.

In the final chapter of the thesis we turn to some macroeconomic considerations. Some aggregative models are formulated which incorporate some of the findings of our microeconomic studies on research and development into the framework of recent macroeconomic growth theory. The equilibrium properties of these models are then derived and the consequences of alternative government research and development policies analyzed. While providing some interesting results, these models are, however, only first approaches and basically speculative in nature. In order to formulate more complete and realistic models of this nature, a great deal more knowledge must be accumulated concerning such questions as the inter- and intra-industry effects of research and development (i. e. , the diffusion process of innovational activity throughout the economy) and the interactions of industrial research with other productive factors. Microeconomic analyses of research and development would however appear to be necessary first steps in the analysis of these larger questions and therefore our primary attention in this thesis is focused at the firm level.

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[7] The intellectual parent of this group is of course Joseph Schumpeter. More recent proponents are John Galbraith, American Capitalism (Boston: Houghton Mifflin Co. , 1952), Henry H. Villiard, "Competition Oligopoly, and Research", Journal of Political Economy, December 1958, pp. 491-497, and many others.

CHAPTER TWO

THE ROLE OF INDUSTRIAL RESEARCH AND DEVELOPMENT IN THE TOTAL RESEARCH PROCESS

Before turning to a consideration of the particular sample of business firms to be studied, a discussion of the nature and rôle of industrial R and D in the total research process would seem appropriate. Our main purpose here is not to provide a detailed analysis of this process, but merely to elucidate some of its obvious characteristics and interactions. This will serve to provide the reader with some idea of the range and limits of the term "R and D" expenditures that will appear frequently in future chapters.

We may conveniently divide research performers into four kinds of groups: (1) industrial companies; (2) government agencies; (3) universities and other non-profit agencies, and (4) independent inventors. Our discussion here mainly concerns the first three of these categories since comparatively little is known about the fourth group of independent researchers. The basis for most of this discussion will be the National Science Foundation statistics on R and D that have been collected since 1955 for the different economic sectors. These statistics will allow a comparison of the level and character of research performed by each sector and the interactions between them. After considering these questions, we shall briefly look at what is presently known concerning the position of the independent inventor in this process.

I. The Level of Research Activity in Each Sector

In order to first gain an idea of the relative magnitude of research performed and supported by each economic sector, we shall consider the latest available annual NSF figures on R and D classified in this fashion. The definition on which these statistics are based is confined to the natural sciences including engineering but excluding such items of industrial activity as marketing research and technical services. In Table 2-1 the distribution by sector of R and D performed in 1963 is presented, and the distribution according to the source of funds for the same year is given in Table 2-2. In 1963 industry performed approximately three billion dollars worth of R and D or slightly over 44 percent of the U.S. total. This puts it well ahead of any other sector in this category. With respect to the financing of R and D, however, industry provided only two billion dollars or 35 percent of total R and D effort. The dominant sector here was the Federal Government which financed 58 percent of the R and D performed in the United States. Tables 2-1 and 2-2 also show that colleges and universities and other non-profit groups performed 31 percent of total R and D in 1963, but provided only seven percent of the total funds for R and D.

Tables 2-1 and 2-2 show an obvious characteristic of much of our current research activity; namely, the group supporting the research is often different than the one which actually performs the research. In this regard, a detailed account of the intersectoral transfer of funds for 1963 is given in Table 2-3. It reveals that the difference between the size of

Table 2-1

Distribution of R and D Work Performed by Sector, 1963

Sector	R and D performed (in millions)	Percentage of U. S. total
Federal Government	908	15
Industry	3,180	54
Colleges and Universities	1,430	24
Other Nonprofit Organizations	425	7
All Sectors	5,943	100

Table 2-2

Source of Funds for R and D by Sector, 1963

Sector	Funds provided (in millions)	Percentage of U. S. total
Federal Government	3,438	58
Industry	2,080	34
Colleges and Universities	250	4
Other Nonprofit Organizations	175	3
All Sectors	5,943	100

Source for Table 2-1 and Table 2-2:

National Science Foundation, Review of Data on Science Resources, Vol. 1, No. 4, May 1965, p. 3.

Table 2-3

Intersectoral Transfers of Funds Used for Performance of Research, by Source and Performer, 1963

Sources of Funds Used	Research Performers: Federal Government	Industry	Colleges and Universities	Other Nonprofit Organizations	Total
Federal Government	908	1,240	1,060	230	3,438
Industry	-	1,940	50	90	2,080
Colleges and Universities			250		250
Other Nonprofit Organizations			70	105	175
Total	908	3,180	1,430	425	5,943

Source: Same as Tables 2-1 and 2-2.

R and D performed and financed was provided primarily by government funds in the three non-government sectors although there is also a sizeable flow of funds from industry to the educational and nonprofit organizations.

Our principal concern in this thesis will be with the component of industrial research that is both performed and financed by the firms themselves. In 1963, this amounted to almost two billion dollars or one-third of the total R and D in the United States. It is this type of industrial research that is most relevant to technical change and economic growth in the private sector of the economy. Government-supported research performed in industry, which totaled 1.2 billion dollars in 1963, is mainly for the purposes of national defense and the space program. In addition, it is much more highly concentrated in the development stage than privately-financed industrial R and D. While these two components of industrial research are for the most part directed toward quite different ends, the existence of a situation in which very large government R and D expenditures are made on a contractual basis to industry can be expected to influence privately-financed R and D in a variety of ways. Among the most important of these influences are the effects on the supply of scientists and engineers in the private sector, the types of research projects that firms include in their research programs, and the "spillover" of benefits from military R and D to the civilian part of the economy. While a number of large government contractors such as NASA and the Department of Defense have recently shown an interest in evaluating these impacts, very little is currently known of a quantitative nature concerning them. Some research of a qualitative kind has however been done on these subjects by Price, Dupre, and others.[1]

II. The Character of Research Performed in Each Sector

The National Science Foundation also collects statistics on the distribution of research into basic, applied, and development categories in each

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[1]Joseph S. Dupre and Stanford A. Lakoff, Science and the Nation (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1962); Fritz Machlup, The Production and Distribution of Knowledge in the United States (Princeton, N. J.: Princeton University Press, 1962); Don Price, Joseph S. Dupre, and W. Eric Gustafson, "Current Trends in Science Policy in the United States" in Impact of Science on Society, 1960.

sector. While it is exceedingly difficult to make such a classification of R and D in a consistent and meaningful manner, the NSF definitions do provide some basis for gauging the character of research work being undertaken in the economy by different sectors over time.

The essential feature which the NSF uses to distinguish whether research is basic, applied, or development is the motivation for which the research is undertaken. Basic research is research in which

> "the primary aim of the investigator is a fuller knowledge or understanding of the subject under study."[2]

In the case of an industrial firm it consists of research projects involving

> "original investigation for the advancement of scientific knowledge -- which do not have commercial objectives, although they may be in fields of present or potential interest to the reporting company."

For the second category, applied research, the NSF definition reads:

> "Applied research is directed toward practical application of knowledge"

and for the industrial firm it involves

> "research projects which represent investigations directed to discovery of new scientific knowledge and which have commercial objectives with respect to either products or processes."

The final category, development, is defined in the following way:

> "Development is the systematic use of scientific knowledge directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and process."

A percentage distribution of funds used for R and D performance by type of research for the various sectors in 1963 is presented in Table 2-4. These

[2] These definitions are given in the technical notes of Reviews of Data on Research and Development, National Science Foundation, NSF 63-40, No. 41, September 1963, pp. 10-11 and other issues of the Review.

Table 2-4

Percentage Distribution of Funds Used for Performance of Research and Development in Each Sector by Character of Work, 1963

Sector	R and D performed (in millions)	Percent of this figure which is Basic	Applied	Developm.
Federal Government	908	12	26	62
Industry	3,180	4	21	75
Colleges and Universities	1,430	49	35	16
Other Nonprofit Organizations	425	38	42	20
Total R and D	5,943	10	24	66

figures show that the R and D performed in the government and industrial sectors is predominantly of the development variety while the opposite is true for colleges and universities and other nonprofit organizations. Table 2-5 reveals that 57 percent of all the basic research performed in 1963 in the U. S. economy was done at nonprofit institutions along with 20 percent of all applied research. The entire industrial sector performed only 28 percent of the total basic research in the same year. If this appears to be a small sum it may be noted that industrial executives have often justified this small amount not on the basis of its profit opportunities but for reasons of prestige and for the value of having these scientists as "consultants" to its more applied groups.

Since approximately 70 percent of all R and D is performed either in the industrial or government sector (Table 2-1), the figures in Tables 2-4 and

2-5 also mean the greater part of total R and D performance in the economy will be for development. This fact has been the subject of considerable comment by economists who have suggested that a free enterprise system cannot be expected to allocate resources efficiently in the area of inventive activity and unless government or some outside group subsidizes basic research, there will always be an underinvestment in this area. We shall take up this question below in our section on the "external economies" to R and D.

Table 2-5

Percentage Distribution of Funds Used for Performance of Basic Research, Applied Research, and Development by Sector, 1963

Type of Research	Federal Government	Industry	Colleges and Universities	Other Nonprofit Organizations
Basic	15	28	46	11
Applied	15	65	14	6
Development	13	54	24	7
Total R and D	14	73	10	3

Source: Tables 2-4 and 2-5 - National Science Foundation, Review of Data on Science Resources, Vol. 1, No. 4, May 1965, p. 5.

Before turning to this discussion, however, a further characterization of the type of R and D being performed in each sector is presented in Table 2-6. This table shows the percentage distribution of R and D scientists and engineers by type of work for each sector in 1958. Industrial R and D was highly concentrated in engineering, and to a somewhat lesser degree in the physical sciences, with very little participation in the life sciences. This is completely reversed in the colleges and universities sector which has a specialization in the life sciences.

Table 2-6

Percentage Distribution of R and D Scientists and Engineers by Type of Work and Sector, 1958

Employer	R and D Scientists and Engineers in all natural sciences	life sciences	engineering	other physical sciences
All sectors	100.0%	10.9%	63.1%	26.0%
Federal Government	12.1	1.6	6.3	4.3
Industry	72.3	1.6	53.7	17.1
Colleges and Universities	13.9	7.2	2.7	3.9
Other Nonprofit Organizations	1.6	0.5	0.5	0.7

Source: National Science Foundation, Reviews of Data on Research and Development, No. 29, August 1961.

The limitation of our empirical analysis to industrial R and D thus means that we will be dealing with research activity which is primarily in the development stage and which is located in the fields of engineering and the physical sciences. It is this type of research that offers the greatest opportunities for economic payoffs to the groups performing the research, and it is therefore natural that business firms as the basic profit-making organization in a free economy should specialize in it. Of course, the quality of applied research depends ultimately on a continually evolving base of more fundamental knowledge on which to draw. Provided that forces are at work within a society to generate and maintain this scientific base, applied work in the industrial sector should lead to continual technical change in the form of new products and processes. It is to a discussion of these forces within the context of a free enterprise society that we now turn.

III. The "External Economies" Issue

Basic research as the NSF definition of the previous section points up is essentially research that is directed toward increasing the stock of fundamental knowledge about a certain subject. While such research may ultimately have great economic value, the economic payoffs are for the most part unappropriable to the individuals or groups performing the research. This is because the output to basic research is not a concrete product but new knowledge which usually has no direct economic value to the researcher, but which also may be used over and over again by anyone having access to it for the production of possibily profitable applications. From the standpoint of economic theory, basic research is a classical example of a public good. As various studies in the welfare economics clearly show, a free enterprise economy left to itself will tend to invest less in such commodities than the level which is socially desirable.[3]

[3] For a comprehensive survey of these studies see E. J. Mishan, "A Survey of Welfare Economics, 1939-59", Economic Journal, June 1960, pp. 197-256.

A second reason why there will be a tendency toward an underinvestment in R and D is the uncertainty which characterizes R and D activity, particularly for basic research. Arrow and others[4] have emphasized that the risks inherent in R and D projects cannot be perfectly shifted from those performing the research to outside investors. Since some firms will likely be risk-averters, a level of R and D will be undertaken which is less than the amount which would occur if frictionless risk-shifting were possible.

It would thus appear that some group other than the industrial firm must undertake R and D in a free enterprise if there is to be a socially optimum allocation of resources. Colleges and universities and other non-profit institutions have traditionally provided an ideal place for such research to be performed with a large part of the costs of this research being financed by the Federal Government and other groups outside of the universities as was shown in Table 2-1 above. The problem of determining how much government support and to what fields, however, is a very difficult and as yet largely unsolved one.[5]

Economic theory tells us that to achieve a socially optimum allocation of resources to R and D the government should finance research in each field

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[4] Kenneth J. Arrow, "Economic Welfare and the Allocation of Resources", The Rate and Direction of Inventive Activity (Princeton, N. J.: Princeton University Press, National Bureau of Economic Research, 1962); Richard R. Nelson, "The Simple Economics of Basic Scientific Research", Journal of Political Economy, June 1959, pp. 297-306.

[5] For a recent attempt at structuring this problem see Oskar Morgenstern, Ronald Shephard, and Henry Grabowski, "Adaption of Graph Theory and an Input-Output Model to Research Description and Evaluation", forthcoming in The Proceedings of the Second Annual ONR Conference on Research Program Effectiveness, Gordon and Breach, Inc. , New York.

to the point where the marginal social benefits equal the marginal social cost. Cost-benefit studies designed to provide information that would allow implementation of this criteria for various public goods are still however very much in the pioneering stage. Measurement of social benefits are extremely difficult, particularly in the case of R and D which involves so much uncertainty. Scherer and others have analyzed some of the particular problems that arise in a cost-benefit analysis of R and D.[6]

Even in the absence of more refined decision-making techniques, however, the government must continue to decide on the amount and distribution of its R and D outlays. While this thesis with its emphasis on industrial R and D is not directly involved with this question, the policies which the government pursues, particularly in its support of basic research, will in the long run have a great effect on industrial R and D. The optimum public policy in this regard will certainly continue to be one of the most important questions of economic research.

IV. The Role of the Independent Researcher

While a great deal of statistical material has been amassed on organized research in recent years, comparatively little information is available on the amount and significance of the research being done by independent

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[6] F. M. Scherer, Measuring the Benefits of Government Research and Development Programs (Washington, D. C.: Brookings Institute, 1963).

researchers. There has been of course definite trend over time toward the collectivization of inventive activity and away from the individual researcher. This is reflected in the patent statistics which show that, whereas only 12 percent of patents were issued to companies in 1885, the figure was up to 61 percent at the beginning of the 1960's. A list of the most significant inventions in the last twenty years shows, however, that the independent researcher is far from obsolete.

One of the few actual empirical studies that have been attempted on the role of the independent inventor is that of Jacob Schmookler.[7] This study investigates the educational and occupational characteristics of a random sample of approximately 100 persons granted patents in 1953. His results show that only about 40 percent are full-time inventors, another 20 or 25 percent are industrial personnel hired partly to invent, and about one-third are completely independent inventors. The results concerning the educational background of the inventors are quite surprising in that over one-third of those in the study had no more than a high school education and only 25 percent had done any graduate work. From this finding, Schmookler concludes[8]

> "managers of private firms should review, from the standpoint of their own interests, the desirability of continuing to insist on college degrees for <u>all</u> technical personnel. In the light of the inventiveness of non-college graduates suggested by this survey, as well as other evidence indicating that a substantial fraction of the most able high school graduates fail to attend college, the indiscriminate application of the college-degree criterion would appear a poor substitute for careful personal selection."

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[7] Jacob Schmookler, "Inventors Past and Present", Review of Economics and Statistics, August 1957, pp. 321-333.

[8] Ibid, p. 330.

The major shortcoming of a study such as Schmookler's is that the use of patents to measure inventive output does not provide a basis for one to draw implications on the economic significance of the inventions involved.[9] One might suspect that there is much less probability of an invention being a commercial success if it is patented by an independent researcher rather than a corporation. Schmookler advances one plausible reason why this may not be so. He maintains that coporations will tend to participate in indiscriminate patenting to provide barriers to their competitors whereas independent researchers will patent only that which has a good chance of bringing economic returns.

Granting that the increasing specialization of research worker and the use of complex equipment and hardware in modern R and D activity make the position of the independent inventor less tenable, it may be true however that there will always be a significant place in the research process for the independent inventor. In this regard, an important area for future research is a thorough study of the motivational and other psychological characteristics of the successful inventor, whether he be a corporate employee or not. As Mansfield suggests,[10] this research can only fruitfully be done on an interdisiplinary basis utilizing psychologists and sociologists as well as economists. It is only after obtaining information such as the effect of various institutional

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[9] A full discussion of the advantages and limitations of patent statistics is presented in Chapter 5.

[10] Edwin Mansfield, "The Economics of Research and Development: A Survey of Issues, Findings, and Needed Future Research", in Patents and Progress, W. Alderson, V. Trenpstra, and S. Shapiro, Eds. (Homewood, Illinois, Richard Irwin, Inc. , 1965), pp. 107-140.

settings and incentive schemes on the researcher that one can design public policy that will stimulate technical change in an efficient manner.

V. Summary

The current discussion has considered some of the basic characteristics and interactions of industrial, government, and academic research. Our future work will be concentrated on privately-financed industrial R and D, which is primarily oriented toward the development of specific products and processes and motivated for the most part by traditional economic incentives. The quality and success of this R and D activity will however be greatly influenced by the degree of fundamental research performed largely in the university and other nonprofit organizations and by the demands and "spill-overs" of government R and D for military and security purposes. These complimentary and competing interactions raise some complex and intriguing questions in the determination of an optimal public policy with respect to the size and character of government-supported R and D. In the work that follows however we shall treat government policies of this nature as essentially given in order to isolate and study the role of the industrial firm in this entire process.

CHAPTER THREE

THE NATURE OF THE INDUSTRIAL SAMPLES TO BE STUDIED

The significance of research and development as a firm activity varies widely across industry lines. In industries like chemicals and electronics that are characterized by a strong technological base and a high degree of product innovation, it has become a major competitive weapon for the firms involved. In others such as textiles and food products, however, R and D is presently of negligible consequence. A study of industrial R and D activity can therefore at best expect to observe homogeneous behavior over limited classes of industries of somewhat similar technological base and market structure.

Rather than attempt in this thesis to cope with a myriad of different behavioral situations, our approach instead will be to concentrate only on highly research-oriented industries. An additional constraint will be that the R and D activity in the industries selected for study be primarily company motivated and financed. Such industries invariably turn out to be ones with high concentration ratios. We will therefore also be dealing almost exclusively with firms selling under oligopolistic market conditions. A set of behavioral hypotheses applicable to firms in such situations will be formulated in the next chapter and eventually tested on each of our industry samples. The current chapter will be devoted to a discussion of how the industry groups to be studied were selected and the resulting characteristics of the data and sample of firms in these groups.

I. The Selection of the Industries for Our Empirical Study

A list of total company-financed R and D expenditures by industry for 1963 is given in Table 3-1. It reveals that the chemical and allied products industry was the leader in this regard with 989 million dollars expended for R and D (18 percent of the total) and that the seven industry groupings with over 200 million dollars in 1963 accounted for 80 percent of total industrial R and D expenditures. It is from these seven industries which comprise the technological "core" of the economy (chemicals and allied products, electrical equipment, motor vehicles, machinery, aircraft and missles, petroleum, professional and scientific instruments) that we shall choose our industrial samples.

In Table 3-2 the same industries are ranked by the percentage of total research which is government financed. Aircraft and missles (90 percent) is the industry leader here with electrical equipment (63 percent) and professional instruments (47 percent) also registering very high percentages. Table 3-2 further shows that of the seven most research-intensive industries of Table 3-1, only chemicals and petroleum are less than 25 percent government financed.

Given our above described criteria for selection, Tables 3-1 and 3-2 seem to provide a very clear case for including the chemical and allied product or some specific sub-groups of this industrial category since it is the leader in privately-financed R and D and also has very little government-supported activity. Of the other six industries with over 200 million dollars

Table 3-1

Company Financed Expenditures for Research and Development by Industry, 1963

Industry	Amount	Percentage of Total
Chemical and allied products	989	18
Electrical equipment and communication	921	17
Motor vehicles and other transportation equipment	814	15
Machinery	713	13
Aircraft and missles	464	8
Petroleum refining and extraction	295	5
Professional and scientific instruments	265	5
Primary metals	179	3
Fabricated metal products	133	2
Rubber products	107	2
Paper and allied products	71	1
Textiles and apparel	32	1
Food and kindred products	*	*
Lumber, wood products, and furniture	*	*
	5,378	100

*Included in total but not tabulated separately.

Table 3-2

Percentage Breakdown of the Source of Funds in the Performance of Research and Development by Industry, 1963

Industry	Percentage of R and D federally financed
Aircraft and missles	90
Electrical equipment and communication	63
Professional and scientific instruments	47
Machinery	27
Rubber products	27
Motor vehicles and other transportation equipment	26
Chemical and allied products	21
Fabricated metal products	18
Petroleum refining and extraction	6
Primary metals	6
Textiles and apparel	6
Paper and allied products	-

Source for Tables 3-1 and 3-2: National Science Foundation, Reviews of Data on Science Resources, Vol. 1, No. 1, December 1964, pp. 7 and 8.

in R and D expenditures, aircraft and missles, electrical equipment, and professional instruments are clearly much too highly government-supported to be included in a study primarily concerned with privately-financed R and D. This leaves petroleum, machinery, and motor vehicles as the other possible industries in addition to chemicals for includion in our analysis. It was finally decided on a number of grounds to include only petroleum and exclude the other two groupings. The main considerations were: (1) the greater homogeneity of the petroleum grouping than the other two industrial categories; (2) much lower percentage of government-supported R and D in petroleum; (3) higher level of inventive activity of petroleum when ranked by patent statistics[1], and (4) much closer technological tie of petroleum to chemical industry than other two industry groups. If the costs of obtaining R and D data were negligible, these other industries would also have been used despite these shortcomings, but as the discussion in the next section will make clear, this is not the case in the collection of statistical information on R and D.

An examination of the SIC groups spanned by these two NSF industrial categories shows that chemicals and allied products includes firms whose principal products are in the three-digit SIC classes 281-289, whereas petroleum contains firms principally producing in SIC 291. Among the sub-groups in the former category are inorganic and organic chemicals (SIC 281 and 282),

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[1] See the tables in F. M. Scherer, "Firm Size and Patented Inventions", American Economic Review, December 1965, p. 1101. Petroleum is third, behind only chemicals and electrical equipment, in total number of patents received by firms in the United States' top 500 corporations (30 firms).

pharmaceuticals (SIC 283), soaps and cosmetics (SIC 284), paints (SIC 285), fertilizers (SIC 287), and explosives, carbon black, and miscellaneous (SIC 289). Clearly, the NSF chemical and allied products category is much too broad for our current purposes and should be sub-divided further into different industrial groupings.

Of these different three-digit SIC groups included in the NSF category, pharmaceuticals is the most research-intensive one, followed by organic and inorganic industrial chemicals, and then the groups in the classes 284-289 that are substantially less research-intensive than either drugs or industrial chemicals. One natural industrial sub-group that therefore emerges from this NSF aggregate class is pharmaceuticals which is a self-contained competitive structure of high research orientation. A second grouping of similar interest is industrial chemicals, a combination of SIC 281 and 282 which are closely allied in actual industrial practice.[2] Several additional industries could also be constructed from SIC 284-289, but it was decided that these industries were not very suitable for our present study. None of the main competitive groupings in these classes (soaps, paints, fertilizers, and explosives) can be classified as highly research oriented, nor assume the economic importance of the three selected for our empirical study in terms of annual turnover or capital assets. In addition these industries do not provide very many sample observations in a cross-sectional study since they tend to be dominated for the most part by a few large firms.

[2]The usual organizational set-up is for the organic (fibers and plastics) chemicals to be operated as a separate division or group of divisions in a company whose principal production is in inorganic chemicals.

The empirical part of the thesis will therefore test our behavioral hypotheses concerning R and D on the three industries described above. They shall be denoted in our future work merely as chemicals, drugs, and petroleum rather than with any more precise demarcation. Before proceeding into a discussion of the actual data samples in each of these industries, however, a note of caution should be sounded. Namely, it must be emphasized that these three industrial groups are not made up of completely similar marketing units but the firms in each exhibit a fair degree of heterogeneity with respect to their product-mixes. This in general results not so much from subgroups of firms with particular specializations in these industries as it does from the diversification of many firms beyond the industry's normal boundaries. Very little can therefore be done about this kind of heterogeneity beyond recognizing its possible effects on our results. We shall take up a detailed discussion of this topic when we get to the actual empirical work itself.

II. The Characteristics of the Research and Development Data in the Industry Samples

Empirical studies of inventive activity have probably received more criticism on methodological grounds than any other type of economic research. Much of this criticism has centered on the utility and consistency of the presently available measures of this activity -- R and D employment and expenditure data and patent statistics.[3] Since our aim in this thesis is in large part

[3] See, in particular, the papers by Simon Kuznets "Inventive Activity: Problems of Definition and Measurement" and Barkev V. Sanders, "Some Difficulties in Measuring Inventive Activity" in The Rate and Direction of

to study R and D activity in the context of the firm budget process, R and D expenditure data is the appropriate measure of inventive activity for our empirical work. The quality and consistency of R and D expenditure data is however an important issue that must be considered in undertaking such a study. The present section will be devoted to this task and will describe in some detail how our particular data samples were constructed and their possible advantages and shortcomings.

