The conditions for success in technological innovation

PARIS 1971

FOREWORD

In response to a request of the Third Ministerial Meeting on Science in March 1968, the Council of the OECD decided to undertake the following report on the conditions for success in technological innovation. The report attempts to identify the factors influencing the process of technological innovation by analysing the results of empirical research on the subject undertaken over the past ten years, and it discusses implications for national policy.

The report is the latest of a number of studies, which have been prepared under the direction of the OECD's Committee for Science Policy, on the relationships between science, technology and the economy, and is an immediate sequel to the series published under the general title, "Gaps in Technology". Its approach is essentially the same as these previous OECD studies. It throws new light on certain policy problems, and identifies other areas where further information and analysis are required.

The main focus of the report is technological innovation in response to industrial and individual needs - in other words, innovation which lays the basis for economic growth, and which responds to changing patterns of consumer requirements. The promotion of such innovation will continue to be an important objective of national policy in future. And a better understanding of the factors behind successful innovation will help policy makers identify action which can be taken to make technological innovation more responsible to the increasingly "social" and "qualitative" objectives of economic growth.

The report was written by Keith Pavitt, with the assistance of Salomon Wald who was responsible for Part III of the report. Both are staff members of the Directorate for Scientific Affairs of the OECD.

TABLE OF CONTENTS

ANNEXES

SUMMARY OF MAIN CONCLUSIONS OF THE REPORT

RELEVANCE TO SCIENCE AND ECONOMIC POLICIES

Technological innovation is defined here as the first application of science and technology in a new way, with commercial success. Fostering technological innovation is an important objective of national science policy, since considerable scientific and technological resources are devoted to innovative activities.

Furthermore, technological innovation makes a significant contribution to competitive strength in international markets, and the diffusion of innovation amongst its potential population of users to economic growth in all Member countries. The pressures for technological innovation and diffusion will continue to be strong as long as economic growth and international competitiveness are important policy objectives in the Member countries. The report's analysis is concentrated on technological innovation rather than on diffusion, mainly because of the relative lack of empirical information on the latter.

SOME CHARACTERISTICS OF THE INNOVATIVE SYSTEM

The Essential Components

Successful technological innovation always requires the existence of three factors: scientific and technological capability, market demand, and an agent which transforms this capability into goods and services which satisfy the demand. In the OECD countries, this agent is the industrial firm, the pressures and incentives being competition and profit, mainly through product innovations but also through cost-reducing process innovations.

The roles of large and small firms are interdependent because small firms are often started by scientists and engineers with previous experience in large firms. Sometimes the establishment of these "spin-off" firms has been actively encouraged by large firms. Sometimes it has happened by default. Small science-based firms flourished earlier in the U.S.A. than in other Member countries, partly because of a more favourable market and financial environment and of a greater degree of personal mobility.

Finally, the roles of large and small firms are ever changing. As a technology matures in one sector, scale factors tend to become more important. But, as one technology matures, another enters a period of growth, thereby opening other and new opportunities for smaller firms. Hence the need for mobility and flexibility of innovative resources - and particularly skilled manpower and capital - in order to respond to the ever changing opportunities and requirements of technological innovation.

The Size of National Markets

Studies in the USA have suggested that the size and sophistication of the U.S. market has been a key factor in the innovative strength of U.S. industry. However, this explanation does not appear to hold for all Member countries. There are countries with very small national markets, but also with the technological and entrepreneurial capabilities enabling them to respond to demands for innovation on world markets. However, overcoming barriers to national markets has its costs, and can reduce the rewards and returns to successful innovators. In particular, the penetration of foreign government markets appears to have been particularly difficult, and to have had important effects on patterns of innovative performance in certain sectors.

The Management of Innovation

Technological innovation poses many difficult and sometimes novel problems to management, given the uncertainties and long time horizons involved, and given the need for communications across disciplinary and functional boundaries. Hence the need for "entrepreneurial" organisational forms, with flexible definitions of responsibilities and large possibilities for lateral communication, capable of evaluating and responding to new - and often unforeseen - technical and market circumstances. Hence also the need for top management's commitment to taking risks.

Study and teaching specifically related to the process of innovation may be particularly valuable - for both research workers and managers - given the difficulties of applying successfully many of the conventional management techniques. Furthermore, the increasingly worldwide competitive and market environment within which technological innovation takes place requires a careful definition of the role of R and R in achieving environment and objectives, and not enough is known about the impact of various components of government policy. Nonetheless, successful, national innovative systems appear to be bound up with strong fundamental research coupled with a capability in industrial R and D, orientation towards world markets, and flexible structures and methods which ensure that multiple channels are kept open for the creation, transfer and application of technology.