Our first inquiry into the nature of readily available R and D data involved a survey of the annual reports and other published material of firms in the chemical, drug, and petroleum industries. It showed a wide discrepancy in the current practices of firms in disclosing and presenting this kind of information. Some firms publish their total R and D expenditures, others only that spent for certain types of R and D, while another substantial percentage provide no figures on R and D expenditures but lump them together with general administrative and selling expenses. The secrecy of many firms in this regard, most likely because they do not want competitors to have the information, provides the most potentially serious problem in using data samples constructed from company-published statistics. Another problem arises from the fact that very few firms provided any descriptive material on what precisely was included in their R and D figures. A knowledge of these individual firm definitions of R and D has become increasingly important because, owing to the recent interest by security

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Inventive Activity (Princeton, N. J.: Princeton University Press, National Bureau of Economic Research, 1962).

analysts in these figures for evaluating the firms' growth prospects, there has been a definite temptation for firms to "inflate" their published figures and include many quasi-research areas. There are several well known "grey" areas including operations research, marketing studies, and company technical services.

The construction of data samples from company-published figures is therefore open to serious bias on the grounds that (1) many firms choose to remain secretive on their R and D expenditures making the sample a non-representative one and (2) there are incentives for firms that do report R and D statistics to artificially inflate them and there is no way to tell the extent of this practice.

These limitations in the company-published statistics make it highly desirable for us to construct the industry data samples from another source. The National Science Foundation data offer an attractive alternative in this regard since they are based on externally devised definitions and assure the firms of confidential treatment, thereby removing the incentives for secrecy or artificial inflation of the data. These data must however be obtained directly from the firms themselves for it is the practice of the NSF not to release them in disaggregated form even for academic research. This introduces its own problems in that firms must be contacted and persuaded to release their figures for a study of this kind. With limited resources and time, any serious attempt to obtain a high final response rate severely limits the number of available firms that may be approached. The research strategy consequently adopted in this work was to try to obtain a high response rate from the top fifteen or twenty firms in the chemical, drug, and petroleum industries. Specifically, it was decided to try to obtain data on all firms in the Fortune 500 listing in these industries.[4]

Our approach in constructing initial data samples thus has a decided "large" firm bias built into it. Since all three of these industries are highly oligopolistic in nature, however, it was felt that this was preferable to trying to obtain a more representative sample which contained fewer of the large firms. Figures available from the NSF show that the first eight companies in each of these industries perform well over half of the R and D and the first 20 companies do over ninety percent of the total industry amount.[5] In confining our analysis only to firms in the "500", we are nevertheless dealing with the group of firms that do the vast bulk of the R and D in these industries and this is a highly desirable characteristic.

Having described our research strategy in obtaining R and D expenditure data, we may now turn to a brief analysis of the characteristics of the resulting industry samples. A summary of the main characteristics are presented in Table 3-3. Data was obtained for the four year period 1959-1962 from 16 chemical firms, 15 petroleum firms, and 10 drug firms. The response rate in all three industries is approximately 70 percent. The percentage of firms

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[4] A set of NSF data collected by Dennis Mueller formed a considerable portion of the resulting samples and greatly aided in the data-collection process.

[5] National Science Foundation, Reviews of Data on Research and Development, No. 42, September 1963.

in the top fifteen companies ranked by sales is slightly higher for the chemical and petroleum industries and slightly lower for drugs.

Because of promises to the firms not to identify them either explicitly or implicitly, detailed descriptions of the resulting sample cannot be made without endangering this pledge. It may be noted however that the primary reason for the omission of "firms" listed in the "500" from our sample was the non-comparability of R and D data for some firms over the sample period 1959-1962 because of large-scale mergers with other companies. Over half of the omitted firms were excluded for this reason. The other specific reasons for the absence of firms was the refusal of some firms to release this information to us on the grounds that they did not participate in the NSF survey or because it was company policy not to do so. Since this latter group was however a very small minority of the firms contacted (less than 15 percent), these omissions probably do not introduce any large biases into our sample.

Table 3-3

Characteristics of Industry Samples to be Used in the Empirical Analysis

Industry	Number of Firms in Fortune 500 Listing	Number of Firms in Sample	Response Rate in Percentage Terms
Chemical	23	16	70
Drugs	14	10	71
Petroleum	21	15	71
	58	41	71

The usefulness of our approach of course rests to a large extent on the assumption that the firms in our sample actually made a serious attempt to supply the National Science Foundation with R and D data that roughly corresponds with their stated definitions. The specific details of these definitions were provided in Chapter Two and emphasize R and D in the natural sciences and engineering and exclude for the most part research in the social sciences. Some casual evidence that firms did so was provided by a comparison of R and D data in company annual reports and those supplied to us as NSF data by the firms. The figures from the two sources were usually different with the former most often exceeding the latter in value. This means most firms did make some effort to adjust their figures to the NSF definitions, although there is no way of telling to what extent this was done.

However, even if every firm tailored their statistics exactly to the NSF definition, this would of course not eliminate all of the complex problems inherently involved in measuring the dollar inputs to inventive activity.[6] By constructing our samples in the above fashion, we merely seek to obtain the most consistent set of presently available data with the hope that these data will provide a sufficient basis for a meaningful empirical study of R and D behavior. Some insights to whether this is so should be provided by the actual empirical work itself.

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[6] Simon Kuznets, _op. cit._, pp. 31-35.

III. Summary

Due to the wide differences in the performance of research and development activity among industries and the general conceptual problems associated with presently available R and D statistics, a highly non-random procedure was adopted in the construction of our data samples. First, some specific industries were selected for study on the dual criteria: (1) they be highly research oriented compared with the general class of manufacturing industries and (2) the R and D activity undertaken by firms in these industries be largely company motivated and financed. The industries chosen were chemicals, drugs, and petroleum refining. Within these industries unpublished R and D data conforming to the NSF definitions was sought from all firms appearing in the Fortune 500 listing. A response rate of approximately 70 percent was achieved for all three industries.

Our data samples were therefore deliberately contrived to include only very large firms in highly research-oriented industries. Given the constraint of having to limit the scope of our work, it was felt that this procedure would yield the most interesting and important data for study. One would expect also that many of our subsequent results can be generalized to a much larger class of situations, at least in direction if not magnitude. Even to the extent that they do not generalize, however, they should be interesting in themselves since the 40 firms selected for study here perform a highly disproportionate percentage of the total privately-financed research in the U. S. relative to their size and number.

CHAPTER FOUR

SOME HYPOTHESES ON THE DETERMINANTS AND EFFECTS OF INDUSTRIAL RESEARCH AND DEVELOPMENT

I. Introduction

In this chapter a set of hypotheses concerning the determinants and effects of industrial research and development will be constructed. The focus of this work will be on behavior at the firm level. These hypotheses will then be incorporated into some statistical models so that their validity and quantitative significance can be evaluated. Any quantitative analysis of this kind must proceed, however, within the limits imposed by the availability of necessary data.

One approach that could possibly be used in constructing the hypotheses is to assume firms are profit-maximizers and then formally trace out the implications for observable behavior with respect to this particular activity, given the constraints under which the firms operate. This is in the present context, however, not an easy task. As indicated in the previour chapter, the vast bulk of industrial research and development is performed by large corporate firms in highly oligopolistic market structures. We are thus dealing with an environment for each firm characterized by an external interdependence with the decisions of its competitors, and this introduces well-known problems into the traditional analysis with regard to the determination of optimal behavior. In addition, R and D activity is a particularly difficult corporate decision to put into this framework because of the high degree of uncertainty attached to its returns. Because of these limitations, it would be very difficult to formulate testable hypotheses on the basis of a strict economic optimality analysis.[1]

It was therefore decided not to construct hypotheses employing normative economics, but instead utilize a more "eclectic" approach based on the observations and empirical work of others studying similar type corporate behavior and also on personal interviews conducted by the author. In particular, the analysis draws freely on the vast amount of empirical studies analyzing corporate behavior with respect to investment in physical capital.[2] The fact that these studies concentrate on the behavior of large oligopolistic firms engaged in a somewhat similar decision-making situation make them a rich source of hypotheses for our present work. Starting with the results of these studies, hypotheses were formulated which were then discussed with research managers and executives of leading firms and further hypotheses subsequently evolved. These interviews were thus used not to provide

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[1] For one attempt in this regard see Edwin Mansfield, "Industrial Research Expenditures: Determinants, Prospects, and Relation of Firm Size and Inventive Output", Journal of Political Economy, August 1964, pp. 219-240. In testing his model, Mansfield did run into severe problems obtaining suitable data, using finally a sample of only eight chemical and petroleum firms for a total of 13 observations.

[2] For a survey of the alternative theories and a comprehensive bibliography see Robert Eisner and Robert H. Strotz, "Determinants of Business Investment", in Impacts of Monetary Policy, Commission on Money and Credit (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1963), pp. 820-831. For and eclectic point of view to the subject see John Meyer and Robert Glauber, Investment Decisions, Economic Forecasting, and Public Policy, (Boston, Mass.: Harvard University Business School, 1964).

evidence for any given effect but to generate meaningful conjectures that could be tested on a much wider sample.

The use of this approach for formulating hypotheses of course does not mean that the resulting models will contradict those based on rational behavioral postulates but only that have not formally derived from such principles. Implicit in our analysis is the assumption that firms act rationally in the sense that they attempt to achieve certain objectives in accordance with the constraints of their particular situations and the expected consequences of their actions. It is to the relevant factor in this regard for the research and development decision of the large corporate firms that our present analysis is directed. While a great deal of significance in this area is undoubtedly qualitative and intangible in nature and cannot be put into testable form, there are several factors that can be at least partially quantified, and these will serve as the basis for our subsequent empirical analysis.

II. The Factors that Influence Firm R and D Behavior

Research and development in industry essentially involves the employment of highly skilled manpower, equipment, and support personnel with the objective of obtaining eventually profitable new products and processes. From an economic standpoint, it is the same as other investments - an expenditure of scarce funds now with the expectation of a probable future stream of benefits. We may divide the factors influencing R and D decisions into three classes: technological, financial, and marketing. While all three of these categories overlap, it is conseptually useful to consider each of them separately.

A. Technological Factors

At the first level, the technical orientation of the industry to which a firm belongs and the scientific base of more fundamental knowledge upon which it has to draw will be important factors in how much research it does. For successful applied research, it is usually necessary that a stock of more fundamental scientific knowledge be constantly accumulated. In the case of the industries that will be studied here, the chemical-processing industries, there is of course an excellent scientific foundation that is maintained by extensive basic research in academic, government, and industrial laboratories. The research intensity of firms in these industries tends correspondingly to be much higher than in most others.

Even within a research-oriented industry such as chemicals, however, there exists a substantial difference in the firms' capacities to do successful research and development. This is perhaps due to the fact that research has more problems and uncertainties associated with it than most other corporate activities. A great deal has been written on the problems of motivating industrial scientists and engineers and integrating research with other company activities.[3] The successful research administrator must be

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[3]See, for example, Jerome W. Blood, The Management of Scientific Talent, (New York: American Management Association, 1963). James R. Bright, Technological Planning on the Corporate Level, (Boston, Mass.:

a person who can manage creative and often highly individualistic researchers, and at the same time be able to evaluate research projects from the standpoint of economic growth.

While there seems to be no set formulas available for optimal research management, some characteristics of the firms with successful research programs do emerge. These firms generally have a long "research tradition" and possess a reasonably stable staff of highly competent researchers. Why do some firms have a "research tradition" and others do not? Part of the answer undoubtedly lies in the management's general attitude toward risk-taking and economic change. The majority of research projects are economic failures, and a firm engaged in research must be willing to sustain these failures with the hope that the small proportion of successes will make the program as a whole profitable. Similarly, the payoff-periods of industrial research projects are longer than in other corporate investments, and thus a research-oriented firm must also be willing to tie up its investment funds for longer periods of time.[4]

A second set of characteristics of the successful research performer has to do with the ability to utilize technical successes commercially. This involves establishing organizational procedures which allow communication

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Harvard University Graduate School of Business Administration, 1962). Ralph M. Hower and Charles D. Orth, Managers and Scientists, (Boston, Mass.: Harvard University Press, 1963).

[4]The results of a McGraw-Hill survey show that the average expected time to the beginning of full-time production for research projects is three to seven years depending on whether the research is in the basic, applied, or developmental stage.

and cooperation between the researchers and production and marketing personnel, and a receptivity on the latter group's part to the technical changes produced by research. It is here that the research administrator plays such an important role in integrating research and development with other company activities. Isolation of research and development from other firm activities has been an often mentioned reason for its lack of economic success.[5]

The above discussion stresses the importance of technological considerations in shaping a firm's expectations concerning the future returns to research and development. As enumerated above, the firm's expectations will be a function of such technological factors as the caliber of its scientists and engineers, the quality of its research administrators, and the degree of integration of research with other firm activities. While it is impossible to include these essentially intangible factors directly into our regression analysis, they may be taken into account in so far as they are reflected in some part of the past research output of the firm. Our task is therefore to find a proxy variable of this type which embodies them. We shall return to a discussion of the various alternatives in this regard in the section on the empirical analysis itself.

Another factor that has been mentioned as influencing the capacity and motivation of the firm to do research, both technologically and in other

[5] See especially in this regard, Part I of C. F. Carter and B. R. Williams, Science in Industry: Policy for Progress, (London, Oxford University Press, 1959).

ways, is its size. There are currently two widely divergent schools of thought in the economic literature on this question. One school maintains bigness is a positive factor in stimulating research and development since a large firm can better sustain the risks involved in R and D and is more capable of exploiting any technical successes commercially because of its larger and more diversified sales facilities.[6] The other school of thought maintains that large size will have a negative effect due to the fact that larger firms will have less incentive to do R and D and in addition that the larger research organizations in big firms are inevitably more inefficient than those of smaller firms.[7]

While the above controversy has engendered a great deal of heated debate, the issue in the final analysis is an empirical one and cannot be resolved on the basis of deductive logic alone. All involved in the controversy seem to accept the easily verified facts that a certain minimum size is needed before firms will undertake organized inventive activity and also that the absolute amount of R and D expenditures will tend to increase with firm size. The important question that is contested is whether firm R and D expenditures will tend to increase more or less proportionately than firm size after the threshold level. The empirical results thus far have not been

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[6] See Henry Villard, "Competition, Oligopoly, and Research", Journal of Political Economy, December 1958. Joseph A. Schumpeter, Capitalism, Socialism and Democracy, (New York: Harper and Row Publishers, Inc.) and John K. Galbraith, American Capitalism, (Boston, Mass.: Houghton Mifflin Co., 1952).

[7] In this regard, see Jacob Schmookler, "Bigness, Fewness, and Research", Journal of Political Economy, December 1959, pp. 628-632, and Gilbert W. Nutter, "Monopoly, Bigness, and Progress", Journal of Political Economy, June 1959, pp. 520-527.

very conclusive. The work of Mansfield and others has shown no clear tendency in one direction or the other.[8]

The above question of the effect of firm size on R and D expenditures is a very important one from the standpoint of deciding whether government pursuit of a vigorous anti-trust policy is socially desirable. In this regard it is not only important to establish whether big firms spend proportionately more or less on research, but also to obtain some empirical evidence on the reason for such behavior. Depending on whether size-effects are due to differences in technological capacity to do successful research or result from differences in financial or marketing capacities, public policies of very different character would be called for in meeting various national objectives. We shall attempt to provide some insights into these questions in the empirical analysis itself.

Before turning to a consideration of the financial factors influencing research and development, it is appropriate to examine the composition of R and D costs in the chemical industry. In Table 4-1, a percentage breakdown is given for the chemical industry in 1958. The most important fact emerging from these figures is the high percentage of R and D expenditures which are payments for personnel services. Fifty-eight percent of the costs were for scientists and supporting personnel. As was emphasized above,

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[8] Mansfield's work indicates it depends on the specific industry under study with the chemical industry showing a more than proportionate increase in research and development expenditures to firm size and most others showing a less than proportionate increase. See Edwin Mansfield, _op. cit._, pp. 333-334.

the maintenance of a stable research staff is one of the main technological conditions for successful research. This high percentage of personnel cost thus implies that very little flexibility in R and D expenditures is possible in the short run in response to changing conditions. This contrasts markedly with expenditures on physical investment which are mainly materials cost. In the case of R and D expenditures, materials costs accounts for only 15 percent of the total. The other non-payroll costs are divided between depreciation, company overhead, service and supporting costs. While a degree of flexibility is afforded by some of these supporting costs, they form a small percentage of the total research cost. The effect of this kind of production structure on the cyclical behavior of R and D expenditures will be taken up again in the next section on the financial factors influencing research and development.

Table 4-1

Percentage Breakdown of Research and Development
Costs in the Chemical Industry, 1958

	Percent	
Payroll Costs		
Scientists and engineers	38	
Supporting personnel	20	
Total Payroll		58
Non-payroll Costs		
Materials	15	
Depreciation	7	
Other costs	21	
Total Non-payroll		42

Source: National Science Foundation, Funds for Research and Development in Industry, (Washington, D. C. , 1961), p. 81.

B. Financial Factors

Since research is an investment to the industrial firm, one would expect it to be influenced by financial conditions and the supply of investment funds. A completely classical treatment of the R and D decision in terms of economic theory would call for a ranking of prospective projects on the basis of their rate of return and risk and the incorporation of this information along with that from other possible investments into an investment demand curve. This demand curve, together with a supply of funds schedule reflecting the cost of money from both internal and external sources, would then be used to determine simultaneously the lowest acceptable rate of return from a specific project and the total amounts to be spent on R and D and other investment activities. The key exogeneous variable for the firm in this analysis is thus its marginal rate of interest since it is this variable, together with the firm's marginal expected return, that provides the basic equilibrating mechanism of the classical approach.

There has been a good deal of discussion and controversy in the economic literature regarding the strict applicability of the above analysis to plant and equipment investment decisions of businessmen and, in particular, those of large corporations.[9] The reasons for which many economists have questioned the spirit of the classical approach fall into two groups.

(i) investment demand is interest inelastic,

(ii) businessmen have a strong aversion to using external sources of

[9] See references listed in footnote 2 of this chapter.

funds while at the same time imputing a low opportunity cost to internally-generated funds.

Either reason is sufficient to substantially modify the nature of the classical analysis. Those advancing the first reason do so essentially on the grounds that the profitability of physical investment depends on a high level of business activity and rather than make long-term expectations about this level, firms adapt their productive capacity in response to current changes in it. For the case of research and development, however, the reasoning of these accelerator theories of investment is not very relevant, since the profits to research and development are derived from the sales of new products or cost reductions from new processes. Neither of these research outputs are crucially dependent on a high level of business activity for economic success.[10]

The second reason advanced above, the reluctance of firms to use external sources of finance would, if true, be very relevant to the R and D decision. In terms of traditional analysis, this type of behavior has been incorporated into the supply of funds schedule by means of a large discontinuity where the internal and external funds segments are joined together. This is illustrated in Figure 4-1 below.

The implication for investment expenditures is that they are now a function of the availability of internally-generated funds rather than demand

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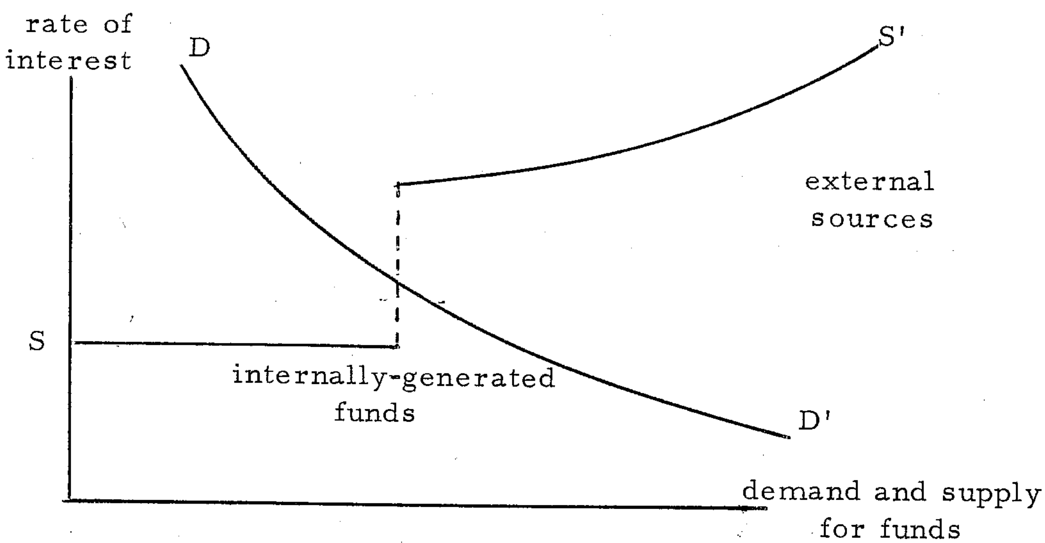
[10] This does not mean to suggest that research and development is functionally unrelated to sales changes of the firm, but only that the normal reasons for expecting an accelerator effect in physical-capital investment are not very relevant to research and development.

Figure 4-1

The Determination of the Optimal Level of Total Investment with a Kinked Supply of Funds Schedule



side considerations or conditions in the external-debt market. If businessmen do in fact follow this kind of behavior in determining their total investment expenditures, this would, of course, still not preclude them from explicitly or implicitly allocating their internal funds between research and development, fixed capital, advertising, and other kinds of investment on a rate of return basis. We would then essentially be dealing with a case of profit maximization under a budget constraint.

In our interviews with financial executives and research directors of large chemical firms, both the influence of the availability of internally-generated funds on R and D expenditures and the interaction between research and development and other types of investment decisions were discussed. We present a summary of these interviews here not so much as evidence for any one position but rather more as useful background information for the purpose of constructing meaningful hypotheses.

With regard to the first issue, the influence of the availability of internally-generated funds on R and D expenditures, the results of interviews with nine different firms[11] are grouped into three basic categories - those in which the firms feel that this influence is very significant, a second group that states it plays a significant but more limited role, and a third group which feels it has little or no part in determining research and development expenditures. The basis for grouping firms in this manner is discussed below. The results are tabulated in Table 4-2. Five firms were classified in the first category, three in the second, and one in the third.

Table 4-2

The Effect of the Availability of Internally-Generated Funds on Research and Development Expenditures, Results of Interviews with Nine Chemical Companies

Number of Firms Indicating the Influence was:	
Very important	5
Significant	3
Not important	1
Total	9

[11] While only nine firms were interviewed, they were responsible for well over half of the total research and development expenditures in the chemical industry. In addition, the results of the interviews are classified by firms without explicitly taking into account the differences in attitudes where more than one person was interviewed in the same firm. This does not present a problem in general, however, because there was basic agreement among the people interviewed from the same firm except for one instance.

The firms in Group I all expressed the opinion that the availability of funds was the most important factor in initially arriving at a figure for R and D expenditures, which could then be adjusted up or down on the basis of other factors such as technological developments or competitive pressures. These firms invested almost entirely out of their internal funds and essentially espoused a philosophy of a research and development program growing in parallel with overall firm growth. In cyclical downturns, however, rather than cutting back expenditures on R and D in response to a decreased internal-funds flow, they instead kept expenditures relatively constant due to the constraint of maintaining a stable research staff for technological reasons.

The second classification was comprised of three firms that stated the availability of internally-generated funds play a more limited role in determining their R and D expenditures. Two of the three firms indicated a willingness to use the external-debt markets and felt that while internally-generated funds were a factor to be considered, it was not a serious constraint to expenditures that could be justified on various other grounds. The third firm in category II indicated it generally had ample funds to finance its desired level of R and D expenditures, although occasionally expenditures might be constrained because the supply of funds were tight.

Only one firm interviewed stated that the availability of internal funds had virtually no influence on the total size of R and D expenditures.

The general conclusions that emerge from these interviews tend to support the hypothesis of the importance of internally-generated funds in determining R and D expenditures. Of the nine firms that were interviewed eight indicated that internally-generated funds were a significant factor, and five of these indicated it was of prime importance. The regression results to be presented later will give a basis for testing this hypothesis and assessing its quantitative significance.

Even if there is a close link existing between various types of investment spending and the supply of internally-generated funds, the proportion devoted to any one type of investment can vary significantly over time in any given firm depending on what criteria are used to allocate funds among investment activities. As stated above, one possibility is that all the possible investment projects are ranked according to their rate of return and corresponding risk, and the allocation made on the basis of the optimal set of projects. The possible use of such a criteria formed the basis for another area of inquiry in the interviews. The results are given in Table 4-3. Only two of the nine firms interviewed indicated the use of company-wide criteria to select R and D projects in the same manner as other types of investment, and this was done only with respect to development projects. Three others indicated the use of such criteria as an aid to choosing between alternative development projects but without using them as a device to decide on allocations between research and development and other types of company investments. In other words, beginning with a certain amount

Table 4-3

The Use of Explicit Rate of Return Criteria by Management to Select Research and Development Projects, Results of Interviews with Nine Chemical Firms

Number of Firms Using these Criteria:	
On the same basis as other company investment	2
As an aid in selecting research and development projects but not in allocating between different categories of investment	3
Not at all	4
Total	9

of total funds for R and D determined by some basis other than by rates of return, these criteria were then used by three firms to aid in deciding on allocations among alternative R and D projects. Four of the nine firms interviewed stated no use was made of these techniques.

The above results tend to argue against the proposition that firms allocate funds to research and development on the basis of an optimality analysis. Only two of the nine firms interviewed were explicitly using any rate of return criteria in an attempt to bring their marginal rate of return in line with other types of investment. This does not mean, however, that the interfirm differences in R and D expenditures do not reflect in some manner the differences in probable returns among firms, but only that most firms face enough uncertainty to avoid making allocations on an explicit rate of return basis. In basic research, in particular, no one used these criteria for selecting projects since at this stage the firm does not even have a specific commercial application in mind, and the technical uncertainties are very great. At the later stages of the R and D process, however, the most important unknown becomes the response of one's competitors.[12] In the next section on marketing factors affecting research and development, we take up some of the problems that naturally arise in this regard for firms involved in an oligopolistic marketing structure.

C. Marketing Factors

One of the factors attesting to the increased importance of research and development as a competitive weapon in American industry is the annual size of new-product flows. A survey of manufacturing sales for 1960 revealed that 10 percent of all sales in that year were for products that did not exist in 1956, and in the chemical industry, in particular, this figure amounted to 16 percent.[13] It would thus appear that research and development along with advertising has become one of the major variables available to the modern corporation (at least in many industries) in its effort to maintain and expand their sales and marketing position.

This increased importance of inventive activity as a competitive weapon in many industries together with the high degree of uncertainty in evaluating

[12] This is more likely to be the case when the research is for new products rather than for new processes. A McGraw-Hill survey of the chemical industry in 1958, however, showed that only 6 percent of the research was for new processes.

[13] 14th Annual McGraw-Hill Survey, Business Plans for New Plants and Equipment, 1961-1964 (New York: McGraw-Hill, 1961).

its probable returns tend to give rise to certain forms of behavior frequently observed in oligopolistic situations. The distinguishing characteristic of this behavior is the "realitivistic" viewpoint which pervades the firm decision-making process. It is not the firm's absolute level of research and development expenditures that matters so much, but its performance relative to its closest competitors or general industry average which becomes crucial. Two distinctly different types of reactions commonly occur in such situations. A firm will either try to stay ahead of competitors in the level and quality of its research performance (i. e., act as an industry leader) or it may merely try to remain on a par with certain other firms or the industry average (i. e., essentially be an imitator). Numerous examples of both types of firm strategies were given in our interviews in the chemical industry.

The large flow of new products potentially realizable from a dominant research and development program make this an especially attractive strategy for the firm that desires rapid growth and diversification of their output mix. The process, if successful, also tends to become self-reinforcing since rapid growth and diversification will tend to make future research and development more feasible and profitable. The inherent risk in pursuing such a strategy is however a greater fluctuation in the firm's potential earnings and this will be an important factor affecting interfirm participation in research and development. In general, then, the more risk-taking growth-conscious firms in any industry can also be expected to be among the leaders in research performance. Under certain conditions, however, such firms may find it more desirable to merge with smaller existing firms to accomplish these objectives than to try to be more research intensive than their competitors. Nevertheless, government anti-trust policies and the lack of enough desirable opportunities will usually constrain expansionary activities of this type and make strategies such as research and development necessary.

While a high level of R and D expenditures by a firm can be classified as a risk-taking strategy, it does not follow that a low level is necessarily a risk-averting one. Firms in oligopolistic market structures must be concerned about the research activities of their competitors leading to products that will result in sales losses in their established markets. It has been alleged that a large part of industrial research and development is really "defensive" in character[14] although it is very difficult to get any meaningful measure of this kind. The fact that a firm's security can be threatened by incorrect research and development policies and great uncertainties prevail in predicting the probable effects of different actions does, however, make a great deal of imitative behavior likely on the part of the more conservative firms. The most often mentioned examples of this phenomenon in our interviews was the use of target R and D to sales ratios determined by some performance measure external to the firm. For example, one firm indicated that their research expenditures were set so that their R and D to sales ratio was roughly equivalent to the industry sales leader. Others

[14] See Donald Hamberg, "Invention in the Industrial Research Laboratory", <u>Journal of Political Economy</u>, April 1963, pp. 95-115.

mentioned the desire to keep their R and D to sales ratio approximately in line with the industry average.

Of course, research and development statistics between firms are often not very comparable and "the keeping up with the Joneses" philosophy described above involves as much subjectively appraising and reacting to the total quality of the research effort of a close competitor as it does a mechanical ajustment in line with a few rules of thumb. Some degree of imitative behavior would appear however to be a consequence of the oligopolistic nature of the industry, and we shall try to obtain some evidence for it in the regression analysis. While this is not an easy proposition to test empirically, the fact that most firms indicate adjustments in this regard in the form of changes in R and D to sales ratios gives us some basis for analyzing the problem.

III. Summary of the Hypotheses

We may summarize the main hypotheses put forth in the preceding section in succinct form as:

1) The technical orientation and scientific base of an industry to which a firm belongs are important first level determinants of how much it spends for research and development.

2) The capacity of firms to do successful research varies considerably among firms within a given industry, even one which is very technically oriented. This is due to the differences in the caliber of the scientists

and engineers, the quality of the research administration, and the degree of integration of research with other firm activities. A firm's R and D expenditures will vary positively with its ability to do successful research.

3) The size of a firm will be an important determinant of the absolute level of its R and D expenditures, but it is difficult to predict a priori whether large firms will spend more or less proportionately in relation to their size than smaller firms and whether this is due to technological, financial, or marketing factors.

4) There exists a positive relationship between a firm's R and D expenditures and the size of its internally-generated funds due to reluctance of most firms to use external sources of finance.

5) This positive relationship described by (4) will operate most strongly in the upturn part of the business cycle; in the downturn it will usually mean lack of growth rather than any large scale contraction of R and D expenditures. This results from the necessity of maintaining a stable supply of research personnel as a technological requirement for successful research.

6) The potential importance of research and development on the competitive position of firms in technically-oriented industries (via new-product innovation) together with the uncertainty in predicting the returns will give rise to a "realitivistic" viewpoint in the decision-making procedures determining the firm's R and D expenditures.

7) The firms motivated toward a high rate of growth and diversification in any such industry and willing also to bear the accompanying risks will be among the industry leaders in R and D performance; there will be a great deal of imitation of these firms and adjustment in line with the industry average by competing firms in the industry less disposed to such risk-taking.

CHAPTER FIVE

AN ECONOMETRIC ANALYSIS OF THE DETERMINANTS OF INDUSTRIAL RESEARCH AND DEVELOPMENT EXPENDITURES

In the present chapter our hypotheses concerning the determinants of industrial research and development will be quantified in so far as possible and incorporated as variables into a statistical model explaining R and D. The parameters of this model will then be estimated and the effects of various variables on R and D evaluated by multiple-regression techniques. The samples that will be used for this analysis are those described in Chapter Three consisting of observations on firms in the chemical, drug, and petroleum industries over the period 1959-1962. Some alternative explanations of R and D expenditures will also be investigated using these data.

I. Some Preliminary Remarks on the Samples

In combining the available data in this study into samples for the purposes of hypothesis-testing and model-estimation, several options are available. At one extreme, one can estimate a separate regression equation for each industry (chemical, drug, and petroleum) and each year (1959-1962) making a total of twelve separate regression equations to be estimated for each model. At the other extreme, one can pool all observations irrespective of industry-grouping or time-period into one grand sample and estimate only a single relationship for each model. The advantage of the latter procedure is the considerable gain in the number of degrees of freedom. If there are inherent inhomogeneities across industry-groupings or over time, however, it will lead to serious biases in the resulting estimates.[1]

In the analysis which follows, we will choose the intermediate course of working with samples that pool the observations across firms and over time only within a particular industry and estimate a separate regression equation for each industry. The main variation in each of these pooled industry samples comes from the cross-section of firms rather than from changes in each firm's observations over time. In order to test whether any significant structural changes occurred over the four-year period encompassed by these samples, F tests of the hypotheses of homogeneous intercepts and slopes over time were performed for several of our regression equations. They showed that one cannot reject the hypothesis of homogeneous parameters over time, and thus the procedure of pooling over time appears justified.

The hypothesis of homogeneous parameters is not true, however, if one uses samples which are pooled across industry lines. Nevertheless, if one still wishes to estimate parameters using a single grand sample, dummy variables may be used to capture these interindustry differences. We will estimate separate regression equations for each industry, however, since one of our main objectives is to compare the overall explanatory power of our hypotheses for different industries with varying characteristics.

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[1] For a discussion of this problem see Chapters V and VI of Edwin Kuh, Capital Stock Growth: A Micro-Econometric Approach, (Amsterdam: North Holland Publishing Company, 1963).

The resulting industry samples in each case are characterized by large variations in firm size. Because several of the factors hypothesized to influence R and D expenditures are also size-correlated, a very large part of the sample variation in the absolute level of R and D expenditures can be explained by corresponding sample variations in some measure of firm size such as sales, assets, or employment. Since we are interested here in quantitatively investigating the separate effects of various factors on research and development expenditures, we must first remove the common effect of firm size on many of the proposed explanatory variables in some manner. In order to remove the size-correlation from these variables, we will use the specific procedure of dividing them by sales and estimate our equations using ratios rather than absolute values. Our dependent variable will therefore be a measure of the research intensity of a firm. Specifically, it will be the size of the firm's R and D expenditures relative to its sales. Sales is chosen as the particular size deflator here because firms indicated in our interviews that it is a more relevant variable in budget considerations than other possible measures of firm size. The results are not substantially altered, however, if some other measure is used.[2]

Estimation of our regression equations in ratio form has the further advantage of removing a statistical problem that is present when the

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[2] For a full discussion of the merits of various alternatives in this regard see F. M. Scherer, "Size of Firm, Oligopoly and Research: A Comment", Canadian Journal of Economics and Political Science, XXXI, No. 2, May 1965, pp. 256-266.

equations are estimated using absolute values of the variables. This is the problem of heteroscedasticity. Plots of the residuals for equations estimated using absolute values show a marked tendency for the size of these residuals to increase as the independent variable increases. This difficulty is eliminated when the same equations are estimated in ratio form.[3]

II. Formulating the Model

Our hypotheses of the preceding chapter propose a set of technological, financial, and marketing factors that influence a firm's research intensity. Some of these factors, such as the flow of internally-generated funds, are readily translated into measurable variables. Other factors, particularly those having to do with competitive interactions, are very difficult to express as variables in a statistical model. In this section we present a discussion of how we plan to quantify these various factors by means of balance sheet items and other indices of firm activity.

A. Technological Factors

Turning first in our discussion to technological factors, it was postulated in the previous chapter that interfirm differences in technological productivity would be an important factor in explaining how research intensive a firm is. However, the characteristics of the firm specified as relevant

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[3] No formal tests for heteroscedasticity were employed because of the existence of ties between observations due to the pooling procedure used here. The difference in the plots of the residuals before and after taking ratios is quite striking however.

to its technological capacity to do research -- the quality of its scientists, the form of its research organization, etc. -- cannot be directly incorporated into a regression model. In their place a proxy variable must be employed which hopefully embodies these essentially intangible factors. In this regard, some measure of the past research outputs relative to research inputs over a sufficiently long period of time would seem appropriate, since it would act as a composite variable showing the net effect of these intangible factors on the firm's research productivity. For our present purposes, we are actually only really interested in the net effect of these factors, since it is presumably what will influence the firm's final decision on R and D expenditures.

In order to construct such a proxy variable of technological capacity, three possible measures of a firm's research output were considered: new-product sales, number of patents granted to the firm, and the number of significant inventions made by the firm. Given the strong product orientation of industrial research and development, perhaps the best measure of the three from a conceptual standpoint is new-product sales. Unfortunately, it is difficult to obtain new-product data from firms, and in addition there are substantial differences in definitions and product classification between firms which make use of these numbers in a cross-section analysis quite hazardous. Of the two other measures of research output, patents is the more attractive since all patented inventions must pass certain uniform criteria of the U. S. Patent Office and patent statistics are readily available.

Attempts at constructing a series of significant inventions made by the firm were beset by serious methodological problems and thus discarded.[4]

Our measure of research outputs will therefore be the number of patents granted to a firm in a specified prior period. To form our technological variable, this research output measure will be divided by a research-input measure -- specifically the number of scientists and engineers over the period when the patented inventions were conceived.[5] Our technological variable is thus an input-output ratio measuring a particular aspect of research-productivity. We are postulating here that, ceterus paribus, firms which have higher research-productivity will be more research intensive.

Before turning to a discussion of other factors affecting research intensity, it may be noted here that patents have been used elsewhere as a measure of inventive output,[6] and their limitations in this regard extensively discussed.[7] One can summarize these limitations into three basic points: (1) not all inventions are patentable; (2) the economic value of

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[4] For some interesting attempts to measure inventive output in this manner see Edwin Mansfield, "Industrial Research Expenditures: Determinants, Prospects, and Relation to Firm Size and Inventive Output", Journal of Political Economy, August 1964, pp. 334-337.

[5] During the period under study, the patent office took an average of approximately three and one-half years to process a patent. In addition, the average lag between conception of an invention and time of patent application has been estimated at less than a year.

[6] For the most recent article and a good set of references to the literature see F. M. Scherer, "Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions", American Economic Review, December 1965, pp. 1097-1125.

[7] See, in particular, the papers by Simon Kuznets, Barkev Sanders, and Jacob Schmookler in The Rate and Direction of Inventive Activity, op. cit.

patented inventions vary greatly; and (3) the propensity to patent inventions may vary significantly from firm to firm. At the very least, these imperfections from an ideal measure of research output will introduce some random measurement error into our independent variable, which so long as it is not systematically related to our dependent variable, will impart some negative bias to our expected positive relationship.[8] At worst, these imperfections could introduce errors that are systematically related to our dependent variable in such a way as to introduce a strong positive bias and possibly produce a spurious acceptance of our postulated relationship.[9]

Given the nature of the samples that we are dealing with, it is highly unlikely that the first two limitations mentioned above would introduce serious problems. Concerning the third point above, however, there appears to be no strong a priori arguments nor any substantial empirical evidence concerning the nature of this relation. It therefore remains a possibility that the propensity of a firm to patent might be systematically correlated in a positive way with its research-intensity. If this were the case, it would result in a positive relation between research-intensity and patent output that was due, at least in part, to a firm's legal activity to obtain patents rather than its true level of inventive output. Some data are, however, available to analyze this question for the firms under study, and we shall defer further discussion to the actual empirical work.

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[8] See Chapter 6 of J. Johnston, Econometric Methods (New York: McGraw-Hill Book Company, Inc., 1963).

[9] A positive bias will result if the research-intensity of a firm is correlated (i) positively with the proportion of patentable inventions of a firm, (ii) negatively with the economic value of the patents, (iii) positively with the propensity to patent.

B. Financial Factors

Turning next to financial factors, we have hypothesized that the size of a firm's internally-generated funds will be an important determinant of its R and D expenditures. This relation is due to the propensity of modern corporations to invest out of their savings rather than using external sources of finance. Our second explanatory variable of research intensity will therefore be a measure of each firm's internal-fund flow in relation to its sales. Internally-generated funds become available to the firm from three sources: profits, depreciation and depletion charges, and other miscellaneous non-cash charges. In this study we shall ignore the third source which usually forms a very small part of the total. We shall take as the size of internally-generated funds available to a firm in any given period, the sum of its profits and depreciation and depletion charges accruing in the immediately preceding period.

There is some question whether the profits component of this internal-fund flow variable should be calculated before or after distribution of earnings to the stockholders. Since firms are free to decide how much of their earnings to retain for internal use, the total level of profits would seem to be the best measure of available funds. The work of Lintner suggests however that dividends payments are viewed by most firms as a priority use of earning and are very sticky in the short run.[10] If this is the case, retained

[10] John Lintner, "Distribution of Incomes of Corporations Among Dividends, Retained Earnings, and Taxes", American Economic Review, May 1956, pp. 97-113.

earnings might be a more appropriate variable to include in a measure of available funds. Since cross-sectional models are basically long-run in nature, we lean here toward the use of total profits rather than retained earnings. Both alternatives will, however, be used in the regression estimates.

As pointed out above, the positive relation that is postulated here between R and D expenditures and internally-generated funds cannot be expected to operate symmetrically over all parts of the business cycle. Firms must maintain reasonably stable research programs if they are to be technologically successful. Any downturns in general level of business activity and the level of internally-generated funds will most likely act therefore to restrict growth in research expenditures rather than cause any large scale contraction. For the present sample, however, we are dealing with a period of years (1959-1962) in which there is an upward trend in available funds for each firm, and the relation between research and internally-generated funds can be specified as time-invariant. In a sample ranging over periods with some cyclical movement, the coefficients can be expected to exhibit this assymetric behavior over the cycle.

C. Marketing Factors

As our third explanatory variable of research-intensity, we will use a measure of firm product-line diversification. As enumerated in our discussion on marketing factors influencing industrial research, the possibility of rapid growth and diversification is one of the main inducement for R and D activity. Since an index of present firm diversification is in part a cumulative measure of the firm's past desires and successes concerning these motives, the addition of this variable should capture some of the intefirm differences in this regard.[11] In addition, the firm's degree of diversification can be expected to positively influence its profit expectations toward R and D, since the more diversified firm is likely to be better able to exploit unexpected research output than one with narrower base of operations. For both of the above reasons, a positive regression coefficient is therefore expected between a firm's degree of diversification and its research intensity.

In order to construct an index of diversification, data were obtained for each firm that classified all its products into standard SIC five-digit product classifications.[12] Our index is based on the number of separate classifications in which a firm produces products. For the case of the chemical and petroleum industries, almost all the product classes appeared of sufficient technical character to at least some potential relevance to the R and D activity. For these two industries our index will therefore be the total number of separate SIC classifications encompassed by the firm's product mix. For the drug industry, however, an examination of the actual

[11] This will be a function in part of a firm's past R and D efforts and therefore this is one of the many factors linking past and present R and D.

[12] The data used here was from the Fortune Plant and Product Directory, 1961 edition. The index is conceptually similar to one used by Michael Gort, Diversification and Integration in American Industry, (Princeton, N. J.: Princeton University Press, National Bureau of Economic Research, 1962).

product mix of highly diversified drug firms indicates a tendency for them to expand into products only tangentially related to the manufacture of drugs proper (i.e., adhesives, brushes, glass bottles, toilet preparations, plastic products, etc.). These product lines offer very little opportunity for the applicability of research outputs. It was therefore decided that a more appropriate index of diversification for the drug industry would be obtained by counting only the number of SIC classifications that are concerned directly with the manufacture of drugs proper.

For the three industries under study, the resulting diversification indices indicate that petroleum firms have the least variability in product structure. Firms in this industry are characterized by a high degree of integration within the industry and very little diversification into products of other industries. The chemical and drug industries, on the other hand, are characterized by considerable differences among firms in the degree of product-line diversification. It is in these latter two industries where diversification can be expected to have a more prominent effect on research decisions.

The remaining set of factors that were considered in our chapter on research determinants have to do with the influence of competitive interactions on the research decisions of firms. As our discussion there indicated, the most important of these interactions are likely to be at the project selection level and also of a very qualitative nature. It was suggested, however, that one consequence of the high uncertainty associated with the returns to research activity together with its potential importance to the oligopolistic firm's growth and market share would be a great deal of imitative behavior in the total size of research expenditures of close rivals. To the extent that this imitative behavior is manifested by firms adhering to a general industry R and D to sales ratio (as was suggested by some firms), it is readily testable by our present analysis. Since research intensity or the ratio of a firm's R and D expenditures to its sales is the dependent variable in our analysis, this specific type of imitative behavior would imply less variability in this variable than might otherwise be expected and cause the intercept of the regression equation to become statistically significant relative to the explanatory variables postulated above. The sign and statistical significance of the intercept term in our regression model will therefore provide a first level test of this proposition. As was emphasized above, however, the type of imitative behavior relevant to the oligopolistic situation encountered here is most likely to be of a more subtle and complex nature and not very amenable to inclusion in a multiple-regression analysis.

D. The Model

The above discussion leaves us essentially with three explanatory variables of firm research intensity -- a research-productivity variable consisting of the level of patented output realized by the firm relative to its input of scientific personnel over a prior period, a variable dealing with the financial resources of the firm which is equal to the level of internally generated funds of the firm as a percentage of its total sales, and an index of firm product diversification. We may express our model formally as

$$\frac{R_{it}}{S_{it}} = b_o + b_1 P_i + b_2 \frac{I_{i,t-1}}{S_{it}} + b_3 D_i \qquad (5.1)$$

where R_{it} is the level of research expenditures of the i^{th} firm in the t^{th} period, S_{it} is the level of sales of the i^{th} firm in the t^{th} period, $I_{i,t-1}$ is the sum of after-tax profits plus depreciation and depletion expenses of the i^{th} firm in the t-1 period, P_i is the number of patents received per scientist and engineer employed by the i^{th} firm in a prior four-year period, and D_i is the index of diversification of the i^{th} firm (the number of separate five-digit SIC product classification in which it produces).

Our hypotheses suggest that coefficients b_1, b_2, and b_3 will all be positive. In addition, the intercept term, b_o, of this equation serves in a sense as a possible fourth explanatory variable since it shows the influence of sales on research expenditures and in particular serves as a test of proposition that firms tend to adhere to an industry-wide R and D to sales ratio. We turn now to an investigation of the empirical performance of this model on our data samples.

III. The Empirical Results

Using our data samples on firms in the chemical, drug, and petroleum industries over the period 1959-1962, least-squares estimates of the coefficients of equation (5.1) were obtained. The results are presented in Table 5-1 below. All of the regression coefficients are of the postulated sign and significant at the one-percent level,[13] except for the diversification-variable coeffficient in the petroleum industry which is positive but statistically insignificant. The overall explanatory power of our model is quite good in the case of the chemical and drug industries given the nature of the samples under study (R^2 = 0.63 and 0.86, respectively), but is low for the petroleum industry (R^2 = 0.25). An examination of the results in Table 5-1 also shows the estimates of the intercepts terms of equation (5.1) are such to cast considerable doubt on the proposition that firms adhere to an industry-wide R and D to sales ratio. The only statistically significant intercept is negative (the drug industry) and the positive coefficients for the other two industries were negligible in value.

Table 5-1

Estimation of Regression Equation $\frac{R_{it}}{S_{it}} = b_o + b_1 P_i + b_2 \frac{I_{i,t-1}}{S_{it}} + b_3 D_i$ for the Chemical, Drug, and Petroleum Industries for the Period 1959 - 1962

Industry	b_o	b_1	b_2	b_3	$\bar{R}^2$	F	n
Chemicals	0.006 (0.004)	0.12* (0.02)	0.078* (0.023)	0.019* (0.004)	0.63	29.76	60
Drugs	- 0.03* (0.01)	0.54* (0.12)	0.26* (0.05)	0.41* (0.07)	0.86	73.71	35
Petroleum	0.002 (0.002)	0.016* (0.005)	0.020* (0.006)	0.0049 (0.0071)	0.29	5.46	55

Notes: Numbers below coefficient estimates are standard error estimates; technological and diversification variables (P_i and D_i) have been multiplied by scale factors in order to present results more conveniently; n = number of observations.

[13] In all of the results, regression estimates demarked with a single asterick

The above regression results indicate that interfirm differences in technology, the availability of funds, and diversification all are important in explaining difference in research intensity with no single factor having a dominant influence. Table 5-1 also shows that the size of the regression coefficient associated with each of these variables increases with the research orientation of the industry involved -- being the lowest in the petroleum industry and the highest in the drug industry in every case. Thus, as research looms more important as a competitive strategy to the firms of an industry, each of our independent variables exerts a correspondingly greater effect on the level of research that a firm performs.

All these results are substantially unchanged when the profit component of our available-funds variable is measured by the firm's retained earnings rather than its total after-tax profits. Regression estimates for equation (5.1) using this alternate form of internal-fund availability are presented in Table 5-2. As this table shows, the fit of the regresssion equation is now slightly better for chemicals and slightly poorer for drugs. Except for these minor differences, however, the results are the same as those obtained previously.

In the present analysis, the positive relation existing between patented output per research input and the research intensity of a firm has been interpreted as a measure of the effect of interfirm technology differences on

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are significant at the one-percent and those with two astericks at the five-percent level. A two tailed test is used in all cases.

Table 5-2

Estimation of the Regression Equation $\frac{R_{it}}{S_{it}} = b_o + b_1 P_i + b_2 \frac{I'_{i,t-1}}{S_{it}} + b_3 D_i$ for the Chemical, Drug, and Petroleum Industries over the Period 1959 - 1962

Industry	b_o	b_1	b_2	b_3	R^2	F	n
Chemicals	0.001 (0.003)	0.10* (0.02)	0.20* (0.04)	0.023* (0.004)	0.67	36.38	60
Drugs	-0.04* (0.01)	0.61* (0.15)	0.32* (0.10)	0.63* (0.08)	0.80	46.02	35
Petroleum	0.002 (0.002)	0.019* (0.006)	0.03* (0.01)	0.004 (0.007)	0.25	5.63	55

Notes: See Table 5-1.

research intensity. As our discussion of Section II pointed out, if it were true that more research-intensive firms have a greater propensity to patent than less intensive ones, this interpretation would be open to serious question. To investigate this latter possibility, data on the number of in-house patent attorneys for all the firms in our sample over the period 1955-1959 was obtained. This is the most meaningful measure of patent activity available, although it is far from a complete index of it.[14]

[14] The crucial factor here is the relation of in-house patent attorneys to those hired from outside the firm. No statistics are presently available on the latter variable. The use of in-house attorneys by the firms in our sample was however quite extensive -- almost all firms had at least one attorney and most had several. In addition, the number of patent attorneys was well correlated with the number of patents ($R = 0.7$).