The Deployment of R and D Resources

Even where variations in absolute size are taken into account, there are big differences amongst Member countries in the level of resources devoted to R and D performed in industry. For R and D financed by industry, the differences are smaller, although still important.

Government performed R and D has decreased as a proportion of total R and D in countries where it has been high. Although total levels of R and D funding, and the objectives of government-financed R and D, have often evolved rapidly, patterns of performance of R and D changed only slowly.

Many governments are taking measures to couple government performed R and D more closely to industrial needs. At the same time, government measures to promote industrial R and D have been successful when R and D has been the main bottleneck in the innovative process, but not otherwise.

National Technological Specialisation

The increasingly open and interdependent OECD region requires national specialisation within areas of advancing technology. The existing patterns of national specialisation reflect government objectives and access to raw materials, as well as the sanctions of commercial success in world markets. Government can reinforce existing patterns of specialisation through rewarding successful, innovating firms, and can help create new patterns in the longer term by building up new strong points in scientific and technological capabilities.

Large-Scale Technological Programmes

Governments are often involved in financing large-scale scientific and technological programmes which have a strong influence on the pace and direction of scientific and technological advance, as well as on the use of resources. These programmes have had important effects on technological innovation in specific sectors. But some countries have a strong national performance in technological innovation without such large-scale programmes. The extent to which governments will finance large-scale programmes related to technological innovation will depend

Part I

INTRODUCTION

A. THE ECONOMIC CONTEXT

1. The importance of the impact of science and technology on the OECD economies is now widely accepted. Thus, in examining the growth of output in OECD countries over the period 1960-1980, a document of Working Party No. 2 of the Economic Policy Committee has said the following:

"Nor is it likely that the sources of the high rates of growth of potential output expected in the 1970's will quickly disappear; on the contrary, all the evidence suggests that the industrial and commercial exploitation of the existing body of scientific and technical knowledge will continue to generate increases in productivity for a long time to come." (138)*

2. Yet the nature and the mechanisms of science and technology's impact on the economy are often misunderstood, so that some effort of clarification is necessary. The distinction between invention, innovation and diffusion is particularly important when considering the macro-economic effects of technological progress. Invention is the idea of how science and technology could be applied in a new way, innovation consists of bringing invention to its first successful commercial use, and diffusion consists of the spread of the use of the innovation amongst its potential population of users. This distinction is, to some extent at least, an artificial oversimplification: for example, the process of invention persists throughout the entire life of a new technology, since the stages of innovation and diffusion may themselves give rise to the requirements for additional inventions related to, say, large-scale production techniques.

3. However, the distinction is indispensable if one is to understand the various economic policy implications of science and technology. For

* References are given in Annex C to this Report.

B. THE SCOPE OF THE REPORT

7. It is on the process of invention and innovation, particularly in industry, that this report will concentrate. This focus has been dictated partly by lack of data. Insufficient empirically based information and analysis exists comparing rates of diffusion of technology in different Member countries, or identifying the factors affecting the diffusion process, to enable any meangful generalisations to be made.* And the Secretariat has not had either the competence or the resources to make a thorough analysis of the factors influencing technological innovation in such areas as agriculture and medicine.

8. Although industrial policy towards science and technology is more than a policy for technological innovation, a number of very good reasons exists for obtaining a better understanding of the process of invention and innovation, and for improving the effectiveness with which the process works. In individual Member countries, the production of technological innovations absorbs a sizeable proportion of national R and D resources; it is therefore an important aspect of national science policy to ensure that these resources are employed efficiently. Furthermore, the successful production of technological innovations has an important influence on competitive positions in world markets, and is intimately linked to national capabilities in fundamental research.**

9. And, for the OECD area as a whole, technological innovations now create the basis for economic growth of the OECD members over the next twenty to thirty years. It would be theoretically feasible for an individual Member country to stop producing innovations and to grow solely on the basis of those produced by others. But it would be disastrous for long

* An attempt to compare levels and rates of diffusion of four technologies in the Member countries has been made in a previous OECD publication (139). Furthermore, a study comparing the diffusion of ten process innovations in six European Member countries has been published by the National Institute of Economic and Social Research (140). Work of a similar nature is being continued with the involvement of the National Bureau of Economic Research, New York.
Mansfield has analysed the diffusion of twelve innovations in four U.S. industries (17). He found that the diffusion of innovation amongst the potential population of users had been a relatively slow process, often taking twenty years or more. He also found that the speed of diffusion had depended on three factors: the extent of the economic advantage of the innovation, the extent of uncertainty associated with it, and the level of investment required. He also found that the speed of a firm's response to an innovation was not related to its rate of growth, profit level, liquidity, profit trend, or age of its management personnel.