In order to test the proposition that more research-intensive firms also have a higher propensity to patent, the coefficient of determination between a firm's research intensity and the number of in-house attorneys it engaged per scientist and engineer employed was calculated for each of the three industry samples. Since our regression estimates have shown a significant relation between the number of patents granted to a firm (per research employee) and its research intensity, one would also expect a significant relation between the number of in-house patent attorneys (per research employee) and research intensity if this relation were merely the result of more research-intensive firms having a greater propensity to patent. The resulting R^2 between these variables, however, are

petroleum		0.09
chemicals	(-)	0.04
drugs		0.03.

These coefficients of determination, none of which are significantly positive at the five-percent level, do not support the position that more research-intensive firms tend to patent a greater proportion of patentable inventions. Although this is admittedly a rather slim reed of evidence, it is all that is available. In view of the fact that there is no strong a priori case for any kind of correlation, however, it may be tentatively accepted as support for the position of no significant relationship between these variables.

Another aspect of the results given in Tables 5-1 and 5-2 that deserves comment is the fact that our model's overall performance is much better for the chemical and drug industries than for the petroleum industry. The rather poor showing in the latter industry compared to the other two is undoubtedly due in large measure to certain basic structural characteristics that set petroleum apart from chemicals and drugs. The most important of these differences for our present analysis are: (1) new-product sales in petroleum are negligible compared to overall sales, (2) research is much more process-oriented, and (3) research as a firm activity consumes a much smaller portion of the overall budget than in these other two industries. The process-orientation of research in petroleum would make patents a less appropriate measure of technological change since a firm has much less incentive to seek patents for new processes (it often being preferable to keep the new processes a secret for as long as possible). This process-orientation of petroleum would also explain why diversification is not very important to research activity. Finally, the smaller role of research compared to other firm activities would make R and D expenditures more vulnerable to variations in variables that consume greater portions of the budget. Our hypotheses would thus appear to be most applicable to industries where research is an important competitive strategy and is oriented toward new product introduction rather than process improvement.

Finally, before turning to another aspect of our empirical analysis, we reiterate a point made in Chapter Three. Namely, the current state of the art in data gathering and measurement of such quantities as research expenditures and other aspects of inventive activity make any empirical study such as the one presented here tentative in nature. Nevertheless, the results are very encouraging. The variables are highly significant and in two of the three industries the overall explanatory power is quite favorable when compared, say, to similar efforts to explain the determinants of physical investment.

IV. Research Intensity and Firm Size

All of the explanatory variables used in our model expressed by equation (5.1) have been cited at one point or another in the extensive literature on technical change and business concentration as a priori reasons why big firms will spend proportionately more for research than smaller ones. For example, Hamberg in a summary account of these arguments has stated[15]

> "Thus the high risks of failure in the various stages of research and development (and innovation too) are well known. The great financial and technical resources of the giant firm, however, enable it to support many R and D projects simultaneously, with the results that it is in an excellent position to pool the risks of failure ... A large firm is also typically a diversified firm making many products. From this characteristic it gains still another big advantage in R and D."

On the basis of these neo-Schumpeterian hypotheses, adherents have drawn important policy implications, particularly with respect to government anti-trust activities. These policy conclusions are based on the belief that big firms, for the above reasons, will not just spend a greater absolute amount on research expenditures but will spend proportionately more for research

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[15] Donald Hamberg, "Size of Firm, Oligopoly, and Research: The Evidence", Canadian Journal of Economics, December 1964, pp. 62-63. Hamberg himself is not a subscriber to these views. In the beginning of this article, however, he presents a good summary of them with supporting references.

in relation to their size than their smaller rivals. However, some previous empirical studies on the relation between firm size and research intensity in a number of industries have provided very little support for this position. While some industries in these studies show a positive relation between research intensity and firm size, most are characterized by decreasing relationship.

In order to cast some further light on this question, we shall first look at this relationship between firm size and research intensity for each of our industry samples. We will then look at the relation between firm size and the technological, financial, and diversification variables used as independent variables in our model of Section II. In this way, we will be able to assess the validity of the separate pillars of the neo-Schumpeterian hypothesis, as well as the total relationship between firm size and research intensity on which their case must eventually rest.

In order to investigate the full relationship, we will use the regression equation

$$\frac{R_{it}}{S_{it}} = \frac{a_o}{S_{it}} + a_1 + a_2 S_{it} \qquad (5.2)$$

which in non-ratio form is equivalent to the quadratic relation:

$$R_{it} = a_o + a_1 S_{it} + a_2 S_{it}^2 \qquad (5.3)$$

In estimating this relation, one would expect the estimate of the a_1 coefficient to be positive due to a simple increase of scale effect. The critical term for the issue under study is however the a_2 coefficient. If this coefficient is positive, it implies that large firms are more research intensive than smaller ones and vice versa if a negative relation holds.

The results of estimating equation (5. 2) for the chemical, petroleum, and drug industries are presented in Table 5-3. The regression estimates given there indicate that a different type of relationship characterized each industry. As expected, the estimates of the a_1 coefficient are positive and highly significant for all three industries. The estimate of a_2 however is positive and statistically significant for chemicals, negative and significant for drugs, and only slightly negative and not statistically significant for petroleum firms. While the R^2 are quite modest, the standard errors of estimate indicate quite good fits to the data.[16]

Plots of the relationships between R and D and sales using the estimated equations of Table 5-3 are given in Figures 5-1, 5-2, and 5-3.[17] These figures show that for the drug industry, research intensity initially increases with firm size but is characterized by a decreasing function for most of the relevant range; for the chemical industry, research intensity increases with size throughout; and for petroleum firms, the relationship is essentially

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[16] This is, of course, because in the ratio form of estimating equation (5. 3), much of the explanatory power now comes from the intercept term a_1 which affects the goodness of fit of equation (5. 2) but not the R^2; the estimates of equation (5. 2) explain a very large portion of the variation in absolute R and D expenditures (due to high explanatory power of a_1 term) but only a moderate amount of the variation in the research intensity of firms.

[17] The units of the sales variables have been changed so that the firms in the sample cannot be identified. The sales of the largest firm in each sample is represented in these new units by 100 and the smallest firm in each case falls in the range 1-10.

linear. On the basis of these results one can conclude that big firms are more research intensive than small ones in the chemical industry, less research intensive in the drug industry, and are approximately alike in this regard in the petroleum industry.[18] In addition, it may be noted that these results are in essential agreement with the work of Mansfield, Scherer, and others who have investigated this question for the industries under study here using somewhat different models and samples.[19] They thus have a much

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[18]It is appropriate to recall the basis for selecting our industry samples here. The firms in each industry were chosen initially from the Fortune 500 Listing. Chemicals includes only those firms whose principal products are in the three-digit SIC classes 281-282; drugs those producing principally in SIC 283; and petroleum firms in SIC 291. Now if it is the case that the <u>nature</u> of firm products in each of these industries varies significantly with size, than the above relationships may be due principally to this phenomenon rather than to any scale effects such as those postulated above. In particular the proportion of products produced in other industries would appear to be very important consideration. A more disaggregated definition of industry classes would be called for in the study of these scale effects if this proportion is systematically related to size.

Casual investigation of the meager amount of presently-available data giving the percentage breakdown of firm sales by product classes indicated that only in drugs is the above problem serious. As indicated earlier in a different context, the large firms in our drug sample tend to have a higher percentage of sales in non-pharmaceutical areas than smaller ones. Whether the presently observed pattern of diversification in drug is a natural tendency of size increases or is merely a peculiarity of existing circumstances is difficult to say. However, it is desirable to estimate equation (5.2) using only pharmaceutical sales for each firm. Until the required data is available, however, the present approach is the only one possible and must accordingly be accepted as very tentative in nature.

[19]E. Mansfield, <u>op. cit.</u> (pp. 333-334) and F. M. Scherer, "Size of Firm, Oligopoly, and Research: A Comment", <u>Canadian Journal of Economics</u>, May 1965, pp. 256-266. Mansfield's estimates were based on a logarithmic model between research and sales for pooled samples of ten chemical firms, nine petroleum firms, and seven drug firms over the period 1945-1959. Scherer used a cubic (undeflated) and a logarithmic cubic for the single year 1955 employing R and D employment data rather than expenditure data. Both found the relation between research intensity and firm size (sales) to be an increasing one for chemicals and a decreasing one for the other industries.

Table 5-3

Estimation of Regression Equation $\frac{R_t}{S_t} = \frac{1}{S_t}\left[a_o + a_1 S_t + a_2 S_t^2\right]$ for Pooled Time-Series Cross-Sections of Firms in the Chemical, Petroleum, and Drug Industries Over the Period 1959-1962

Industry	a_o	a_1	a_2	R^2	F	n
Chemicals	0.04	0.03*	0.9×10^{-5}*	0.28	22.22	60
	(0.03)	(0.02)	(0.2×10^{-5})			
Drugs	-6.21*	0.17*	-0.4×10^{-3}*	0.40	19.35	35
	(1.29)	(0.02)	(0.1×10^{-3})			
Petroleum	0.59	0.0069*	-0.2×10^{-7}	0.08	2.27	55
	(0.37)	(0.0008)	(1.6×10^{-7})			

greater applicability than the particular cross-section of firms and time period of the present study.

Keeping the above results in mind, let us turn now to an examination of the relation of size to the research determinant variables used in equation (5.1) for each of these three industries. In Table 5-4 the simple correlations between size as measured by sales and our technological, availability of funds, and diversification variables (P_i, $\frac{I_{i,t-1}}{S_{it}}$, and D_i) are presented. A glance at this table indicates why the neo-Schumpeterian hypothesis between firm size and research intensity fails to hold for all industries -- not only are many of these variables not strongly correlated with size but in some cases they are significantly negatively correlated with

Figure 5-1

Estimated Quadratic Regression Equation of R and D on Sales for Chemical Firms

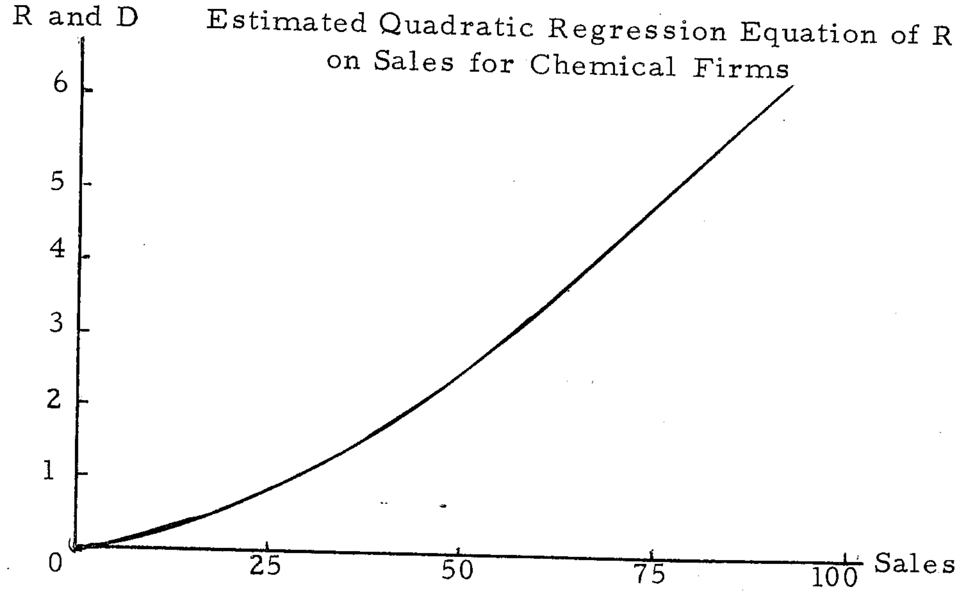


Figure 5-2

Estimated Quadratic Regression Equation on R and D on Sales for Drug Firms

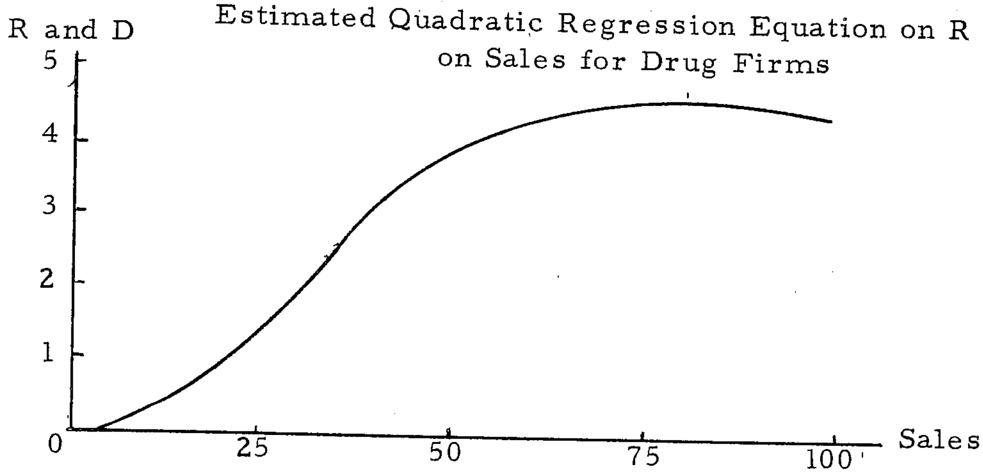
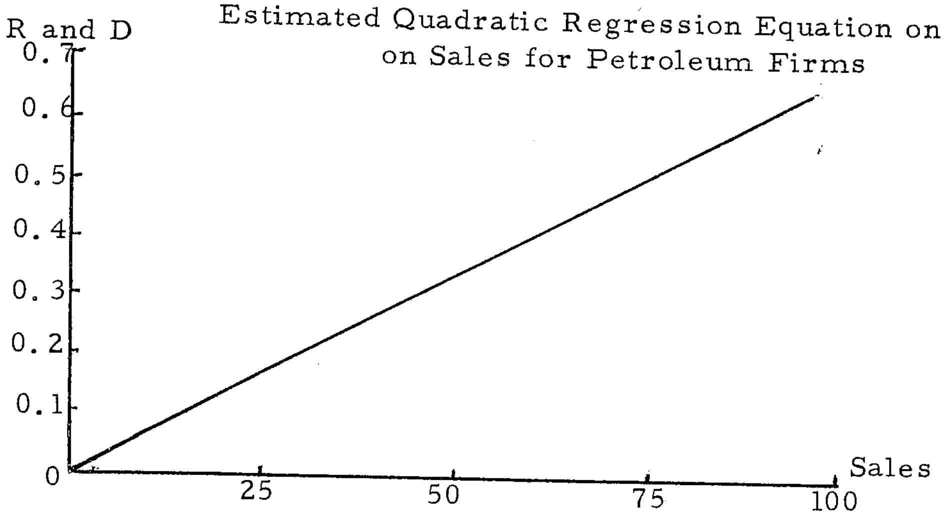


Figure 5-3

Estimated Quadratic Regression Equation on R and D on Sales for Petroleum Firms



firm size! Moreover, the trend of the correlations for each industry in Table 5-4 are in general accordance with our results on firm research intensity and size (Table 5-3), in that the highest positive correlations are in the chemical industry and the lowest in the drug industry. Given this pattern of behavior of research-determinant variables with size in the three industries, the somewhat surprising results of Table 5-3 are thus more readily comprehended.

Table 5-4

Simple Correlation of Size and the Variables P_i, $\frac{I_{i,t-1}}{S_{it}}$, and D_i for the Chemical, Drug, and Petroleum Industries.

Industry	P_i	$\frac{I_{i,t-1}}{S_{it}}$	D_i
Chemicals	- 0.2	0.5*	0.8*
Drugs	+ 0.3**	- 0.4*	0.2
Petroleum	+ 0.3**	- 0.3**	0.2

A further examination of the correlations of Table 5-4 shows that the research-determinant variable which is the least size correlated is the patent variable. Of all of the arguments put forth by the proponents of corporate bigness, the one maintaining large firms are more technically efficient is potentially the most important. The results of Table 5-4 however, do not offer any real evidence for this position.[20] For the other two

[20] The empirical results here would also be open to question if the propensity to patent was significantly correlated with firm size. By similar

determinant variables, the level of internally-generated funds as a percentage of total sales and the index of firm product diversification, the neo-Schumpeterian position is supported only for the chemical industry. For the drug and petroleum industries, this variable is either significantly negatively correlated with firm size or not significantly related to it.

In the current analysis, we have acted on the presumption that any significant relation between firm size and research intensity will be the result in large measure of one or more of our underlying independent variables being significantly related to size in this same fashion. As pointed out above, the general tendency of correlation across industries in Table 5-4 does not contradict this assumption. If our interpretation is correct, Table 5-3 indicates that the major factors causing the opposite behavior between research intensity and firm size in chemicals and drugs is the behavior of the available funds and diversification variables for these two industries. In order to offer some evidence that this is actually the case, we add these two variables to equation (5.3) and observe the behavior of the sales coefficient a_2. As is shown in Table 5-5, when these two size variables are present, the variable a_2 loses its statistical significance in both cases. This is consistent with the general approach used here that maintains that the relation between research intensity and size arises from the size characteristics of our independent variables.

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procedures to those discussed in the previous section, this was not indicated to be the case. See also discussion of this issue in Scherer, "Firm Size, Market Structure, Opportunity, and the Output of Patented Inventive Activity", American Economic Review, May 1965, pp. 1110-1112.

Table 5-5

Estimation of the Relationship $\frac{R_{it}}{S_{it}} = \frac{a_o}{S_{it}} + a_1 + a_2 S_{it} + a_3 \frac{I_{i,t-1}}{S_{it}} + a_4 D_i$ for the Chemical and Drug Industries over the period 1959-1962

Industry	a_o	a_1	a_2	a_3	a_4	R^2	F
Chemicals	0.05 (0.04)	0.009 (0.005)	0.006×10^{-7} (0.28×10^{-7})	0.20* (0.05)	0.20* (0.06)	0.50	13.81
Drugs	-2.18 (1.46)	0.01 (0.03)	-0.14×10^{-3} (0.09×10^{-3})	0.50* (0.14)	0.60* (0.10)	0.72	22.07

Our concern here with the relation of research to size has of course been motivated by the important implications it has for anti-trust policy. The main conclusion that emerges from our analysis in this regard is that, contrary to the professed beliefs of many, large size does not automatically engender the characteristics that promote a high level of research activity. Neither have we found, however, that it acts as a strong force to hinder a firm's research intensity.

V. Some Alternative Hypotheses

One factor that has been suggested elsewhere as a variable influencing the level of a firm's research expenditures that is not included in our present analysis is the short-term rate of change of sales experienced by the firm.

For example, Hall[21] has advanced the hypothesis

> "Since R and D is undertaken to develop new products, we expect it to increase where the sales difference is negative."

In postulating this relation, Hall is apparently suggesting that firms will turn to R and D as a compensatory measure to alleviate pressures caused by a poor sales performance and will devote less resources to it when they are experiencing a high level of demand for their normal product lines. In his work, he has found some econometric support for this position. On the other hand, it has also been suggested that short-term sales differences will act as an expectational variable in influencing research expenditures causing businessmen to spend more for R and D in relatively good times when their spirits are buoyant and correspondingly to slacken off in this activity when the level of demand turns down and their optimism wanes.

In order to see what effect sales changes have on research expenditures for the firms in our present analysis, we add it as an additional independent variable to our basic regression model. Since our dependent variable in the present analysis is research expenditures as a percentage of sales, we also deflate the sales difference variable by sales and in effect estimate the relation between firm research intensity and its annual percentage sales growth. The new regression equation to be estimated is therefore of the form

$$\frac{R_{it}}{S_{it}} = b_o + b_1 P_i + b_2 \frac{I_{i,t-1}}{S_{it}} + b_3 D_i + b_4 \frac{\Delta S_{it}}{S_{it}} \quad . \qquad (5.4)$$

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[21] Marshall Hall, "The Determinants of Investment Variations in Research and Development", IEEE Transactions of the Professional Technical Group on Engineering Management, March 1964, p. 9.

The least-squares estimate of equation (5.4) for our data samples are presented in Table 5-6. They indicate that the estimate of the sales growth coefficient ($\hat{b}_4$) is not statistically significant in any industry and the overall explanatory power of the variables remain unchanged from that found for equation (5.1) in each case. However, the sales-growth coefficient is negative for the chemical and drug industries and virtually zero in the petroleum industry, and therefore the results might be construed as offering weak support for the hypothesis put forth by Hall. Alternatively, these negative coefficients might reflect the existence of a weak substitution effect between research expenditures and physical capital expenditures, with the normal accelerator relation in physical capital expenditures causing the opposite behavior for research expenditures under the operation of a budget constraint. In any case the observed relation is not a very strong one and not much importance need be attached to it.

It must be emphasized that the above discussion refers to the effects of <u>short-term</u> changes in sales on research expenditures and not on the relation between R and D and sales growth measured over any long periods of time. The latter relation will be investigated within the context of our study in the next chapter on the effects of R and D on other firm variables. There we will be explicitly concerned with the effect of research intensity on the long-term growth rate of the firm as well as the inter-relatedness between these variables over time. We shall thus defer further discussion of this problem until the next chapter where we will be working with samples that span much longer periods of times than those used in the present analysis.

Table 5-6

Estimation of the Regression Equation $\frac{R_{it}}{S_{it}} = b_o + b_1 P_i + b_2 \frac{I_{i,t-1}}{S_{it}} + b_3 D_i + b_4 \frac{\Delta S_{it}}{S_{it}}$ for Firms in the Chemical, Drug, and Petroleum Industries Over the Period 1959-1962

Industry	b_o	b_1	b_2	b_3	b_4	R^2	F
Chemicals	0.003	0.09*	0.19*	0.022*	-0.017	0.68	29.12
	(0.004)	(0.01)	(0.04)	(0.004)	(0.012)		
Drugs	-0.03	0.06*	0.27*	0.59*	-0.06	0.81	35.88
	(0.01)	(0.01)	(0.11)	(0.08)	(0.05)		
Petroleum	0.23×10^{-2}	0.019*	0.03*	0.004	0.14×10^{-3}	0.25	4.14
	(17×10^{-2})	(0.006)	(0.01)	(0.007)	(3.88×10^{-3})		

VI. Summary of Results

The empirical work presented in this chapter had a dual purpose. First, the technological, financial, and marketing factors hypothesized to be relevant for the R and D expenditure were quantified by balance sheet items and specially constructed indices of firm activity, and the effects of these variables assessed by means of regression analysis. The second purpose was to see what insights these factors provided for the relation between firm size and research intensity which has been so widely discussed in the recent literature particularly with respect to its implications for anti-trust policy.

With respect to the first objective, the main conclusion that emerges is that interfirm differences in technology, availability of funds, and diversification all are important in explaining research intensity with no single factor having a dominant influence. In the two highly research-oriented industries under study, chemicals and drugs, these independent variables collectively explained a sizeable portion of the sample variation in research intensity (R^2 = 0.63 and 0.86 respectively), and these variables were highly significant in all regressions considered. In the third industry, petroleum, while the availability of funds and diversification variables were statistically significant, the model explained only twenty-five percent of the total sample variation in research intensity. R and D in this industry is apparently more of a residual budget item, influenced to a greater extent by other firm activities such as capital investment and advertising that consume much larger portions of the budget and are more important competitive tools.

While all of our independent variables are significant explanatory variables of research intensity, the neo-Schumpeterian hypothesis that these variables will also have a strong positive correlation with firm size causing big firms to be more research intensive did not receive wide support from our empirical analysis. First of all, our technological measure of research productivity was not significantly size-correlated in any of the three industries. For our other two explanatory variables, only in the chemical industry did these variables show a significant positive correlation with firm size. For drugs and petroleum, the variables either had a significantly negative correlation or were uncorrelated with it. These results are consistent with our regression of firm size on research intensity in which the chemical industry was characterized by a positive relation and the drug and petroleum industries by a decreasing one.

The above results are not without the implications for public policy and these will be discussed in our chapter on policy recommendations. Before doing so, however, we turn our attention on the next chapter to a statistical examination of the effects of R and D on firm growth.

CHAPTER SIX

AN ECONOMETRIC INVESTIGATION OF THE EFFECTS OF A FIRM'S RESEARCH AND DEVELOPMENT EXPENDITURES ON ITS RATE OF OUTPUT GROWTH

The present chapter will be primarily concerned with an econometric investigation of the effects of research at the firm level. Since most industrial research is oriented toward product innovation, the main focus here will be on the relation between a firm's research intensity and its rate of output growth. The analysis will be conducted using a sample of firms in the chemical and drug industries for the period 1950-1964.

We have followed the methodological procedure in this thesis of separating our statistical investigation of the determinants and effects of R and D. This procedure is motivated by the fact that the effects of research occur only with a substantial time-lag while the expenditures are influenced by conditions at the time of budget commitment. Thus, while the level of a firm's research expenditures may depend on certain variables and in turn subsequently influence these same variables, the relationships are distinctly identifiable because of the time-lags involved. However, if the relevant variables are highly correlated over time, it becomes very difficult in actual practice to distinguish between determinants and effects. We shall examine this and other possible econometric difficulties in the empirical analysis which follows.

I. The Sample, Nature of Data, and Research Procedures

In recent years there has been an increased emphasis on the importance of growth to the modern oligopolistic firm. For the group of industries that can be classified as technically progressive, product innovation and modification are among the most important business strategies for maintaining a high rate of growth. Two of the three industries studied in the previous chapter, chemicals and drugs, certainly fall into this category. A McGraw-Hill survey of these industries in 1960 showed that 16 percent of sales were in products that did not exist in 1956. Since research is the main input to new-product innovation, firms that are more research intensive can be expected, *ceterus paribus*, to grow at a faster rate. Our work in this chapter will be directed toward an empirical test of this proposition. We shall work with samples from the chemical and drug industries and omit consideration of the petroleum industry. As pointed out above, research in the petroleum industry constitutes a much smaller portion of the total firm budget and is much more process oriented. The above proposition would thus seem much less applicable to it, and we shall therefore concentrate here on the other two industries.

A second departure from the methodology of the preceding chapter has to do with the sample-pooling techniques used there. In the previous work, pooled time-series cross-sectional samples were employed to study the factors determining the firm's annual research expenditures. Such a procedure would however seem inappropriate for an investigation of the effects of research. It would necessitate the specification of a unique relationship in time between research and sales that also held for all cross-sectional variation in these variables. The measures of firm research effort that are available are aggregated quantities that include several diverse projects being pursued simultaneously in a given time period. The fraction of these projects which are successful can be expected to influence firm revenue and profit streams with different time-lags and in general possess different life-cycles. In addition, short-term fluctuations in any given time period are likely to be large compared to the effects associated with some particular amount of past research.

The specification of a fixed distributed-lag relationship between research and sales is thus likely to offer a poor representation to the data and the actual effects will tend to be obscured by short-term fluctuations peculiar to the firm or the economy in a given time period. Rather than using a pooled time-series cross-sectional sample here, we therefore employ a cross-sectional one in which the variables are measured over several time periods. In this way, the problem introduced by short-term fluctuations will be minimized and some measure of the average effect of research expenditures on sales growth over a period of years will hopefully be obtained.

The disadvantage of such an aggregative procedure is a loss of information on the specific nature and time properties of the relationship between research and sales growth. The type of aggregative data available here however do not warrant this kind of analysis. Data relating research outlays at the project level to the sales of the specific products developed from these projects would seem to offer the best means of analyzing the lags and other time properties of this relationship. The current work will concentrate instead on investigating whether there is any evidence for a causal relationship between a firm's research intensity measured over some reasonable interval of time and its average rate of total output growth in a subsequent period of time.

There are, however, still some severe data problems that confront a study of this kind. First of all, the National Science Foundation statistics on research and development used in the previous chapter are inappropriate because they are of recent origin and do not allow enough elapsed time to measure effects.[1] A second possible set of data are some time-series observations on R and D that were provided by several of the firms interviewed by the author. These data however are based on individual firm definitions and as a group do not constitute a very large sample. A third alternative is to use R and D professional-employment data rather than expenditure data. The former are available for a large sample of firms at selected intervals in time.[2] In order to check the similarity between these two kinds of research-input statistics, their simple correlation coefficient was calculated for the group of firms in the previous sample for the

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[1] While the National Science Foundation began collecting research expenditure data in 1955, the number of firms initially participating in the industries under study was not large, and one must begin a study much later in time to get an adequate sample.

[2] National Research Council, Industrial Research Laboratories of the United States, published at five year intervals over most of the Twentieth Century.

year 1960. The resulting R was 0.94. On the basis of this high correlation, it was decided that employment data could be used as a viable alternative to expenditure data. The former measure will therefore be used in the current analysis because of its greater availability.

One possible disadvantage of using employment rather than expenditure data as a measure of inventive effort is that firms with a high rate of expenditures per R and D professional employee (i.e., due to higher salaries, more support personnel, etc.) might be expected to attract higher quality scientists and engineers, and therefore achieve greater results with a given amount of professional employees. Data are available on the number of supporting personnel used by each firm and the possible effect of this factor will be considered in the empirical analysis which follows. The effect of higher salaries and various other benefits of a non-monetary type on research performance must remain outside the current analysis because of a lack of necessary data.

Having found an acceptable body of research-input statistics, the next task is to choose a sample of firms in the chemical and drug industries. In order to remain consistent with our previous industry definition and range of selection, the procedure followed here was to select all firms appearing in the 1957 Fortune 500 Listings whose main SIC classification was either 281, 282, or 283 (inorganic, organic, and drugs). This yielded a base group of 39 firms. Research-employment data were unavailable on four of these firms and they were therefore eliminated from the sample. For the remaining 35 firms, the average number of professional research personnel employed over the period 1955 to 1960 were assembled for use in the current analysis.

Next, the precise period must be selected over which the rate of output growth is to be measured. Any period that is chosen will have a somewhat arbitrary character since, as pointed out above, our measure of research activity is an aggregate over several projects with different impacts on sales over time. The midpoint of the research-input variable, 1957, would appear to be a convenient base year for measuring the rate of growth. Since the results may be highly sensitive to the base period selected, however, it is desirable to try also some other alternatives. The main problem here, of course, is the effect of short-term cyclical fluctuations on the growth measure.[3] While the nature of our data do not allow too much leeway in this regard, some investigation of the consequences of using different base years will be undertaken. For the terminal year of the growth measure, the last year of available data at the time of the study (1964) will be used since the effects on our research-input measure can be expected to persist well beyond this point. Because the years toward the end of the sample are much more cyclically stable than those at the beginning, the selection of an end point is

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[3]Scherer, in a study of the effect of patented output on sales and profits found pronounced business-cycle effects in his results. The period of years relevant to the present study has much more cyclical stability than that of Scherer's, however, and does not allow a real investigation of these phenomena. See F. M. Scherer, "Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions", American Economic Review, December 1965, pp. 1097-1125.

potentially less troublesome.

A second data problem that now arises is the fact that several of the companies in our sample were involved in corporate mergers during the period of years spanned by the present study. In some of the cases, the mergers were of the minor variety and the accounts can be consolidated with very little change in the actual data. For others, however, the mergers involved substantial size additions and simple consolidation would appear to conceptually inappropriate. The independent operation of each of the companies through part of the period along with the fact that the period after merger will be characterized by some short-term adjustment phenomena, makes this procedure undesirable. In addition, for many of these companies data on the subsidiary to be merged are only available for a year or two prior to the merger and consolidation is impossible even if it were conceptually desirable. We therefore thave little choice but to eliminate those companies experiencing large mergers (on the order of twenty percent of total size or greater) from the present study. This reduces the sample from 35 to 27 firms. It is very difficult to assess the possible effect of these omitted firms on the subsequent results of our empirical analysis. These omissions together with these previously noted due to lack of R and D data admittedly give our sample a very specialized character. Hopefully, however, the behavior of the firms deleted is not such as to materially change the general nature of the results obtained, and we must labor under this act of faith.

The above discussion therefore leaves us with data on average professional-research employment over the period 1955-1960 and the corresponding growth rate of sales over the eight-year period 1957-1964 for 27 firms in the chemical and drug industries. We turn now to a discussion of the models and empirical analysis in which these data will be used.

II. The Empirical Results

A survey of the relevant economics literature shows that very little previous work has been done on explaining interfirm differences in growth rates.[4] This is undoubtedly due to the intangible quality of many of the relevant factors. Differences in firm growth rates can be expected to reflect differences in managerial attitudes toward risk, rate of time discount, attitudes toward stockholders, etc. as well as basic differences in managerial efficiency. These will in turn result in different strategy mixes between firms with respect to their research, financing, and marketing activities. While neither the theory nor the empirical data is presently available to incorporate these factors into a general model of firm growth, some partial analyses such as that attempted here would appear desirable in light of the importance of the subject.

As indicated in the previous chapter, our dependent variable in this cross-sectional analysis is the firm's growth rate measured over the period 1957-1964 and our main independent variable is a measure of the firm's research intensity over the period 1955-1960. Specifically, the former variable is the firm's logarithmic rate of sales growth[5] and the latter is the average number of professional-research

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[4] For some analysis of the relation between firm growth rates and various financial parameters, see Edwin Kuh, Capital Stock Growth: A Micro-Econometric Approach, (Amsterdam: North-Holland, 1963), pp. 319-335.

[5] Of course, there are several possible ways to measure the rate of growth of a series changing over time other than a log-linear trend factor. However, little appears to be known of a formal nature about the properties and relative

personnel employed by the firm deflated by a measure of its size.[6] A possibly serious criticism of relating these two variables directly is the fact that a positive regression estimate may reflect not a causal link from a firm's research activity to its subsequent growth rate, but vice versa. This would result if firm growth were an important determinant of research, and if also firm growth rates were highly correlated over time. In order to guard against this possible source of spurious inference, we shall include as an additional explanatory variable the rate of growth of each firm in an immediately prior interval to the one explained. This will also serve as a proxy variable that should pick up some inter-firm differences relevant to its growth behavior that are not reflected in its research activity. We will this in the first instance estimate a regression equation whose general from is

$$G_{\sigma i} = f(G_{\sigma-1,i}, \bar{R}_{\delta,i}) \qquad (6.1)$$

where $G_{\sigma i}$ = logarithmic rate of growth of firm i measured over interval σ

$\bar{R}_{\delta i}$ = average research intensity of firm i measured over interval σ

Specifically estimates of equation (6.1) in both linear and quadratic functional form will be made, i. e. , in the form:

$$G_{57-64,i} = a_o + a_1 G_{50-56,i} + a_2 \bar{R}_{55-60,i} \qquad (6.1')$$

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desirability of the various alternatives in different situations. From an intuitive standpoint, logarithmic growth rates appear as good as any others and one might even venture to guess they will be less sensitive to base-period selection than the other commonly used methods of measuring growth. Intuition can be deceiving in such cases, however, and some research on this question is very much needed.

[6] The measure of size used here is the average sales of the firm measured

and

$$G_{57-64,i} = a_o + a_1 G_{50-56,i} + a_2 \bar{R}_{55-60,i} + a_3(\bar{R}_{55-60,i})^2 \quad (6.1'')$$

Since our cross-sectional sample is a pooled one of chemical and drug firms, dummy variables on the intercept and slope terms will be used to capture any significant differences in the coefficients between these two industries. These will be denoted by a "d" in the regression equations.[7]

The least-squares estimates of equations (6.1') and (6.1'') for our sample of 27 firms are presented in Table 6-1. They have some surprising aspects. First, the interfirm pattern of growth rates shows considerable change over the two periods. While the lagged growth-rate variable is significantly positive as one might expect, it explains by itself less than twenty percent of the total sample variation. The research-intensity variable (in the linear formulation) is also significantly positive and explains an approximately equal amount. Including the industry dummy intercept variable (the other dummies being insignificant), the total $R^2 = 0.47$.

The quadratic formulation of equation (6.1), also presented in Table 6-1, indicates that diminishing returns characterize the relation between research intensity and sales growth for our sample of firms. The quadratic term is not statistically significant, however, and adds less than a two-percent increment to the total explained variance. We shall therefore concentrate

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over the same period. While this gives rise to a somewhat hybrid variable, results are not substantially changed with other measures of firm size.

[7] For all of the regressions, d = 0 for chemical firms and d = 1 for drug firms.

Table 6-1

Linear and Quadratic Regressions of Research Intensity on Sales Growth, Sample of 27 Chemical and Drug Firms

1. Linear Formulation

$$G_{57-64,i} = \underset{(1.13 \times 10^{-2})}{0.50 \times 10^{-2}} + \underset{(0.80 \times 10^{-2})}{1.50 \times 10^{-2}}d + \underset{(0.12)}{0.39^{*}}G_{50-56,i} + \underset{(0.50)}{1.02^{*}}\bar{R}_{55-60,i}$$

$$R^2 = 0.46, \quad F = 5.94$$

2. Quadratic Formulation

$$G_{57-64,i} = \underset{(2.50 \times 10^{-2})}{-0.80 \times 10^{-2}} + \underset{(0.88 \times 10^{-2})}{1.60 \times 10^{-2}}d + \underset{(0.14)}{0.38^{*}}G_{50-56,i}$$

$$+ \underset{(0.48)}{0.52}\bar{R}_{55-60,i} - \underset{(0.54 \times 10^{-2})}{0.35 \times 10^{-2}}\bar{R}^2_{55-60,i}$$

$$R^2 = 0.47, \quad F = 4.44$$

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on the linear formulation of equation (6.1) in the subsequent analysis.

As emphasized above, the selection of the base year of our growth variable may have a significant influence on the nature of our results. In order to investigate this possibility, we also estimate equation (6.1') measuring the rate of growth alternatively from 1956 and 1958 as base years. Likewise, we also shift the terminal year of lagged growth rate in a corresponding fashion (i.e., so that the terminal year of the lagged variable immediately precedes the base year of the dependent variable). This shift in years in the growth rates should provide a good test of the stability of our results to cyclical effects since the newly selected years encompass different stages of the business cycle. While 1957 was a year of moderate growth, 1956 was one of rapid growth and 1958 of recession.

The least-squares estimate of equation (6.1') using these new base years are presented in Table 6-2. The general character of the results of Table 6-1 are confirmed. Both the lagged growth-rate and research-intensity variables are statistically significant as before. Surprisingly however, the R^2 of the regression equation when the base year 1958 (recession) is used, is considerably higher than before, and the increase is due mainly to the lagged growth-rate rather than the research-intensity variable. Thus, some of the capriciousness normally observed in regression estimates when growth rates are measured over different periods is reflected in this surprising increase in the explanatory power of the lagged growth rate. The main concern here is with the sign and significance of the research-intensity variable, however, and the behavior of this variable is not significantly altered by the change in base year. We therefore continue to use 1957 as the base year of the dependent variable in subsequent regressions.

The regressions in Tables 6-1 and 6-2 show that given a firm's past growth rate and industry trend over time, its research intensity explains a significant portion of its current growth rate. Hence, research is an important variable in explaining interfirm changes in growth rates from one period to the next. In order to provide some further evidence that the direction of causation is firm research intensity to growth rather than vice versa, we

Table 6-2

Linear Regression of Research Intensity on Sales Using New Base Years in the Growth Rate Variables, Sample of 27 Chemical and Drug Firms

1. With 1956 as Base Year

$$G_{56-64,i} = \underset{(0.01)}{0.02^*} + \underset{(0.01)}{0.02^*d} + \underset{(0.14)}{0.43^*}G_{50-55,i} + \underset{(0.50)}{0.85^{**}}\bar{R}_{55-60,i}$$

$$R^2 = 0.48, \quad F = 6.56$$

2. With 1958 as Base Year

$$G_{58-64,i} = \underset{(0.81 \times 10^{-2})}{0.63 \times 10^{-2}} + \underset{(0.07)}{0.46^*}G_{50-57,i} + \underset{(0.30)}{0.60^*}\bar{R}_{55-60,i}$$

$$R^2 = 0.67, \quad F = 25.01$$

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regress the research-intensity variable on the lagged growth rate rather than the subsequent growth rate. Doing so one obtains

$$G_{50-57,i} = \underset{(0.02)}{0.07} + \underset{(1.38 \times 10^{-3})}{0.33 \times 10^{-3}}d - \underset{(0.87 \times 10^{-2})}{0.28 \times 10^{-2}}\bar{R}_{55-60,i} \qquad (6.2)$$

$$R^2 = 0.04, \quad F = 0.05$$

The results are strikingly different from those presented in Table 6-1. Research intensity is insignificantly related ($R^2 = 0.04$) to past growth rates and the least-squares estimate is negative in sign. The regression estimates of equation (6.2) thus show that the lead-lag structure between R and D and output growth are consistent with the postulated causal chain

R and D → New Product Innovation → Sales Growth

rather than a reverse causal mechanism.

Furthermore, these results indicate that some firms experiencing poor growth rates over extended periods have probably turned to R and D as a long-run competitive strategy for improving relative market position and vice-versa. The latter kind of behavior on the part of some firms would help explain why R and D is unrelated to past growth rates in the present analysis even though it is shown to be strongly related to the flow of profits and internal-fund flow on an annual basis in the previous chapter. It further means that such firms undoubtedly turn at some point to sources of finance other than the normal flow of retained earnings when confronted with such situations.

III. Some Alternative Hypotheses

Our interpretation of the results in Table 6-1 as evidence for a causal link between firm research activity and growth deserve further scrutiny. The significant positive relation between these two variables may be due to a mutual correlation with a third variable. It is possible for example that the above result is due to a common dependence on research and growth on the level of a firm's investment expenditures for physical capital. Thus would result if, say, firms' increases in capacity lead their actual growth in output by a considerable interval in time and firms also adjust research expenditures in parallel with physical investment outlays.

In order to test this proposition, the level of a firm's physical-investment expenditures as a percentage of sales, measured over the same interval as research intensity (1955-1960), was used as an explanatory variable of firm growth with and without the research-intensity variable present. The results are presented in Table 6-3. They do not offer any support for the above proposition. The investment variable is not significant in either case and the research-intensity variable remains statistically significant as before. We may thus reject the hypothesis that the results of the regression estimates of equation (6.1') are due to a mutual correlation of growth and research intensity to the firm investment activity.

Table 6-3

The Effect of Capital Investment on the Relation between Research Intensity and Growth, Sample of 27 Chemical and Drug Firms

1. The Addition of the Capital Investment Variable, $\bar{C}$, to Equation (6.1) Without $\bar{R}$ present

$$G_{57-64,i} = \underset{(0.15 \times 10^{-1})}{0.12 \times 10^{-1}} + \underset{(0.36 \times 10^{-1})}{0.30 \times 10^{-1}} d + \underset{(0.16)}{0.33}\, G_{50-56,i}$$

$$+ [\underset{(0.16)}{0.16} - \underset{(0.65)}{0.08} d]\, \bar{C}_{55-60,i} \qquad R^2 = 0.39, \; F = 3.44$$

2. The Addition of $\bar{c}$ to Equation (6.1) With $\bar{R}$ present

$$G_{57-64,i} = \underset{(1.17 \times 10^{-2})}{-0.19 \times 10^{-2}} + \underset{(0.34 \times 10^{-1})}{0.38 \times 10^{-1}} d + \underset{(0.15)}{0.34}\, G_{50-56,i}$$

$$+ \underset{(0.50)}{0.97}\, \bar{R}_{55-60,i} + [\underset{(0.15}{0.13} - \underset{(0.66)}{0.40} d]\, \bar{C}_{55-60,i}$$

$$R^2 = 0.49, \quad F = 3.51$$

A second possible source of spurious inference between research activity and growth is a mutual correlation with the level of internally-generated funds. Even though our results of the previous sections would cast some doubt on this proposition, it is desirable to actually test it measuring the firm's level of internal-fund flow over the same period as our research-intensity variable. We thus add as an additional explanatory variable to equation (6.1') the average level of a firm's level of internally-generated funds (measured in the two ways previously used) as a percentage of its sales over the period 1955-1960. The results are presented in Table 6-4. They are similar to those found in Table 6-3 and do not offer any support for the hypothesis that our previous results are due to a mutual correlation of both growth and research intensity to the level of internally-generated funds. This is not meant to suggest, however, that the level of internal funds is an unimportant consideration in the growth process, but only that, ex-post, the method of investing these funds as well as the past growth record of a firm offer better explanations of its subsequent growth rate.

At this point several other balance sheet variables could also be introduced into equation (6.1'). Among the available variables (long-term debt, liquidity-stock variables, selling and administrative expense, etc.) however, there is neither a strong a priori case for inclusion nor any significant relation to growth indicated from a simple correlation analysis. There are of course some pricing and marketing variables that are very

Table 6-4

The Effect of Flow-of-Funds Variables on the Relation between Research Intensity and Sales Growth, Sample of 27 Chemical and Drug Firms

1. $\bar{I}$ = Profits plus Depreciation (deflated by sales)

$$G_{50-57,i} = \underset{(0.15 \times 10^{-1})}{0.12 \times 10^{-1}} + \underset{(0.08 \times 10^{-1})}{0.13 \times 10^{-1}} d + \underset{(0.13)}{0.40}\, G_{50-56} + \underset{(0.54)}{1.06}\, \bar{R}_{55-60,i}$$

$$- \underset{(0.082)}{0.088}\, \bar{I}_{55-60,i} \qquad R^2 = 0.48, \quad F = 4.78$$

2. $\bar{I}$ = Retained Earnings plus Depreciation (deflated by sales)

$$G_{50-57,i} = \underset{(1.16 \times 10^{-2})}{0.86 \times 10^{-2}} + \underset{(0.09 \times 10^{-1})}{0.12 \times 10^{-1}} d + \underset{(0.13)}{0.39}\, G_{50-56} + \underset{(0.56)}{1.06}\, \bar{R}_{55-60,i}$$

$$- \underset{(1.17)}{0.73}\, \bar{I}_{55-60,i} \qquad R^3 = 0.47, \quad F = 4.33$$

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relevant to a firm's growth in output demand and would certainly be expected to explain some of the large residual variances of the above regression results. These variables - advertising, sales efforts, average price of products relative to competitors, etc. - are not publicly available, however, and are even more difficult to obtain from firms than data on research and development.

On the basis of the present analysis, we therefore reject the hypothesis that the significant relation found between a firm's research activity and its growth rate is due to a mutual correlation with a third variable. Because of the limited availability of many of the relevant variables, however, we must attach the caveat that a more detailed analysis of the growth process may very much change the character of the current results.

IV. Research Intensity, Number of Supporting Personnel, Firm Size, and Rate of Growth

What is the effect of the number of research-supporting personnel employed by a firm on the efficiency of its research program? Does the rate of a firm's growth vary systematically with the absolute size of its research program or the size of its total operations? These are important questions regarding the optimal environment and characteristics of a firm's research program. This section involves some regressions designed to provide some tentative answers to these questions.

In order to investigate the first question, the ratio of a firm's research-supporting personnel to its professional staff was included as an additional explanatory variable in equation (6.1''). Thus we are now estimating the regression equation

$$G_{57-64,i} = a_o + a_1 G_{50-56,i} + a_2 \bar{R}_{55-60,i} + a_3 K_{55-60,i} \qquad (6.3)$$

where K = ratio of supporting to professional research personnel over the period 1955-1960.

Alternatively, equation (6.1') will also be estimated using the broader definition of research input as the total number of personnel employed in research rather than just the number of the professional staff. This will also provide some basis for analyzing the effect of the number of supporting personnel.

The results of estimating these two regressions for our sample of chemical and drug firms are presented in Table 6-5. They do not indicate that the level of a firm's research-supporting personnel is an important factor in explaining growth rates.[8] In the regression estimates of equation (6.3), the ratio K is positively related to the growth rate but is not statistically significant. Likewise, when equation (6.1') is estimated using total research personnel rather than just professionals, the statistical significance of this variable decreases from its previous value (Table 6-1).

Table 6-5

The Effect of Research-Supporting Personnel on Sales Growth, Sample of 27 Chemical and Drug Firms

1. Addition of the Ratio of Supporting to Professional Research Employees, K_i, to Equation (6.1)

$$G_{57-64,i} = \underset{(0.17 \times 10^{-2})}{0.24 \times 10^{-2}} + \underset{(0.8 \times 10^{-1})}{0.15 \times 10^{-1}} d + \underset{(0.13)}{0.40} G_{50-56,i} + \underset{(0.54)}{0.98} \bar{R}_{55-60,i}$$

$$+ \underset{(1.38 \times 10^{-2})}{0.41 \times 10^{-2}} K_{55-60,i} \qquad R^2 = 0.46, \quad F = 4.28$$

2. Measurement of $\bar{R}$ as Total Research Personnel

$$G_{57-64,i} = \underset{(1.45 \times 10^{-2})}{0.77 \times 10^{-2}} + \underset{(0.08 \times 10^{-1})}{0.16 \times 10^{-1}} d + \underset{(0.13)}{0.40} G_{50-56,i} + \underset{(0.35)}{0.54} \bar{R}_{55-60,i}$$

$$R^2 = 0.44, \quad F = 5.49$$

[8] This finding is in substantial agreement with the results of William S. Comanor presented in the article, "Research and Technical Change in the

For the sample of firms used here, the level of professional employment is thus a more important aspect of a firm's research effort for growth rate considerations than measures which include various supporting personnel. While a certain minimum amount of the latter kind of employees are necessary to complement a firm's professional staff, the addition of more employees beyond this necessary amount apparently has little effect on the outcome of most research projects.

A second important question is whether there is any systematic relation between firm growth rates and firm size - i. e., whether scale effects exist either in the firm's research program or other firm activities that affect the rate of growth. In order to examine these questions, the average level of a firm's research employment undeflated by firm size was added to equation (6.1') as an additional independent variable. In addition, the average size of the firm over the period 1955-1960 (as measured by sales) was added to equation (6.1') as a general scale variable. The results are given in Table 6-6. Neither of these variables are statistically significant even when ten percent or even much larger confidence intervals are used. Thus there is no evidence provided by the current analysis for any scale effects of a direct kind from either a firm's research activity for other operations. Other kinds of scale effects, involving interaction terms with various firm variables, are however still a possibility that will not be examined here.

Pharmaceutical Industry", Review of Economics and Statistics, May 1965, pp. 182-190.