** For a detailed examination of the links between fundamental research and industrial innovation, see Part III of the Report.

as distinct from theoretical speculation. Some would argue that all generalisations about technological innovations are -and always will be - useless, given the uniqueness of each innovation, and given the inherent uncertainties in the direction of scientific progress and in the evolution of market requirements. The authors of this report accept that each innovation is unique and that there are considerable uncertainties, but are convinced that useful generalisations can nonetheless be made. In some senses, innovations are like new-born babies. Each baby is unique (especially to its parents), its sex and physical characteristics cannot be predicted, nor can the number of babies to be produced in a given family. It is nonetheless possible at the national level to predict the number of babies of each sex, and the distribution of their physical characteristics. It is also possible to identify the factors which influence the scale and nature of national births. Few would deny the usefulness of such analyses for policy making.

14. The difficulties in the way of similarly useful generalisations about technological innovation do not have to do, then, with its unique nature. They have to do with the comparatively recent growth of data collection and analysis related to it. There are, nonetheless, a number of sources of relevant information and analysis. First, statistical data collected at the national level on such factors as research and development, education, fundamental science and technological innovation. Second, studies on technological innovation in specific industries. Third, studies on technological innovation in relation to institutional and organisational factors. Fourth, the recorded experience of individuals who have been involved in the innovative process. Fifth, historical case studies of individual or groups of innovations. The OECD and the Science Policy Committee have contributed enormously to the first source of information, and to some extent to the second. The universities have been the main contributors to the third source. The fifth source is the most recent, the most rapidly growing, and is likely in the long term to lead to a more fundamental understanding of the processes of technological innovation (48, 142).

15. The following report uses information from all these sources, on the basis of which some useful propositions about the innovative process can be made and some relevant policy questions identified. But lack of information and of time has meant that certain problems have not been clarified. In particular, it should be noted that a very high proportion of all information and analysis of technological innovation has been undertaken in the USA. Since the U. S. system is so well documented, and since information about it is so readily available, there is a danger, in any report of this kind, of slipping into an almost exclusive discussion of the U. S. system, its policy problems and solutions, without sufficient consideration of the different levels of resources, environmental conditions and policy objectives of the other Member countries. The Secretariat has tried its utmost

Table 1. CORRESPONDENCE OF RESEARCH INTENSITY OF INDUSTRY GROUPS TO THE OUTPUT OF NEW PRODUCTS IN THE U. S. A.

	R AND D FUNDS AS A PERCENTAGE OF SALES (1964) 1	EXPECTED PERCENTAGE OF 1969 SALES IN NEW PRODUCTS (1966) 2
Aircraft and parts	20.8	40
Electrical machinery	12.0	24
Machinery	4.2	23
Vehicles	3.4	22
Chemicals	5.2	18
Fabrication of metals	1.7	17
Stone, clay and glass	1.4	17
Textiles	0.5	13
Food and beverages	0.3	11
Petroleum and coal products	1.0	5
Non-ferrous metals	1.0	9
Iron and steel	0.6	7
Rubber	2.0	4

The rank correlation coefficient between Columns 1 and 2 is 0.7, which is significant at the 1% level.

SOURCE: Column 1: National Science Foundation.
Column 2: See Reference 3.

Part II

INDUSTRY

A. INTRODUCTION

19. In industrially advanced Member countries, the industrial firm is the main agent of technological innovation. It transforms scientific and technological knowledge into new or better goods and services which satisfy economic needs. The objectives of innovative activities in industry are profit and growth. The pressures on the firm for such activities come from changing factor prices, from the innovative activities of competing firms, and from the accumulation of scientific and technological knowledge. The benefits to the firm are reduced costs and bigger markets. These benefits are, in some cases, sustained through the temporary monopoly afforded to the innovating firm through the patent system.

20. Technological innovations is as old as man, but it is only in the 20th century that science, technology and the industrial firm have come together to play such an inportant role in it (17). Suffice it to say here that the two key factors appear to have been: first, the increasing explanatory power and applicability of science; second, the pressures of industrial competition - both national and international - which have pushed industrial firms to make ever better use of knowledge and intellectual resources emanating from the universities. The importance of these factors is amply illustrated by the historical development of the plastics industry, which grew out of scientific discovery, and where large programmes of R and D, together with major technological innovations, have been made by industrial firms competing in world markets - and often in collaboration with university scientists (1).