Table 6-6

Introduction of Scale Effects into Regression Equation of Research Intensity on Firm Growth Rates, Sample of 27 Chemical and Drug Firms

1. Introduction of Total Number of Research Personnel, R, into Equation (6.1)

$$G_{57-64,i} = \underset{(0.50 \times 10^{-2})}{0.65 \times 10^{-2}} + \underset{(0.08 \times 10^{-1})}{0.14 \times 10^{-1}} d + \underset{(0.14)}{0.40}\, G_{50-56,i} + \underset{(0.53)}{0.95}\, \bar{R}_{55-60,i} - \underset{(1.43 \times 10^{-6})}{0.43 \times 10^{-6}}\, R_{55-60,i}$$

$R^2 = 0.46, \quad F = 4.29$

2. Introduction of Total Sales of Firm, S, into Equation (6.1)

$$G_{57-64,i} = \underset{(1.60 \times 10^{-2})}{0.80 \times 10^{-2}} + \underset{(0.08 \times 10^{-1})}{0.14 \times 10^{-1}} d + \underset{(0.13)}{0.40}\, G_{50-56,i} + \underset{(0.53)}{0.92}\, \bar{R}_{55-60,i} - \underset{(1.99 \times 10^{-6})}{0.83 \times 10^{-6}}\, S_{55-60,i}$$

$R^2 = 0.46, \quad F = 4.32$

V. Some Qualifying Remarks

In this chapter, we have been primarily concerned with the effects of research and development on the rate of sales growth of firms in the technologically-based chemical and drug industries. As indicated above, the regression estimates of our simple model tend to support the hypothesis of a significant positive relationship between a firm's research intensity and its subsequent logarithmic rate of sales growth. Furthermore, attempts to show that this relationship arises from the reverse causal mechanism or from a mutual correlation with a third variable were not substantiated. Nevertheless, these results remain tentative in nature and some qualifying remarks are now in order.

First of all, there are the data problems that were enumerated in section II. These fall into two categories: (i) missing observations due to mergers and other reasons; (ii) the specific nature of the available data.

While our sample initially comprised all chemical and drug firms in the 1957 Fortune 500 Listing, twelve firms or approximately 30 percent of this original sample were eliminated because of mergers or missing data. Composite corporate mergers will always present a problem for this kind of study and it is very difficult to assess whether the characteristics of the omitted firms on this account were such as to reinforce or substantially alter our observed estimates. The above results must therefore be interpreted as strictly applicable only to the group of firms in our sample.

Secondly, the research-input data used here, the average number of R and D professional employees over the period 1955-1960, is a source of some problems. The aggregative nature of these data and of all available statistics on inventive effort makes it difficult to study the specific characteristics of the relation between research and sales (i. e., the length of lags, cumulative nature of process, etc.). The above regression analysis therefore constitutes a first level investigation of this relation and primary emphasis is placed here on the signs and statistical significance of the estimates rather than the exact magnitudes involved.

A second possible disadvantage associated with these data is the fact that employment rather than expenditure data were used. However, the analysis of data on the average number of research-supporting personnel used in conjunction with the professional R and D staff, indicated no significant relations between the amount of these secondary personnel used and our dependent variable. Since additional supporting personnel mean greater R and D expenditures, these results suggest that the number of professional researchers may actually be a more meaningful input statistic for our present purposes than the dollar value of research expenditures. The use of this variable can thus be viewed as a step toward decomposing total R and D effort into more meaningful categories. More research in this general direction with finer breakdowns of R and D statistics than are now available is certainly very much needed.

Aside from the problems concerning the nature and availability of R and D data, there are some objections to the above analysis on methodological grounds. Our general statistical approach has been to use single-equation least-squares regression techniques and keep the current analysis separate from the previous one on the determinants of research expenditures. While the substantial time-lag in the effectiveness of research causes the two mechanisms to be somewhat independent in actual practice, there is obviously considerable interconnection between them over time. It would therefore be desirable to formally link the current study with the previous one by means of a formal model. Some of the difficulties in doing so are illustrated by the empirical work of the past two chapters.

The construction of a single model would presumably proceed by relating the past effects of research to current expectations which would then influence current outlays and hence future effects. In other words, one would specify a recursive relation between these variables over time. The technological-performance variable was included in the previous analysis on the determinants of annual research expenditures partly with this in mind, and the results were in accordance with rational behavioral postulates on expectations. On of the surprising results of the current analysis, however, is the lack of a relationship between the firm's research intensity and its past long-run growth rate. If an increase in the firm's rate of growth causes its expectations for future research to be greater, a positive relation should hold between these variables. The fact that we did not observe such a relationship here is consistent however with the general observation that there is considerable change in the relative performance of different firms over long intervals of time. Any study encompassing long periods of time must be prepared to accept the fact that basic changes will occur in the behavior and motivation of many firms, and this instability over time will make an analysis of long-run interactions between determinants and effects very difficult.

As a final qualifying remark, we may note that the above empirical analysis offers only one test of the proposition that a firm's research intensity is significantly related to its growth. An attempt was made to extend the results backward in time, using the same methodological approach as above, but several more firms had to be eliminated due to mergers and data unavailabilities. Even so, regression estimates over this reduced sample were in general agreement with those above, though the significance of the variables were in all cases much lower. While the above results are thus hardly conclusive, they are all that are currently available.

Despite all of the above limitations, the above results do provide some statistical evidence for a link between industrial research and output growth. They also may be viewed as a useful first step toward obtaining an estimate of the firm's marginal rate of return from research expenditures. In order to extend the current analysis in this direction, more theoretical and empirical information is of course needed on the investment and marketing costs of bringing research results to the production and distribution stage. In addition, more insights are also needed concerning the specific properties of the relationship between research and output growth. Hopefully, more work toward these ends will be forthcoming by economists in the near future.

CHAPTER SEVEN

POLICY IMPLICATIONS OF THE MICROECONOMIC EMPIRICAL STUDIES

Organized research and development activity has an important bearing on several of the traditional social policy objectives of a mixed economy. As the main input to inventive activity and technical change, R and D is one of the central considerations in government stabilization policies concerned with the long-term rate of economic growth. Research and development activity is also relevant to government fiscal policies because of its public-good characteristics. This involves not only public expenditures for military and national security matters, but also the support of civilian technology where the latter is a source of external benefits that would otherwise not be realized by society. In addition, the relationship between research and development, technical change, and market structure has important ramifications for government anti-trust policy.

The empirical work of the previous two chapters provides a basis for considering some of these policy questions. Using the results on the determinants and effects of industrial research, we shall first discuss how various types of government fiscal measures can be expected to affect expenditures on industrial R and D. Then some specific comparative statics results on the efficiency of various fiscal devices for stimulting growth will be derived using a model of firm behavior based on our empirical results.

Finally, we will then turn to a discussion of the implications of our results for government anti-trust policy.

The third major area of government policy concern mentioned above, the external economies to R and D, will not be taken up here. Our empirical work has concentrated on the private benefits to industrial R and D, and no attempt was made to measure the broader category of social returns. The latter is an extremely complex problem that so far has not been attempted for industrial research and development. It is particularly crucial in the case of basic research where many observers have suggested an underinvestment in resources on the basis of theoretical or intuitive considerations. Probably some empirical measures of the social returns to industrial research and development will be forthcoming in the future. For the present, it remains an area of much speculation and little empirical progress.

I. Government Fiscal Policy and Growth

A. General Considerations

While the empirical work in Chapters Five and Six does not leave one with a completely specified decision-making structure, it does point to some important general conclusions. The analysis there indicates that R and D expenditures are dependent on the level of available funds as well as on other variables reflecting the profit and growth expectations of R and D, at least in a gross manner. This means that R and D outlays will be influenced by the broad class of government policies that affect the financial incentives confronting the firm. In particular, government measures that significantly change the incentives for investment in physical capital will also be highly relevant to the firm's R and D policy. Both of these activities involve expenditures largely connected with firm expansion that must be financed from the same supply of investment funds. Government measures can influence these two activities either through (1) a flow of funds effect or (2) a profitability effect, which may arise not only directly but also indirectly from a change in the profitability of any activity substitutable for or complimentary to R and D.

With regard to the flow of funds effect, any tax change that increases the level of retained earnings plus depreciation charges can be expected, on this account, to increase expenditures on <u>all</u> competing uses of these funds. An important factor in determining the magnitude of this effect for different government policy actions is the nature of the firm's dividend policy. There will only be a flow of funds effect on measures increasing the firm's earnings if these earnings are retained for internal use. A tax measure that causes a substantial increase in after-tax profits will have little or no effect on the firm's internal activities if this increase is primarily paid out in dividends to the stockholders.

Likewise, taxes whose impact on the flow of funds may seemingly be the same can actually have very different implications. For example, a reduction in the corporate income tax may result in greater pressures on the firm from stockholders to pay larger dividends than say an accelerated depreciation measure of equal revenue loss because the former leads to an immediate increase in earnings on the firm's profit and loss statement whereas the latter actually decreases the stated profits initially. The nature of the relationship between firm management and stockholders will thus be a key element in determining the size of flow of funds effect on activities such as R and D. Whatever this relationship may be, however, maximal effectiveness in preventing dividend leakages will always be realized by taxes which are specifically designed to operate only on retained earnings (such as a retained-earnings credit). The use of such a tax to accomplish some stabilization objective is usually less preferable to one with a more general tax base because it violates the commonly accepted principle of horizontal equity. The social desirability of any tax must always rest on a number of considerations including efficiency, equity, and administrative convenience.

Beside flow of funds effects, government measures can influence R and D expenditures by means of profitability effects. Since any measure which enhances the profitability of activities complimentary (substitutable) to R and D will produce an effect tending to increase (decrease) R and D expenditures, it is important to identify where such effects are likely to be significant. Because R and D has its principal effect on firm growth through new-product innovation, significant complimentarity effects can be expected for any measures that provide strong growth incentives to the firm. Any of the specific measures that have been recently discussed by economists and policy-makers -- investment credit, accelerated depreciation, or growth subsidy -- should also stimulate the level of R and D expenditures. The effectiveness of these fiscal devices in stimulating R and D (as measured in usual efficiency terms) will however be weakened to the extent that these measures are also applicable to activities connected with the maintenance of the firm's established products. An investment credit based on net investment will thus have a much greater effect than one which includes investment for replacement demands (i. e. , one based on gross investment). The more narrowly confined in applicability a tax is to new-product activity, the greater will be its effect on R and D.

While any tax which operates on the margin of increased production will generally have a greater effect on R and D than ones that operate on the total level, choosing between alternative taxes operating on the margin cannot be done without making some more definite assumptions concerning firm behavior. In the next section we will consider the effects of some alternative tax schemes within the framework of a specific model of firm behavior. While this model is far from a complete charaterization of the situation facing the typical industrial firm, it does capture many of the relevant considerations for firms located in technologically-based high-growth industries such as those studied in our microeconomic models. Our analysis will therefore provide some insights for government stabilization policy designed to encourage economic growth.

Before turning to this model, we may summarize the current discussion with the general conclusion that any government measure which significantly affects the level of available funds or enhances the profitability of rapid growth will have a beneficial effect on firm R and D expenditures in the technologically-based industries considered here. Government policy actions concerned with stimulating growth should therefore be concerned with both of these effects if an efficient program is to be devised to fullfil this objective.

B. Some Comparative Statics Results - A Digression

Our analysis of the efficiency of several tax schemes for stimulating growth will employ a model of firm behavior based on a theoretical framework originally suggested by Baumol.[1] The basic supposition of this model is that the firm's output grows at a steady rate over time, g, and the value of g depends on its choice of decision variables such as R and D. The assumption of a steady rate of growth is predicated on constant external conditions and is made so that equilibrium time-paths may be analyzed. Given the conditions of its environment, the firm makes a once-and-for-all decision concerning its policy variables which then results in a steady rate of growth. Non-equilibrium adjustments to changes in external conditions are therefore excluded from the present analysis, and the model is essentially one of comparative statics.

With respect to the substantive assumptions, the model differs from those previously used in public finance in that it attempts to incorporate

[1] W. J. Baumol, "On the Theory of the Expansion of the Firm", American Economic Review, January 1963, pp. 1078-1087. For a further development see also John Williamson, "Profit, Growth, and Sales Maximization", Economica, February 1966, pp. 1-16.

some of the specific characteristics of the modern oligopolistic firm observed here and elsewhere. The basic framework assumes a separation of managers and owners, and competition between firms only by means of non-price variables. We will proceed by considering first the solutions of the different cases of this model with no government policy measures present. Then, several tax incentive schemes will be introduced into the model, and their effect on these solutions analyzed.

1. Formulation of the Model

In a model concerned with the long-term course of events, the firm's rate of growth is a key decision variable, analogous to the selection of the appropriate level of output in the static analysis of the firm. In our model we shall assume that the firm has an initial level of output and capital stock, and it is faced with a production situation in which it can grow at any rate below a certain threshold level, $\bar{g}$, and face no diseconomies in operation -- i.e., its revenues and costs will expand in proportional fashion. The threshold rate of growth, $\bar{g}$, will depend on the general economy-wide growth in demand for the firm's traditional products at their initial-period price (due to population growth, technical change external to the firm, etc.), and is therefore an exogeneous factor for the firm. In order to grow at a rate faster than $\bar{g}$, however, the firm must either steadily lower prices on its traditional products or modify and diversity its product line. In an oligopolistic situation the firm will generally prefer the latter strategy, and we shall assume the only competition is by this means. For rates of growth higher than $\bar{g}$, the firm must therefore incur special expansionary costs entailed by the diversification of its products (research, development, and extra selling effort) as well as any managerial diseconomies associated with diversification.

Among the costs assumed to grow proportionately with the firm's rate of growth will be the depreciation expenses associated with the obsolence of firm's capital and the need for replacement. Therefore, these costs are not included in the special expansionary costs of growth. Replacement costs will grow proportionately with the firm's overall operation if a constant capital-output ratio is assumed and a constant percentage rate of obsolence is incurred by the firm.[2] While the actual costs of the capital input therefore do not increase in a non-proportionate manner in our model, higher values of g will require a greater absolute amount of net investment in every period[3] which in turn necessitates a greater supply of investment funds. Now, in this model, it will also be assumed that investment can be financed only by internal means,[4] and therefore a further "cost" of higher rates of firm

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[2] Other assumptions such as a constant life of capital, will also yield a rate of growth in depreciation expenses proportional to the firm's growth in overall operations. See Robert Eisner, "Depreciation Allowances, Replacement Requirements and Growth", American Economic Review, December 1962, pp.

[3] We have assumed an initial capital stock and a constant capital-output ratio. Therefore the higher the rate of growth in output, g, the greater the net investment must be in the first and subsequent periods so that capital may also grow proportionately with output.

[4] Most of the results can however be extended to the case of borrowing in which the level of debt increases at a rate identical to firm's growth in operation.

growth will be a higher percentage of the firm's earnings being retained for internal use. In addition to the special diversification costs, the firm thus must consider also the impact on their stockholders of high-growth policies -- a lower initial level of distributed earnings but a higher growth in dividends over time.

The above two paragraphs describe the basic environment under which the firm operates. The level of growth actually selected will depend also on the basic motives of the firm. Specifically it will depend on whether the firm desires to maximize long-term profits, growth, stockholder well-being, etc. In this analysis we shall consider the cases of both the profit maximizer and the growth maximizer subject to the constraint on both instances that the firm will not allow the discounted value of distributed earnings to the stockholders to fall below a certain level. Thus the basic premise is that the managers attach goals to the firm separate from those of the actual owners, the stockholders, and the latter group is treated mainly as a source of investment funds. The constraint on the value of distributed earnings can be viewed either as arising from a desire on the managers' part to avoid stockholder unrest and possible takeover or by a sense of fairness to the stockholders. This model is in keeping with the spirit of some of recent literature on the modern corporation which points a managerial utility function based on firm performance -- a utility function that is separate from but constrained by the utility function of the firm's stockholders.[5]

[5] W. J. Baumol, Business Behavior, Value and Growth, (New York: The Macmillan Company, 1959); Robin Marris, The Economic Theory of Managerial Capitalism, (Glencoe, Illinois: Free Press of Glencoe, 1964); Oliver E. Williamson, The Economics of Discretionary Behavior: Managerial

Let us consider the case of the profit-maximizing firm first. Let R be the firm's initial net revenue before taxes, g the rate of output growth, i the rate of interest and t the tax rate on profits. By our assumptions, the firm's net revenue in period n, R_n, (exclusive of expansionary costs) will be

$$R_n = R(1 - t)(1 + g)^n \tag{7.1}$$

and the present value of this revenue in period 0, R_{no}, will be

$$R_{no} = R(1 - t) \frac{(1 + g)^n}{(1 + i)^n} \quad . \tag{7.2}$$

Taking into account now the expansionary costs associated with growth above a certain level and denoting these costs in the present period as C(g), we have, assuming proportional growth also for these costs over time,[6] the discounted value of expansionary costs incurred in period n, C_{no} as

$$C_{no} = C(g) \frac{(1 + g)^n}{(1 + i)^n} \quad \text{with} \quad \begin{array}{ll} C(g) = 0 & \text{for } g < \bar{g} \\ C(g), C'(g) > 0 & \text{for } g > \bar{g} \end{array} \tag{7.3}$$

The objective function for the profit maximizing firm, π, will then be the sum of discounted revenue stream minus the discounted value of the cost of expansion, or

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Objectives in the Theory of the Firm, (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1964), and many others.

[6] We are thus assuming a proportionately growing stream of diversification costs associated with any level of growth above $\bar{g}$, whose absolute level in every period must increase as higher levels of g are sustained. This is in the spirit of a permanent growth model in which a firm makes a once-and-for-all decision concerning key variables and then these variables grow proportionately at the same rate. Some reasons why expansion costs must continually grow at the same rate as output (thereby maintaining a constant ratio to it) can be provided by plausible technological and competitive relationships. This is also roughly similar to the situation assumed for our empirical model of Chapter Six that offered a reasonable fit to the data.

$$\pi = \sum_{n=0}^{\infty} \left[R(1-t) \frac{(1+g)^n}{(1+i)^n} - C(g)(1-t) \frac{(1+g)^n}{(1+i)^n} \right] = \frac{(1+i)(1-t)}{(i-g)} [R - C(g)]. \quad (7.4)$$

The assumption that the firm finances its investment internally introduces the constraint

$$I_n(g) = v(1-t)[R_n - C_n(g)] \quad \text{with } I_n' > 0 \quad (7.5)$$

where $I_n(g)$ is the level of net investment in period n, and v is the firm's retention ratio, a policy variable.

Finally our assumption concerning the firm's behavior toward its stockholders, that the firm's present value of dividends stream must be greater than a certain minimum value, introduces the constraint

$$\sum_{n=0}^{\infty} (1-v) \frac{(1+g)^n (1-t)}{(1+i)^n} [R - C(g)] \geqq D_o$$

$$= \frac{(1-v)(1+i)(1-t)}{(i-g)} [R - C(g)] \geqq D_o \quad (7.6)$$

In the case of the profit-maximizing firm, the solution of the model involves the selection of a rate of growth, g, and a retention ratio, v, such that the function in equation (7.4) is maximized subject to the constraints expressed by equation (7.5) and equation (7.6). We may envision the model as operating in the following fashion. If the rate of growth, g* , which maximizes the objective function unconstrained by equation (7.5) or (7.6) implies a retention ratio (obtained by the substitution of g* in equation (7.5)) which satisfies the inequality constraint on the value of distributed earnings to the stockholders (equation (7.6)), then the firm selects this rate of growth and retention ratio and behaves similarly to an unconstrained profit maximizer.

If, however, the rate of growth implied by the unconstrained maximizer involves a retention ratio which is incompatible with equation (7.6), then the highest rate of growth mutually compatible with this constraint and equation (7.5) will be the one for which the highest firm's profits stream will be attained.

Besides the profit-maximizing firm, another interesting case to analyze is the firm which desires to maximize its growth rate. As we shall see below, this case is easily treated in the present framework.

2. Solution of the Model

Turning now to a specific analysis of the model's solution, we shall analyze first the profit-maximizing case where the constraints are ineffective in limiting profits. In this case, the conditions for profit maximization will be the ordinary calculus conditions. We thus differentiate the objective function by g and set it equal to zero, i.e.,

$$\pi_g = \frac{d}{dg} \frac{(1+i)(1-t)}{(i-g)} [R - C(g)] = 0 \qquad (7.7)$$

which implies

$$\frac{(1+i)(1-t)}{(i-g)^2} [R - C(g)] - \frac{(1+i)(1-t)}{(i-g)} C'(g) = 0$$

or

$$R - C(g) - (i-g)\, C'(g) = 0\,.$$

The second derivative of π is given by

$$\pi_{gg} = 2\frac{(1+i)(1-t)}{(i-g)^3} [R - C(g)] - \frac{(1+i)(1-t)}{(i-g)} C''(g) \qquad (7.8)$$

Equations (7.7) and (7.8) show that there will be a unique maximum, g^*, somewhere in the range $g < i$ provided that the cost function $C(g)$ involves increasing marginal costs ($C''(g) > 0$) at a sufficient rate so that the second order condition $\pi_{gg} < 0$ is satisfied when $\pi_g = 0$. The problems caused by a rate of growth equal or greater than the interest rate in a model such as ours have been discussed in the literature.[7] When this is the case, the geometric series in our objective function will not converge and the profit stream will no longer be finite. Without becoming involved in this discussion, we may note here that some good reasons have been advanced why this is not a serious possibility in a long-term steady-growth model. The unconstrained profit-maximizing firm can therefore be expected to arrive at a rate of growth, g^*, somewhere in the range $\bar{g} \leq g^* < i$. The firm will always choose a rate of growth at least equal to $\bar{g}$, the general economy-wide rate of growth, for up to this rate it incurs no special expansionary costs.

For the case of the constrained profit maximizer, the rate of growth selected will be the maximum g mutually compatible with the investment and value of stockholders' earnings constraints or with the equations[8]

$$I(g) = v(1 - t)[R - C(g)] \qquad (7.5)$$

[7]See Merton H. Miller and Franco Modigliani, "Dividend Policy, Growth and the Valuation of Shares", Journal of Business, October 1961, pp. 112-119. See also the comments by J. Williamson, op. cit., p. 6.

[8]Previously equation (7.5) was written with subscripts n on I, R, and C, denoting the fact that it must be satisfied in each period. However, in our model these variables all grow at the steady rate g over time. Hence, we may omit the consideration of each period and only specifically work with the first period. As indicated before, the firm begins with an initial capital stock and the higher the rate of growth, the greater will be the net investment required in the first period. In subsequent periods, output, capital,

$$\frac{(1 - v)(1 + i)(1 - t)}{(i - g)} [R - C(g)] \geqq D_o \qquad (7.6)$$

The situation is best illustrated graphically in Figure 7-1, where the rate of growth is given on the vertical axis and the retention ratio on the horizontal axis. The investment budget constraint will define a curve similar to II' in Figure 7-1, which starts at the origin and increases at a declining rate.[9] Movement upward along this curve to the point g*, the unconstrained profit-maximizing growth rate, will imply steadily increasing levels of profitability to the firm. Also plotted on Figure 7-1 are a series of iso-valuation curves, each curve showing the values of v and g for which the discounted value of the dividend stream is equal to a given value.[10] Curves associated with higher values of discounted stockholders' earnings are obtained by movement in an upward and right to left direction. The curve associated with the minimum acceptable value of stockholders' earnings, D_o, is demarked by $D_o D_o'$ and the firm must therefore operate at a point above and to the left of this curve to satisfy the constraint expressed by equation (7.5). Now an examination of the diagram shows immediately that the point on II' with the highest g which is also above and to the left of $D_o D_o'$ is point g** where II' and $D_o D_o'$ intersect. This is the point of maximum profitability attainable by the constrained firm. This case is distinguished from the first one analyzed above in that the point at which profitability will be an absolute maximum

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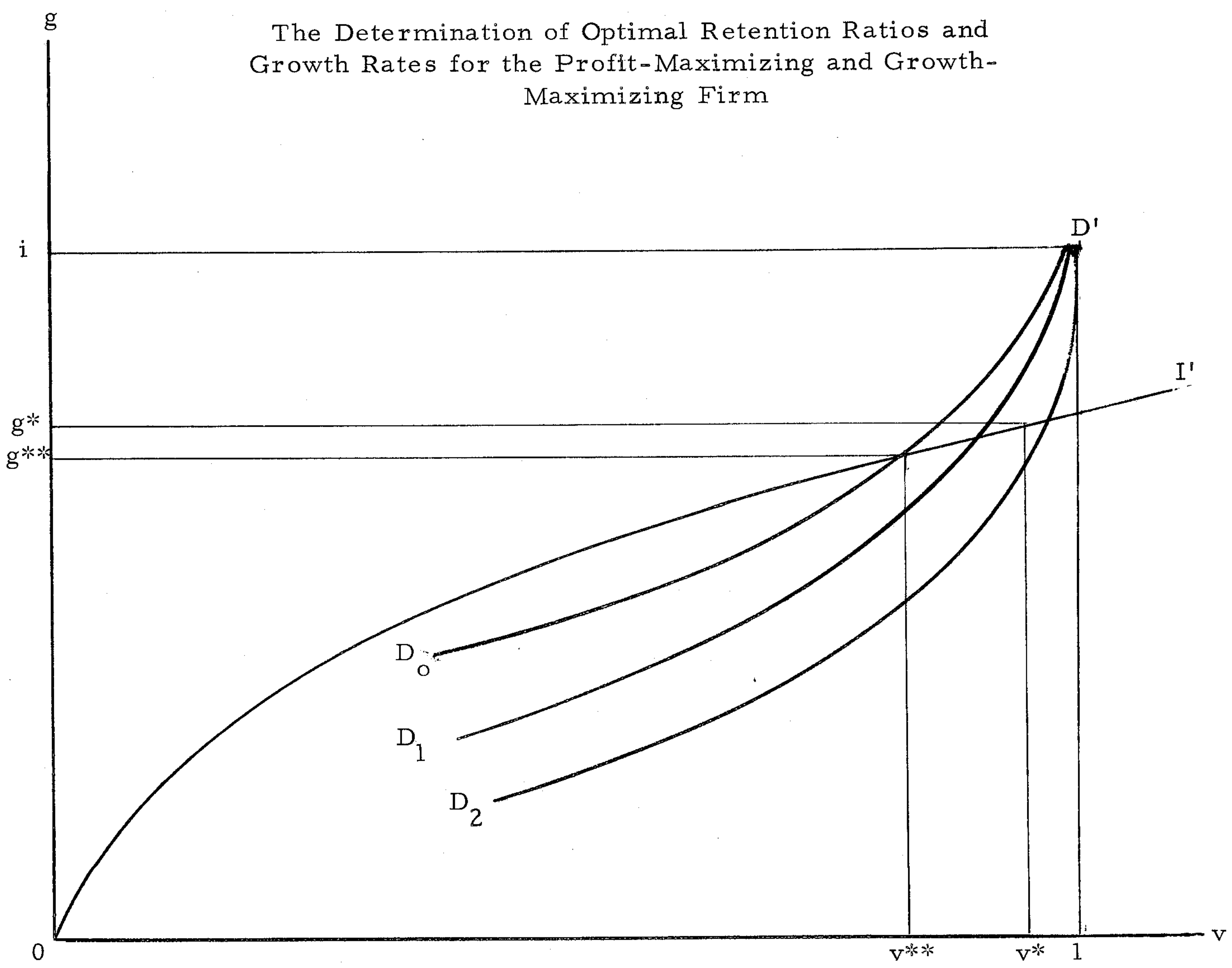
revenue and costs are multiplied by a factor of (1 + g) and the constraint will continue to be satisfied at the same retention ratio chosen in the first period.