21. Data collected for the U.S.A. and the U.K. suggest that the main objectives of industrial R and D and innovative activities are new and better products rather than new and better production processes. The main purpose of industrial R and D programmes in the U.S.A. in 1966 was new product development in 45% of firms, improving new products in 41%, and new production processes in 14% (3). A study of 567 innovations in U.S. industry since 1945 confirms this pattern; 58% led to

25. Two studies have measured the broad economic characteristics of research intensive industries in the U. S. A. (23, 24). From these studies, it would appear that, by comparison with other industries, the research intensives industries employ relatively more scientists and engineers not only in R and D, but also in production and sales; employment outside production is relatively high, as is the degree of industrial concentration. On the other hand, the research intensive industries are not particularly capital intensive, they do not manufacture a relatively high proportion of intermediate goods, nor do they use relatively large amounts of raw materials. It must be stressed that these characteristics pertain to the U. S. A. Similar studies for other countries to see if the research intensive industries have similar characteristics would be very valuable.

26. However, one drawback to this type of study is that it does not determine whether the above industrial characteristics cause, or are caused by, their research intensity. Some authors stress the importance of other factors. Schmookler, on the basis of analysis of patent statistics over long periods of time, has concluded that market demand is the determining factor in patterns of industrial invention (25). Others argue that radical innovations open up new markets through creating possibilities of application that did not exist before:

"... a jet plane is around two orders of magnitude faster than unaided human transportation, while modern computers are around six orders of magnitude faster than hand computation. It is common knowledge that a change by a single order of magnitude may produce fundamentally new effects in most fields of technology: thus a change by six orders of magnitude in computing has produced many fundamentally new effects." (105)

27. And a recent report to the U. S. Government has concluded that the main factor is management:

"Are highly innovative industries progressive because of the manner in which they respond to technological opportunities? Are they primarily this way because their managements have extraordinary capabilities for grasping and managing technological change? What characterizes the relatively uninnovative industries? Are they this way because they failed to exploit innovative opportunities? Because they possess excessive built-in barriers to technological change? Is it that their managements have not learned the importance of utilising technological opportunities and innovative skills?

"We find that we must answer each of these questions affirmatively. The main barrier is one of attitude and environment. It is primarily a problem of education - not of antitrust, taxation or capital availability." (2).

28. The available empirical evidence on the relative importance of these three factors - markets, technological opportunity and management -

direction of technological growth can be inferred from the former but the rate of growth will be dictated by the latter." (8).

30. In this context, radical innovations (or "precursor type events") - often growing out of new technological opportunities - can perhaps be seen as innovations which open up opportunities for a far wider number of need-oriented innovations. And the research intensive industries can perhaps be seen as the main source of radical innovations, opening up opportunities for a far larger number of often more minor innovations in a wider number of industries. The classic contemporary example of such a phenomenon would be the development and still proliferating range of utilisations of the computer.

31. Many studies of specific technological innovations also stress the management factor, and in particular the presence of outstanding individuals able to identify market needs or technological opportunities (86). But no studies exist on the effects of the management factor in different types of industry. Nonetheless, it may well be that the innovative quality of management is intimately bound up with technological and market developments. Firms in sectors of rapidly advancing technology are more likely to find new market opportunities, to employ qualified scientists and engineers in all functions, to develop innovative attitudes and skills, to have close relations with the universities, to be searching for new technologies and markets to enter, and to have sufficient skills to do so.

32. The converse of this proposition is that technologically stable industries are not likely to have these dynamic characteristics. Indeed, A. Stinchcombe has gone so far as to argue that the organisational and managerial characteristics of different industries reveal fundamental differences deriving from the fact that firms in each industry were founded at different times in the development of organisational and managerial skill and knowledge, and that further evolution is slow (104). How, then, will present day technological opportunities in such sectors as materials, automation and informatics be exploited effectively in the non-research intensive sectors of industry? Will it be through the process of "invasion" by the research intensive industries? Or will management in the non-research intensive industries follow the examples of shipbuilding in Japan - or indeed, office machinery in the U.S.A. - in actively absorbing, developing and integrating skills and technologies from a wide number of sectors? This is a subject that merits a great deal of attention, but where little documented evidence and study exists. But it is perhaps safe to assume that the relative balance of these two mechanisms of technology transfer will depend in part on the quality of management in the non-research intensive industries.

37. The same pattern of R and D and invention exists in France. In 1965, the R and D/sales ratio was, on an average, higher in small firms performing R and D than in large firms. Of 16 industrial sectors, the ratio was equal or higher in small or medium sized firms in the following: electrical, electronic, precision equipment, chemicals (excluding pharmaceutical products), glass and ceramics, power, mechanical, cars and bicycles, textiles and leather, construction and construction materials, food, wood and paper, and services (28). The same study found that small and medium sized firms take out relatively more patents than large firms, and that they receive relatively more receipts for patents and licences. Perhaps similar data should be collected in other Member countries, in order to see if this pattern is repeated elsewhere.