[9] The reason for the declining first derivative is the assumption $C''(g) > 0$ together with the assumption of a constant capital-output ratio.

[10] The functional nature of equation (7.6) is such that as $v \to 1$, $g \to i$, and therefore the curves have the general shape given by Figure 7-1 and all meet in the limit at the point $v = 1$, $g = i$, where the function is actually undefined.

Figure 7-1

The Determination of Optimal Retention Ratios and Growth Rates for the Profit-Maximizing and Growth-Maximizing Firm



DD' - Iso-Valuation Lines
II' - Investment Budget Constraint Line
g*, v* - Unconstrained Solution
g**, v** - Constrained Solution

along the curve II', the point (g^*, v^*), now lies somewhere to the right of D_oD_o' and is not a feasible point of operation for the firm. Previously, in the case of the unconstrained profit-maximizer, this point was assumed to be to the left of D_oD_o' and in the region of possible operation. The constrained profit-maximizing firm, unable to operate at (g^*, v^*) on II' where its profits are an absolute maximum, will get as close to this point on II' as possible, and this is the indicated intersection point (g^{**}, v^{**}). Algebraically, it will be the rate of growth and retention ratio which satisfies both equation (7.5) and the equality form of equation (7.6).

Now a moment's reflection will reveal that this will also be the solution for the firm wishing to maximize its growth rate subject to these constraints. The constrained profit maximizer will always select the highest growth rate compatible with the two constraints and this is exactly what the growth maximizer wishes to do. It will therefore be the optimal solution for the growth maximizer as well. However, the growth maximizer will always operate at the point where the two constraints are effective even if this is not the point of maximum profitability. In other words, if the various parameters are such that the profit maximizer can achieve the unconstrained maximum (case I above) the growth maximizer will nevertheless push to the point where these constraints are effective because he can achieve a greater growth rate by doing so at the cost of losing some profits. The growth maximizer will be always willing to sacrifice profits to achieve growth, but at some point he will be prevented from doing so by the investment and stockholder constraints.[11]

[11] If there is no stockholder constraint, the growth maximizer will always go to the point $v = 1$, but the profit maximizer will not necessarily find it desirable to do so.

3. Introduction of Taxes Into the Model

We shall now introduce four tax schemes into the model and evaluate their marginal effect on growth for the three specific cases considered above (unconstrained profit maximizer, constrained profit maximizer, and growth maximizer).

The fiscal schemes that we shall explicitly consider are: a reduction in the corporate income tax, a subsidy proportional to the firm's percentage rate of output growth, a subsidy proportional to the firm's absolute rate of output growth, and a subsidy proportional to the firm's special diversification costs. All of these measures except the first operate on the margin of increasing production for the firm, and therefore are among the class of government policy measures of potential maximum effectiveness in stimulating growth. The percentage growth rate subsidy was suggested as a serious policy measure for accelerating the country's growth rate by a group of economists in 1961.[12] The next subsidy plan, a government rebate proportional to the absolute rate of output growth is equivalent within the context of our model to a net investment credit because of the assumption of a fixed capital-output ratio. The third measure is in the same spirit as the more recently proposed matching grants to a firm's R and D. The reduction in corporate income tax is also included because it is a frequently suggested means of stimulating growth of less radical character

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[12] See W. J. Baumol and Klaus Knorr (eds.), What Price Economic Growth (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1961).

than the other devices considered here. While this device will be less desirable on efficiency grounds, it does have advantages in terms of administrative feasibility and equity considerations. It therefore is also worth considering for a final decision on the desirability of taxes involves a trade-off of these various criteria.

Let us now turn to the algebra of the various tax devices. Subsidy scheme i involves payments to the firm in period n, S_{in}, of

$$S_{1n} = s_1 g \qquad \text{(percentage rate of growth)} \quad (7.9)$$

$$S_{2n} = s_2[R(1+g)^n - R(1+g)^{n-1}] \qquad \text{(absolute rate of growth)} \quad (7.10)$$
$$= s_2\, g\, R(1+g)^{n-1}$$

$$S_{3n} = s_3\, C(g)(1+g)^n \qquad \text{(cost of growth)} \quad (7.11)$$

The capitalized value to the firm of these schemes will therefore be[13]

$$S_1 = s_1 g \sum_{n=1}^{\infty} \frac{1}{(1+i)^n} = \frac{s_1 g}{i} \quad (7.12)$$

$$S_2 = s_2 g R \sum_{n=1}^{\infty} \frac{(1+g)^{n-1}}{(1+i)^n} = \frac{s_2 g R}{(1+i)} \sum_{n=0}^{\infty} \frac{(1+g)^n}{(1+i)^n} = \frac{s_2\, g\, R}{(i-g)} \quad (7.13)$$

$$S_3 = s_3 \sum_{n=0}^{\infty} C(g) \frac{(1+g)^n}{(1+i)^n} = \frac{s_3(1+i)}{(i-g)}\, C(g)\,. \quad (7.14)$$

Our principal aim here is to evaluate the efficiency of these various schemes for stimulating growth, or mathematically, to evaluate and compare $\frac{dg}{dS_i}$ for each of the proposed subsidies. We shall first consider the case of

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[13] Note that S_1 and S_2 are calculated from n = 1 rather than n = 0 since they are based on the difference in firm performance between successive time periods and initially two periods must elapse before the first subsidy may be determined.

the unconstrained profit maximizer. In order to illustrate how $\frac{dg}{dS_i}$ may be evaluated, we shall explicitly consider the effect of subsidy plan 1 on the rate of growth, g. In the presence of this subsidy the objective function of the firm, denoted by π^1, becomes

$$\pi^1 = \frac{(1+i)}{(i-g)}[R - C(g)] + \frac{s_1 g}{i} \tag{7.15}$$

The effect of a change in the subsidy rate on growth rate of the firm, $\frac{dg}{ds_1}$, may be evaluated by differentiating the first-order maximum condition $[\pi_g = 0]$ totally and rearranging terms, or

$$d\pi_g^1 = \pi_{gg}^1 dg + \pi_{gs_1}^1 ds_1 = 0 \tag{7.16}$$

which implies

$$\frac{dg}{ds_1} = -\frac{\pi_{gs_1}^1}{\pi_{gg}^1} = -\frac{\frac{1}{i}}{\pi_{gg}^1} > 0 . \tag{7.17}$$

Next in order to obtain the change in the rate of growth per dollar of government outlay, $\frac{dg}{dS_1}$, we differentiate equation (7.12) to obtain

$$\frac{ds_1}{dS_1} = \frac{1}{\frac{g}{i}} \tag{7.18}$$

and multiplying (7.18) by (7.17), we obtain

$$\frac{dg}{dS_1} = -\frac{1}{g\pi_{gg}^1} . \tag{7.19}$$

By a similar procedure, it may be shown that

$$\frac{dg}{dS_2} = -\frac{i}{g(i-g)\pi_{gg}^2} \tag{7.20}$$

increase of C(g) and C'(g) compared to quadratic function of growth implied by subsidy two.

For an unconstrained profit maximizer the most efficient measure therefore will be either the subsidy proportional to the absolute rate of growth, or the one proportional to the special costs of diversification. The subsidy proportional to the percentage rate of growth will offer lower marginal growth returns than these measures while the corporate income tax will offer zero marginal returns.

For the case of the constrained profit maximizer and the growth maximizer, the situation is quite different. As shown in the previous section, the rate of growth selected in these cases will be given by a solution of the two constraints

$$I(g) = v(1 - t)[R - C(g)] \qquad (7.7)$$

$$\frac{(1-v)(1+i)(1-t)}{(i - g)} [R - C(g)] = D_o \qquad (7.8)$$

Any fiscal measure that results in a given sum of dollars being interjected by the government initially and increasing at a rate g over time must affect both of these constraints identically. The marginal growth returns per dollar of government dollar, $\frac{dg}{dS}$, will therefore be the same no matter how the particular scheme is tied to the firm's activities. Put more intuitively, our assumption of a constrained profit or growth maximizer means that the firm will seek the highest rate of growth made possible by the interjection

The inequality $g > \frac{C(g)}{C'(g)}$ (step 2) is equivalent to saying that marginal cost is increasing faster than average cost which follows from our assumption that $C''(g) > 0$.

stimulating growth have been forthcoming, a model that incorporates several of the factors stressed in our previous interviews and empirical work has been constructed and analyzed. This analysis provides some relevant insights that should be useful to policy-makers in the design of stabilization policies for maintaining a high rate of economic growth. Of course, the actual selection of a particular scheme must be also based on its performance with respect to a number of criteria other than efficiency which will not be specifically considered here.

II. Anti-Trust Policy

Our current anti-trust policy is based on the premise that a substantial concentration of market power in any industry will have a harmful effect on the general social welfare of the economy. The main theorectical underpinnings for this belief come from traditional price theory with its various models of market structure and corresponding patterns of resource allocation. The well-known price-theoretic result that Pareto Optimality will be achieved under perfect competition and a socially inefficient allocation of resources under other market conditions offers a powerful theoretical justification for the government acting to keep the numbers of firms in any industry large and especially to prevent the larger firms from expanding their market share through mergers with their competitors.

The main challenge to these views have traditionally centered around arguments that maintain large size and substantial market power are necessary if a firm is to achieve scale economies in production and assume that great risks inherent in innovational activities. The most elegant spokesman in this camp was, for course, Joseph Schumpeter,[16] who first stressed the importance of innovation as an economic activity and the role of corporate bigness in fostering it. While it is often difficult to distill a set of logical hypothesis and arguments from Schumpeter's rhetoric, there is no doubt concerning his central position. He felt any general assault on bigness and attempt to bring about a market structure approximating perfect competition would if successful, destroy our main "engines" of technical progress, the large corporate enterprises.

If one interprets Schumpeter's ideas as applying at "threshold" levels, they are undoubtedly true for the NSF and other statistics on innovational effort show very little organized inventive activity for the smallest firms in any industry.[17] Within the range of firms most relevant to anti-trust activity, the top ten or twenty largest firms in the industry, the issue is however far from clear. It is uncertain whether an increase in size over this range is beneficial to innovation and if it is, whether this is sufficient grounds to allow mergers of competing firms with their resulting lessening of competition in other areas. It is on the basis of these kinds of trade-off that most anti-trust cases must be evaluated, however, and they therefore give rise to immensely difficult conceptual and empirical problems.

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[16] Joseph A. Schumpeter, Capitalism, Socialism and Democracy (New York: Harper and Brothers, 1942).

[17] See National Science Foundation, Research and Development in Industry 1961, NSF 64-9, (Washington, D. C., 1964).

The empirical work presented in Chapter Five addresses itself to the specific question of the role of firm size in influencing the level of R and D expenditures. As such, this is not a test of the original Schumpeterian proposition concerning market power and firm innovation but to a more specific, if weaker, hypothesis. Probably the most serious shortcoming of the analysis in Chapter Five is that innovational effort on the part of a firm, as measured by R and D expenditures, does not necessarily imply a similar degree of successful innovation. Until we have some adequate measures of the latter phonomena on a large scale, however, we are forced to use surrogates such as R and D despite their obvious limitations. Nevertheless, it does seem reasonable to believe that there will be some correlation between a firm's input to technical change and its outputs, and the few empirical studies on this question have borne this out. While some important distinctions will obviously be lost by proceeding in this fashion, it seems useful to do so in the absence of more refined measures.

Since the sample of firms used in our analysis was intitially derived from the Fortune 500 Listing, all of the resulting firms may be classified as large. The size of the largest firm in each industry sample is however several times the smallest one, and the range of variation provided by these industry groupings would seem to be that most relevant to anti-trust considerations. The range of this sample does not permit, however, any inquiries into the threshold levels of firm participation in organized research and development.

With respect to the nature of the relationships studied and samples used, our analysis is very similar to the recent pieces by Mansfield, Schmookler, Scherer, and others.[18] It attempts to extend the scope of these previous studies somewhat by looking not only at the relation between firm size and R and D but also that between firm size and the determinant factors of R and D in order to see whether any particular factor might be responsible for the observed correlations between the two main variables under study. The general hope of this and the other recent studies is that by obtaining some quantitative information on these kinds of questions, some progress can be made toward resolving some of the complex and elusive issues that currently surround public policy toward the private sector.

We may now summarize the main results presented in Chapter Five and put them in the perspective of the current discussion. First, for the three industries under study, research intensity increased with firm size only in chemicals, decreased in drugs, and was roughly constant in petroleum. Moreover, the technological-performance variable (patents per R and D input) that was a statistically significant explanatory variable of research intensity in all three industries was relatively uncorrelated with firm size. The other statistically significant explanatory variables of R and D, diversification and the level of internally-generated funds, were significantly correlated with firm size only in the case of the chemical

[18] See the discussion of these studies in Chapter Five, Section IV.

industry. The flow-of-funds variable was actually negatively correlated with firm size in the petroleum and drug industries.

The mixed nature of these results tend to suggest that the neo-Schumpeterian arguments are in general valid only when interpreted as part of a "threshold theory". In particular, the fact that internally-generated funds may rise less than in proportion to firm size over the range of our samples, as it did in two of three industries, counters one of the central beliefs of Schumpeter himself concerning the role of profits in positively linking bigness with innovational activities. Likewise, the lack of any strong correlation between technological performance and firm size would indicate no strong scale economies present over this sample range. A qualifying remark must be made here, however, in that our empirical work is concerned only with the total level of dollar expenditures for research and not the character of the work performed. Some preliminary empirical work by Mueller[19] on the latter question has indicated that large firms spend a greater percentage of their funds on basic research than smaller ones. An extension of this approach together with the development of some techniques to measure the social usefulness of innovations and innovational activity undertaken by industrial research may thus yet rescue some aspects of the Schumpeterian argument.

In summary, the basic implications for public policy resulting from our study would appear to be similar to most of its recent predecessors:

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[19] Dennis C. Mueller, The Determinants of Industrial Research and Development, unpublished Doctoral Dissertation, Princeton University, 1965.

namely, over the range of firms that are most relevant for anti-trust activity, there seems to be little basis for strongly championing or condemning business on the basis of its effect on the level of innovational activity. While this is hardly a conclusion on which an evaluation of the overall social desirability of our current anti-trust policy can be made, it does serve to discount some of the strong claims that have been on both sides of the fence in the past concerning the necessary ties between market size and innovation.

CHAPTER EIGHT

RESEARCH AND ECONOMIC GROWTH: SOME MACROECONOMIC SPECULATIONS[1]

I. Introduction

It was indicated in the introductory chapter that this thesis would concentrate primarily on the microeconomic issues and problems of industrial research. Now that our main work in this regard is complete, it seems desirable to add as a kind of postscript some speculations on the possible macroeconomic implications of our results. We will do so in this chapter, using the conceptual framework of the recent growth-theoretic literature. We must emphasize the word "speculations", however, since there are large gaps between the microeconomic analyses hitherto considered and the macroeconomic growth models that will be now studied. While our previous microeconomic results do provide some general conclusions concerning the possible nature of aggregate relationships between R and D and other economic variables, they give very little clue as to the specific functional forms appropriate for any macroeconomic growth models. In view of this fact, we will use various alternative relations that appear to be plausible on a priori grounds. Even if the resulting models only crudely approximate

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[1]Several months after the material of this chapter was first presented to a seminar in Princeton, an article by Phelps appeared with a somewhat similar orientation; E. S. Phelps, "Models of Technical Progress and the Golden Rule of Research", Review of Economic Studies, April 1966.

any actual situations, it is nevertheless felt that this type of analysis is important as a first step in structuring the problem.

The main point of departure of our analysis from recent growth-theoretic models will be in the treatment of technical change. The traditional models almost invariably assume technical change in an exogeneous factor. This reflects the once widely held belief among economists that successful inventive activity is not significantly influenced by normal economic variables but depends essentially on technological conditions and other non-economic factors. The results of the previous chapters and other empirical studies indicate, however, that one important aspect of technical change, new-product output, is positively related to research expenditures at the firm level.[2] In addition, although we have not tested for it here, the level of a firm's process improvements can also be expected to be a significant positive function of its research expenditures.[3] Both of these microeconomic relationships would seem to provide a case for making the aggregate level of a society's technical change an increasing function of its research expenditures.

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[2] While we actually regressed sales growth on research intensity, the link is through new-product sales. Comanor, having access to new-product sales data in pharmaceuticals, found a significant positive regression relation between new-product sales and research intensity that is in accordance with our results for chemicals and drugs. See William S. Comanor, "Research and Technical Change in the Pharmaceutical Industry", Review of Economics and Statistics, December 1965, pp. 182-189.

[3] An empirical study by Mansfield seems to bear this out for chemical and petroleum firms. See his discussion in "Rates of Return from Industrial Research and Development", American Economic Review, May 1965, pp. 310-322. It may also be noted that in many cases the technical change will occur not in the firm's own productive process but in the production process of the users of its products (machinery manufacturers offer a good example of this). In an aggregate model where society's R and D is related to its aggregate technical change, this will, however, not produce any complications.

Furthermore, the fact that industrial R and D expenditures depend on economic variables such as the level of a firm's internally-generated funds makes it especially desirable to do so, because these variable are capable of being influenced by normal government policy actions.

For the specific growth models that follow here, we will first consider the nature of their equilibrium solutions and then turn to the general question of optimal policy action when the government is able to influence the level of resources devoted to R and D. Of course, all of the limitations concerning these models in their standard form are equally applicable to the present analysis. Some of these will be discussed in some detail below. We emphasize here at the outset, however, that this analysis is only concerned with equilibrium solutions and not with transient or non-equilibrium behavior. The latter behavior may be of crucial relevance to government policy-makers because it may take several time periods for an equilibrium solution to be achieved. Another area of concern for policy-makers which the aggregative nature of the present analysis ignores is the problems of equity that arise out of any government policy to stimulate economic growth. The present focus is merely on the equilibrium growth effects of research and development expenditures in an aggregative context.

II. Growth Model I - A Single Sector Cobb-Douglas Production Function

We begin our analysis by employing a growth model which is one of the original and most extensively used of the growth literature. In this model there are two basic factors of production, labor and capital, which are used to produce a single homogeneous output. Technical change is an increasing function of the cumulative amount of expenditures on research and development and also includes an exogeneous component to reflect other non-research factors. It is assumed that the production function is of the Cobb-Douglas variety. The production function in mathematical form is therefore

$$Y = f(R)\, e^{ut}\, L^{\alpha} K^{\beta} \qquad (8.1)$$

where $\alpha + \beta = 1$,

and f(R) is the relation between technical change and research and development, which is denoted by R, u is the exogeneous component of technical progress, Y, L, and K are the amounts of output, labor, and capital - all functions of time.

It is further assumed that the amount of labor is given by an exogeneously determined expotential rate of growth and is fully employed. Thus,

$$L = L_o\, e^{nt} \ . \qquad (8.2)$$

On the demand side of our model we assume that there exists a Keynesian consumption function - specifically that consumption is a fixed proportion of income:

$$C = c\, Y \ . \qquad (8.3)$$

Equilibrium in this model exists when consumption plus non-consumption demands (in this case physical investment and research and development) equal total output

$$C + I + R = Y. \qquad (8.4)$$

It remains only to specify how the non-consumption or saving component of Y is allocated between I and R and also to specify the exact functional relationship between research and development and technical change in equation (8.1).

We shall tackle this latter problem first. The appropriate functional form of f(R) is a question that requires considerable thought. It seems reasonable to suppose that f depends on the total stock of research effort rather than just the current amount and that the research becomes effective only after a certain period of time has elapsed. Another desirable property is that of diminishing returns to the amount of research done in a particular period of time.[4]

One convenient function to work with that satisfies the above conditions is[5]

$$f(R) = A \left[\int_{-\infty}^{t-\theta} R \, dt\right]^{\sigma} \quad \text{where A is a constant.} \qquad (8.5)$$

This specifies that there is constant elasticity between the stock of accumulated R and D and total output similar to that of other factors in the

[4] One reason for expecting diminishing returns to increasing increments of research done in a particular period of time is that there is less likelihood of the full diffusion of the research progress and results which will tend to make the whole process less efficient. Another reason is inhomogeneities in the factor supplies, particularly in the labor force.

[5] It may be noted here that the only empirical studies undertaken on the relation between R and D and technical change have used this formulation and have reported good fits to the data. However, the empirical samples have been very restrictive in nature and do not offer a very good basis for

Cobb-Douglas formulation. The above formulation also provides for a lag of θ time periods in the effectiveness of research which is in accordance with our microeconomic results of Chapter Seven.

There are a few possibilities concerning the allocation of effort between research and physical capital that seem worth investigating. The first alternative (Growth Model I) is to assume that in equilibrium the level of research and development, physical investment, and consumption will all have a fixed relationship to each other.[6] We may express this assumption together with that of the equilibrium condition of equation (8.4) by the equations

$$I = s_i Y \qquad (8.6)$$

$$R = s_r Y, \qquad (8.7)$$

where $s_r + s_i + c = 1.$

Another possibility is to assume that the special nature of research and development expenditures makes an assumption of proportionate growth of research and total output unlikely in long-term equilibrium. Growth

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making a judgment on this question. See the discussion in Mansfield, op. cit., on his results and how they relate to a previous unpublished paper by Jora Minasion. See also Ellias Johnson and Herbert E. Steiner, "The Quantitative Effect of Research on National Economic Growth", Proceedings of the Second International Conference on Operational Research, (New York: Wiley and Sons, Inc., 1961), pp. 499-450. Footnote 18 of this chapter provides a more detailed analysis of these studies.

[6] This assumption does not arise from any technological inter-relationship between research and capital investment (these are expressed by equation (8.1)) but from the nature of what one means by a long-term equilibrium in a system that grows over time. The allocation of resources between the two items in a capitalistic economy will depend on the budgeting procedures of the decision-making unit which in turn should reflect many forces.- the supply of the factors, technical productivity, government actions, etc. In a growing system, however, one would not normally expect the allocation of GNP to one

Model III considers this possibility by treating R and D as arising from a different production structure than physical output and makes some assumptions on the relationship between R and D and the growth of the labor force. A third possibility to look for is the functional relationship between physical investment and R and D which maximizes the discounted consumption stream over time. This gives rise to a problem in the calculus of variations and will not be treated in the present paper. We will however compute optimal saving-ratios for Growth Model I by ordinary calculus after analyzing its equilibrium properties for arbitrary values of s_i and s_r. We will make some similar calculations for Growth Models II and III.

Formally, Growth Model I consists of equations (8.1), (8.2), (8.3), (8.5), (8.6), and (8.7). We may combine equations (8.1) and (8.5) into (8.1') and write the total system as

$$Y = A\, e^{ut} \left[\int_{-\infty}^{t-\theta} R\, dt \right]^{\sigma} L^{\alpha} K^{\beta} \qquad (8.1')$$

with $\alpha + \beta = 1$

$$L = L_o\, e^{nt} \qquad (8.2)$$

$$C = c\, Y \qquad (8.3)$$

$$I = s_i\, Y \qquad (8.6)$$

$$R = s_r\, Y \quad \text{with } c + s_i + s_r = 1\,. \qquad (8.7)$$

The above model is essentially a "neoclassical" growth model of the type which Solow[7] first introduced in more general form. Research and

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of these factors to become negligible over time compared to the other, given a production function such as equation (8.1). This is what this assumption prevents.

[7] Robert M. Solow, "A Contribution to the Theory of Growth", Quarterly Journal of Economics, February 1956, pp. 65-94.

development is introduced into this model on the supply side as a source of technical change and on the demand side as a user of total output. These neoclassical models differ from earlier growth models[8] in that they assume variable instead of fixed coefficients of production. As shown by Solow, this assumption together with assumptions of a Keynesian demand structure and full employment of the labor force yield a model which has a stable equilibrium solution characterized by a steady growth rate of output. It is also true of such models that the equilibrium rate of growth is independent of the savings ratio and depends only on supply-side considerations. A change in the saving ratio however affects the equilibrium level of output, and thus it still remains an important parameter for government policy considerations.

We now turn to an analysis of the solution of the above model. The system of equations yields an equilibrium solution[9] for I given by

$$I = Q e^{rt} \tag{8.8}$$

where r and Q are related to the parameters of the model by the relationships

$$r = \frac{n\alpha + u}{\alpha - \sigma}$$

and

$$Q = (A\, r^{-(\sigma+\beta)}\, s_r^{\sigma}\, s_i^{1-\sigma}\, e^{-\sigma r \theta}\, L_o^{\alpha})^{1/\alpha-\sigma} \tag{8.9}$$

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[8] See, for instance, Evesy D. Domar, Essays in the Theory of Economic Growth (New York: Oxford University Press, 1957) and Roy F. Harrod, "An Essay in Dynamic Theory", The Economic Journal, March 1939, pp. 14-33.

[9] This may be found by substituting equations (8.2), (8.6) and (8.7) into (8.1') (using the implicit definition I = dK/dt) and obtaining an equation only in K. Integrating and rearranging terms one obtains a non-linear mixed difference-differential equation which has the above solution.

The corresponding solutions for Y and R are given by

$$Y = Q' e^{rt} \qquad \text{where } Q' = Q/s_i \tag{8.9}$$

$$R = Q'' e^{rt} \qquad \text{where } Q'' = s_r Q/s_i . \tag{8.10}$$

A look at these solutions reveals several interesting results. First, the equilibrium rate of growth, r, is independent of the allocation of total output to investment and to R and D given by the saving ratios s_r and s_i. Thus it is dependent only on parameters arising from the supply side of the aggregate production function as in the Solow model. As $\sigma \rightarrow \alpha$ the rate of growth becomes arbitrarily large. The condition $\alpha = \sigma$ implies $\sigma + \beta = 1$ which means the sum of the elasticities of output with respect to factors that are producible from that output (investment and R and D in this model) is unity and this allows an infinite growth rate. When this condition on the sum of the elasticities of R and D on investment holds, the fact that labor is a scarce factor with a constrained growth rate no longer matters in limiting the growth rate of output. Since in actual empirical studies $\alpha \approx 0.7$ and estimates of σ are much lower, it is unlikely that one need be too concerned about this when using this model empirically. In the discussion here we shall assume $\alpha > \sigma$. It may be further noted that for this model the growth rate is independent of the lag in the effectiveness of research and development expenditures. It is an increasing function of the rate of growth of labor, n, the exogeneous rate of technical progress, u, and the elasticity of output with respect to R and D, σ. It is a decreasing function of the elasticity of with respect to labor α,[10] and thus an increasing function of β, since $\alpha + \beta = 1$.

While the growth rate is independent of the proportions of output devoted to R and D and investment, the equilibrium level of output is crucially dependent on these factors as well as the lag in the effectiveness of R and D. In the case of the latter parameter, θ, the level of output is a strictly decreasing function of the size of the lag. With respect to the proportions of output devoted to investment and R and D, the situation is more complicated. While the equilibrium level of output will be increased by higher values of s_r and s_i, after a certain point the increases in output will be at the expense of consumption rather than increasing this component also. Some alternative equilibrium consumption tracks are illustrated in Figure 8-1.

A natural question to pose at this point is what values of s_r and s_i maximize C_t. Up to this point we have been considering s_r and s_i to be parameters of our model. We will now assume that these parameters are a function of government tax policies and other policy actions. Without specifying a complete structure of inter-relationships in this regard, we shall assume for analytical purposes that the government has enough policy tools to manipulate s_r and s_i in appropriate fashion.

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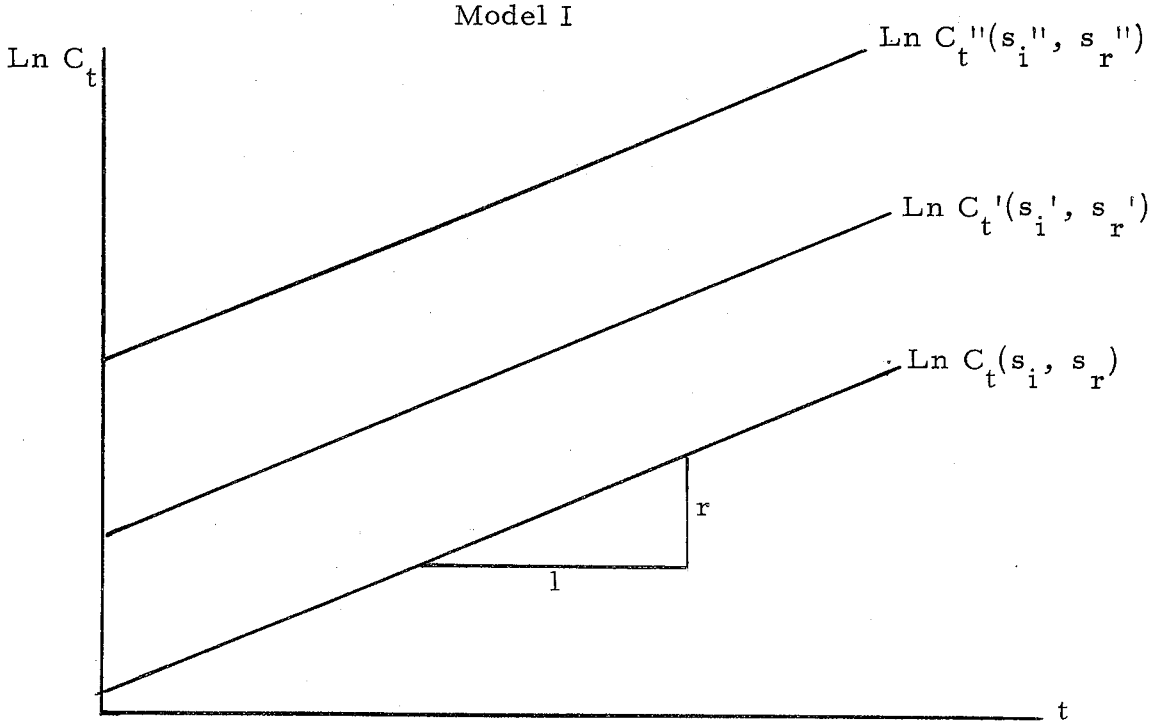
[10] We are speaking here for the range $\alpha > \sigma$ - this may be seen by re-writing r as $r = \frac{n + u/\alpha}{1 - \sigma/\alpha}$ and investigating r as α increases from σ.

Figure 8-1

Alternative Equilibrium Consumption Tracks for Growth Model I



Now the question of what values of s_r and s_i maximize C_t can be solved by ordinary calculus[11] and the resulting optima turn out to be

$$s_i^* = \beta \tag{8.11}$$

$$s_r^* = \sigma . \tag{8.12}$$

The above marginal conditions tell us that in order to maximize the equilibrium level of consumption, one should allocate the proportion of total output to R and D and investment which is equal to the elasticity of output of these respective factors. The above condition is an extension of those

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[11] C_t is given by $C_t = (1 - s_r - s_i)Y$ and one then sets $\frac{\partial C_t}{\partial s_r} = 0$ and $\frac{\partial C_t}{\partial s_i} = 0$ and solves for s_r^* and s_i^*.

first derived by Phelps[12] and often referred to in the literature as "golden rules of accumulation".

Thus Growth Model I shows that when R and D is viewed as contributing to total output in basically the same manner as total investment (except for the lag assumption on R and D) and when a fixed proportion of total output is allocated to R and D on the demand side, everything which holds for the single investment good model generalizes to the "two investment good" model proposed here. Thus, in such an economic world, the course is fairly straightforward to a government desiring to maximize the long-run level of consumption and capable of manipulating the overall saving rate and the proportion of this rate devoted to R and D and investment.

Let us now re-examine some of the assumptions upon which the above results depend. Implicit in this model is that labor and capital can be combined to produce research in the same fashion that can be combined to produce physical output (i. e., by means of the same Cobb-Douglas production function). Since we have assumed a single homogeneous output, this implies also that the technical change (both exogeneous and endogeneous) which affects the production of physical output also affects the production of research in the same manner. One would think, however, that the diverse natures of R and D and physical outputs make the above assumption somewhat unrealistic, and one should definitely try to formulate the model with two production functions - one for R and D and one for physical output.

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[12] Edmund S. Phelps, "The Golden Rule of Accumulation: A Fable for Growthmen", American Economic Review, September 1961, pp. 638-643.

In Growth Model III, we formulate a model which assumes that research is governed by a fixed production function while a Cobb-Douglas function holds for the output sector. It is also recognized in that model that all labor is not homogeneous with respect to their ability to do research and therefore labor is divided into two groups - workers whose training permits them to be employed in the R and D sector and workers who are engaged in the normal productive sector. In long-term equilibrium it is assumed that the proportion of workers in each sector will remain constant. Before turning to a detailed analysis of this model, however, we shall indicate in Section III that our results for Growth Model I also hold when the Cobb-Douglas production function has capital-embodied technical progress and coefficients of production which are variable ex-ante and fixed ex-post.

III. Growth Model II - A Single Sector Capital-Embodied Cobb-Douglas Production Function with Variable Coefficients Ex-ante and Fixed Coefficients Ex-post

The most recent growth literature[13] has seen the refinement of the model presented above into one in which the following more appropriate assumptions are made concerning the production function:

(1) Technical change occurring at time t can only be embodied in capital constructed at time t, thus giving rise to different productivities from different vintages of capital.

[13] See the references listed in footnote 4 of Chapter One, p. 4.

(2) Ex-ante the capital labor substitution possibilities are given by a variable-coefficients production function; ex-post fixed coefficients of production hold.

(3) There is a fixed period of capital longevity which can be the result of technical or economic obsolescence.

These new assumptions necessitate the formulation of a vintage production function, $Y_v(t)$, which associates different vintages of capital with different levels of technical change. Total output at time t, Y(t), is then the integral of the outputs of different vintages of capital in existence at that time.

For the case of a Cobb-Douglas production function with the assumptions on technical change made in Growth Model I, the vintage production function will be

$$Y_v(t) = A\, e^{uv} \left[\int_{-\infty}^{v} R(g)\, dg \right]^{\sigma} L_v(t)^{\alpha} K_v(t)^{\beta}; \quad \alpha + \beta = 1 \qquad (8.13)$$

where $K_v(t)$ is the capital stock of vintage v still in existence at time t,

$L_v(t)$ is the labor employed with capital of vintage v at time t, and

$Y_v(t)$ is the output obtainable at time t from $K_v(t)$ and $L_v(t)$.

Total output at time t, Y(t) is then given by

$$Y(t) = \int_{t-\delta}^{t} Y_v(t)\, dv \qquad (8.14)$$

where δ is the period of capital longevity. The new production function defined by equations (8.13) and (8.14), together with our previous assumptions concerning the exogeneous growth of the labor supply and the fixed relationship in equilibrium between consumption, physical investment, and research provide a model with similar properties to Growth Model I.

We may develop the equilibrium solution to our new model in the following way. First, capital of vintage v in existence at time t must by definition be equal to gross investment at time v, or

$$K_v(t) = I(v) \, . \tag{8.15}$$

Second, by our assumption that labor is fully employed over the vintage of capital in existence at time t, we have

$$L(t) = \int_{t-\delta}^{t} L_v(t) \, dv \tag{8.16}$$

or

$$L_o \, e^{nt} = \int_{t-\delta}^{t} L_v(t) \, dv \; . \tag{8.16'}$$

Now it may be easily shown that equation (8.16) yields an equilibrium solution for $L_v(t)$ in terms of v of the form[14]

$$L_v(t) = L_o \frac{n}{1-e^{-n\delta}} e^{nv} \tag{8.17}$$

Finally we make use of the relationships

$$R(v) = R_o \, e^{rv} \tag{8.18}$$

[14] By making use of the second assumption on page 155, that fixed coefficients of production hold ex-post, we may differentiate equation (8.16') and obtain

$$L_t(t) = n \, L_o \, e^{nt} + L_{t-\delta}(t) \, .$$

Substituting the relation $L_{t-\delta}(t) = L_{t-\delta}(t-\delta)$ into this equation, we obtain a difference equation whose solution is given by equation (8.17).

and

$$I(v) = I_o e^{rv} \qquad (8.19)$$

which follows from our assumption that research and physical investment both grow in parallel with output when the model is in equilibrium.

Now in order to obtain the solution of the model in terms of its basic parameters, we first combine equation (8.13), (8.15), (8.17), (8.18), and (8.19) to obtain an expression for $Y_v(t)$ in terms of v:

$$Y_t(v) = A e^{uv} \left(\frac{R_o}{r}\right)^{\sigma} e^{\sigma r v} L_o^{\alpha} \left[\frac{n}{1-e^{-n\delta}}\right]^{\alpha} e^{n\alpha v} I_o^{\beta} e^{r\beta v} \qquad (8.20)$$

Now, substituting equation (8.20) and integrating we obtain the equilibrium solution:[15]

$$Y(t) = Q e^{rt} \qquad (8.21)$$

where $r = \frac{u + n\alpha}{\alpha - \sigma}$

and $Q = [A r^{-\sigma-1} s_r^{\sigma} s_i^{\beta} L_o^{\alpha} n^{\alpha}(1-e^{-n\delta})^{-\alpha} (1-e^{-r\delta})]^{1/\alpha-\sigma}$

The growth rate of Model II is the same as for Model I and also the level of output is related to s_r and s_i in the same fashion as before. The addition of the capital-embodiment assumption therefore does not alter the optimal government policy for maximizing the equilibrium level of consumption and the golden rules of accumulation derived for Model I still apply.

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[15] In order to obtain the folution in this form, we make use of the relations $I_o = s_i Y_o$ and $R_o = s_r Y_o$ to eliminate I_o and R_o.

IV. Growth Model III - A Two-Sector Growth Model

As indicated above, it seems desirable because of the diverse natures of technical change and physical output to formulate different production structures for them. In the case of technical change, the crucial input would appear to be the man-hours of scientific effort employed, since ultimately research is a process of applying the trained imaginative mind of man to unsolved problems. While capital is a necessary complement in most instances and usually improves the efficiency of a given scientific effort, it can never act as a substitute for the scientist. In recognition of this general lack of substitutability in the process of technical change, we will use a fixed-coefficients production function in the research sector in Model III, while continuing to assume that physical output is produced by a Cobb-Douglas function. In this new model we shall further assume that the labor force is divided into two groups - people who are trained and able to produce research outputs and people who are not. The portion of labor force that can produce research outputs, denoted here by L_r, will be fully employed in the research sector; the rest of the labor force is employed producing physical output. In long-term equilibrium, the portion of the labor working on research will be assumed constant. This constant, of course, will be influenced by people's preference and abilities, the demand for research and development, as well as government measures which are designed to stimulate R and D and improve the training of research workers.

Since the portion of labor performing research, L_r, is a constant function of the labor force it must grow at the same rate as the labor force. Hence,

$$L_r = k L_o e^{nt} \qquad \text{where } 0 < k < 1 . \qquad (8.22)$$

We have assumed fixed coefficients of production in the research sector - thus capital expenditures for research, K_r, and total expenditures for research, R, must grow at the above rate also. Hence,

$$K_r = a k e^{nt} \qquad (8.23)$$

$$R = b k e^{nt} \quad \text{where a and be are constants.} \qquad (8.24)$$

Turning now to the productive sector one has a production function similar to Growth Model I :

$$Y = A e^{ut} \int_{-\infty}^{t-\theta} R \, dt^{\sigma} \; L_p^{\alpha} K_p^{\beta} \qquad \alpha + \beta = 1 \qquad (8.25)$$

where L_p and K_p are the labor and capital utilized in the productive sector. From the above assumption concerning the division of labor between research and physical output, it follows that

$$L_p = (1 - k) L_o e^{nt} \qquad (8.26)$$

and from the assumption of a stable consumption function and the normal total demand equal total supply equilibrium condition, we obtain the relationship

$$I = s Y = \frac{d(K_p + K_r)}{dt} . \qquad (8.27)$$

The complete model is given by equations (8.22) - (8.27). In order to solve this system of equations, one can substitute (8.23), (8.24), (8.26), and (8.27) into (8.25) and obtain the single differential equation in K_p given below:

$$\frac{1}{s}\frac{dK_p}{dt} + \frac{n}{s} a e^{nt} = A e^{ut} k^{\sigma}\left(\frac{b}{n}\right)^{\sigma} e^{-n\sigma\theta} e^{n\sigma t}(1-k)^{\alpha} L_o^{\alpha} e^{n\alpha t}(K_p)^{\beta}. \qquad (8.28)$$

Unfortunately, the exact solution to (8.28) has not been obtained and there is some doubt as to whether it can be expressed in closed form.[16] An approximate solution can be found, however, and is given by[17]

$$K_p \approx H e^{xt} \qquad (8.29)$$

where $x = \dfrac{u + n(\sigma + \alpha)}{1 - \beta}$

and $H = A^{1/1-\beta} s^{1/1-\beta} \left(\frac{b}{n}\right)^{\sigma/1-\beta} e^{-(\sigma n\theta/1-\beta)} [(1-k)L_o]^{\alpha/1-\beta} x^{1/1-\beta} k^{\sigma/1-\beta}$

$= [s A L_o \left(\frac{b}{n}\right)^{\sigma} e^{-\sigma n\theta} (1-k)k^{\sigma} x^{-1}]^{1/1-\beta}$

similarly

$$Y \approx H' e^{xt} \qquad \text{where } H = x H'/s . \qquad (8.30)$$

[16] The above equation is a special case of the following equation:

$$\frac{dy}{dx} + A f(x)y^{a} = B g(x) \qquad \text{where } 0 < a < 1.$$

This is an first-order, first-degree, ordinary differential equation, and a basic theorem in the theory of differential equations assures the existence of a unique solution to this equation. However, attempts to obtain this solution in a closed functional form have been unsuccessful.

[17] This approximate solution is valid for large value of t, since on the left-hand side of equation (8.28) $e^{xt} >> e^{nt}$ for large values of t (because $x > n$), and the term, e^{nt}, may be ignored. This mathematical approximation has the economic interpretation that over time, the amount of capital utilized in the research sector will become a smaller and smaller portion of total capital consumed by the economy, and therefore may eventually be ignored. The approximation given above is actually an overstatement of the level of income at any time, since it would be an exact solution if no capital were needed in the research sector. With some capital acutally being diverted to the research sector (at a rate e^{nt}) the level of income will be smaller than that given by

The growth rate given by the approximate solution above is less than that of Growth Model I. However, the growth rate in this model has the same type of functional relationship to the basic parameters as before - being an increasing function of u, n, σ, and β and a decreasing function of α. The level of income also depends on the savings ratio and the lag in research effectiveness in the same manner as the former model.

We are now in a position to pose the same kind of question with this model as we did above - assuming that the fraction of the labor force doing research can be influenced by government actions (at least within some range) both on the demand and supply side, what is the value of this fraction that maximizes the equilibrium level of consumption? In Growth Model I we computed the optimal allocation of total output to research - here we compute the optimal portion of the labor force doing research which maximizes equilibrium consumption. Proceeding in the same manner as above, we obtain as the optimal proportion of the total labor force to be employed in the research sector as

$$k^* = \frac{\sigma}{\alpha + \sigma} \qquad (8.31)$$

and hence the optimal portion for the productive sector will be

$$1 - k^* = \frac{\alpha}{\alpha + \sigma} . \qquad (8.32)$$

Thus the optimal ratio of labor employed in the research sector to the productive sector should be

---

the above approximation but the economy will eventually grow at the above rate as this capital in the research sector becomes a negligible part of total capital utilized in the economy.

$$\frac{L_r}{L_p}^* = \sigma/\alpha \qquad (8.33)$$

or in the ratio of their respective output elasticities, this result is of the same general nature as the golden rules of accumulation derived earlier.

V. Some Concluding Remarks

The main conclusions that emerge from the preceding analysis is that similar golden rules apply to a society's research effort as were previously set forth for capital accumulation in these neo-classical growth models. This is perhaps more surprising than it initially appears since research in these models is not homogeneous of degree one with labor as is capital, but appears in the production function as a general scale effect. These results, however, apply only as an approximate solution in the two-sector growth model set forth here.

Since the main purpose of this chapter was theoretical in nature, no attempt was made here to implement these results empirically. The highly simplified nature of these models together with the general lack of suitable data make this latter task difficult. It may be noted however that two empirical studies[18] that utilized a production function similar to the one

[18] One of these studies, done by Mansfield op. cit., was at the micro-economic level and used firms only from research-oriented industries which would obviously tend to bias the coefficients in an upward direction. However, Mansfield measured only the effect on the parent firm and since the economy-wide effect will necessarily be greater, this will tend to offset the upward bias induced by his choice of sample. The other study done by Johnson and Steiner, op. cit., was at the aggregate level and resulted from a cross-sectional analysis of different countries.

postulated in our models (Cobb-Douglas with technical change related to accumulated research expenditures with constant elasticity) yielded coefficient for the elasticity of output (σ in the previous models) in the range of 0.11 - 0.15. Without belaboring the questionableness of using these figures for our present purposes, it is significant that when these estimates for σ are substituted in our optimal resource allocation formulas, they yield figures that are an order of magnitude higher in percentage terms than present research efforts in the United States. This large discrepancy is nevertheless consistent with the most prominent fact concerning research expenditures in the United States and several other industrially-mature nations - namely, the rapid growth of research relative to the rest of the economy. For example, the percentage of GNP devoted to research and development in the U.S. has been steadily increasing over time - doubling itself about every six years since the early 1920's when such statistics were first regularly recorded. This equilibrium exhibited by research over the past half-century is precisely what one would expect if the optimal rate is considerably above the actual rate as suggested by these models and estimates.

While the above results hardly provide a definitive basis for championing higher government subsidies to research, they do suggest further work on the general question of the relationship between research, technical change, and economic growth is potentially a most important and profitable venture. By coupling these studies with more intensive ones on the behavior of the various groups actually performing the research, we can better evaluate the consequences of the current "research revolution", and also evolve optimal government policies for this sector of the economy. Hopefully, some of our current gaps of knowledge in this area will be closed in the not too distant future.

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ABSTRACT

This study is a microeconomic empirical analysis of industrial research and development. A number of hypotheses on the determinants and effects of R and D expenditures are formulated. These are then incorporated into regression models of the single-equation variety. The models are estimated using data on firms from the Fortune 500 Listing in the chemical, drug, and petroleum industries over selected portions of the post-war period.

The first model studied postulates that a firm's R and D expenditures are determined by various technological, financial, and marketing variables. Among the specific variables used as independent variates explaining R and D are an index of the firm's capacity to do research successfully (as measured by its patented output), the level of its internally-generated funds, and an index of its product-line diversification. The estimates of the regression coefficients associated with each of these variables are significant at the one-percent level for the three industries studied here (with one exception). The overall explanatory power of these variables is quite sizeable in drugs and chemicals ($R^2 = 0.86$ and $R^2 = 0.63$ respectively) but only moderate in the petroleum industry ($R^2 = 0.25$). Regression estimates associated with other variables are not statistically significant. In particular, the short-term rate of sales growth is not a significant factor influencing R and D and also no evidence is observed for the frequently-mentioned proposition that oligopolistic firms adhere to an industry-wide R and D to sales ratio.

A second question which is investigated empirically is the relation between firm size and research intensity (the latter variable being defined as R and D expenditures divided by sales). This is obviously an important consideration for government anti-trust policies. However, the results emerging from the empirical analysis are very mixed in nature. Only in the chemical industry is firm research intensity significantly related to size in a positive manner. In drugs a significant negative relation is observed, and for petroleum firms, the variables are uncorrelated. The observed relationships between the research-determinant variable and firm size exhibit similar characteristics. The mixed nature of these results therefore do not provide grounds for a presumptive bias in favor of or against large-scale mergers, and each case must be judged on its own merits in this respect.

A third question considered in this thesis is the effect of a firm's research intensity on its rate of output growth. A much longer time period is employed in this analysis, and only firms in the chemical and drug industries are included. Despite the many econometric difficulties that beset an empirical study of this kind, the observed results do provide some evidence for a causal link between a firm's R and D activity and its subsequent rate of output growth. Attempts to show this link is a spurious one and arises due to a mutual correlation of these variables with a third variable were not substantiated. Due to the nature of the present available data on R and D input, however, these results must be accepted as tentative in nature.

These empirical results have important implications for government policies concerned with economic growth. They indicate that fiscal policies designed to operate on R and D are potentially potent weapons for accelerating economic growth. Furthermore, given the results on the determinant variables of R and D, government measures can affect R and D either through (i) a flow-of-funds effect or (ii) by incentive effects. In order to consider the efficiency of alternative fiscal devices affecting R and D, a model is formulated incorporating the above empirical results and analyzed under different assumptions about firm motivation and environment. Some of the possible macroeconomic implications are also considered by analysis of some models in the spirit of the recent growth theoretic literature.

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13. ABSTRACT

Several hypotheses on the determinants and effects of industrial research and development expenditures are formulated, and then tested on firms in the chemical, drug, and petroleum industries. The empirical results indicate a significant relation between R and D and various other technological, financial, and marketing variables of the firm. The implications for government anti-trust and fiscal policy are considered, and some theoretical models which incorporate the main empirical findings are developed to analyze various policy questions.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Patents						
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