38. A number of historical studies have also been undertaken on the contribution of large firms and small firms to technological innovation. Mansfield found that, in the U. S. steel, petroleum and coal industries between 1939 and 1958, the largest firms contributed more technological innovations than their share in production in petroleum and coal, whilst the contrary was true in steel (29). Freeman found that, in the plastics industry, 30 firms in the world account for nearly 20% of the patents granted, and that the proportion of patents granted to firms rather than to individuals has increased over time (1). He also found that the majority of key innovations were launched by established large firms. The OECD study of the pharmaceutical industry also found a heavy concentration of innovations in large firms (30). Finally, mention should be made here of the high correlation found between ten Member countries' performance in technological innovation since 1950 and the number of home-based large firms (see Annex A).

39. Other empirical studies have shown the large firm in a somewhat less favourable light. By far the most famous is that of Jewkes, Sawers and Stillerman which found that, out of 61 important inventions and innovations of the 20th century which the authors selected for analysis, over half stemmed from independent inventors or small firms (31). In addition, Hamberg has confirmed Mansfield's conclusion that the largest firms have not made a relatively strong contribution to innovation in the U. S. steel industry (42). Peck has found a similar pattern in inventive activity in the U. S. aluminium industry (33), and Enos in inventive activity in the refining and cracking of petroleum (9).

40. It could still be argued, however, that the importance of the large firm in innovation is increasing over time. Mansfield found this to be the case in petroleum, coal and steel in the U. S. A. (29). Freeman has undertaken a supplementary analysis of Jewkes' data and found that the role of the individual in invention and innovation was relatively stronger before 1928, whereas that of the firm was relatively stronger afterwards (32). Enos found, in his study of petroleum refining, that the

reliability in performance are required. This is obviously the case in relation to weapons and defence systems, in aerospace, in nuclear energy and - given more stringent regulatory standards - perhaps also pharmaceutical products. But it is difficult to make generalisations about technological scale requirements, except that they can vary widely within a sector according to the product considered: in his study of electronic capital goods, Freeman estimated annual R and D expenditure thresholds which varied from a hundred to tens of millions of pounds sterling (39).

45. Scale factors can also be important in relation to the nature of the market for technological innovation. Selling an innovation to a large number of customers is obviously more expensive than selling to a few. That is why marketing scale is important in pharmaceutical products (30, 40), and probably also in consumer electronic products. Marketing expenditures are also likely to be heavy when the level of technological sophistication of the innovating firm is much higher than that of potential customers, or - as one writer has stated - when there is a big difference between supplier and customer in the level of "Innovation Quotient" (41). In such circumstances, relatively large efforts are required by innovating firms in order to identify potential customers' needs, to sell the resulting innovation, and to give the necessary training, aftersales and support services to users. Innovation in the 1950's and early 1960's in commercial EDP computers is a good illustration of this type of situation. Firms selling such computers spent large sums on marketing and after-sales service, sometimes more than on R and D itself (39, 40). In the electronic components field, however, the required scale of marketing has been lower, since customers are industrial firms and government establishments, both of which are better able to define their requirements (35). *

46. The converse of the above set of propositions is that small, innovative firms will tend to specialise in product areas which do not require large scale R and D or marketing efforts, but where they can nonetheless build up a technological advantage. The areas in which they are able to do this will depend on the rate of technological change. In areas where there is a high rate of change, a relatively large number of product

* It should be mentioned that the degree to which R and D in a sector leads to highly differentiated products will influence the incentive of firms to penetrate foreign markets. In the pharmaceutical sector, for example, where products are highly differentiated, it has proved to be more efficient for firms to concentrate their heavy R and D expenditures and to conquer a small share of a large number of national markets, rather than to spread R and D expenditures and to conquer a large share of one national market (30).

clearly likely to be the case in small firms whose main competitive arm is their technological capability, and which - unlike large firms - do not require strong and related production or marketing capability, nor manufacture and sell products of low research intensity.

51. But another reason often advanced to explain the high R and D/sales ratio in small firms is that a minimum R and D "threshold" imposes a certain absolute level of R and D for it to be effective. However, some doubt can be cast on this hypothesis. "Thresholds" in R and D are likely to be coupled with equivalent "thresholds" in production and marketing. A small firm striving to meet "thresholds" in production and marketing as well as in R and D is likely to be in a transient state. In a competitive environment, either it will grow to reach the required "thresholds", or it will disappear. Thus, although the R and D "threshold" explanation may be valid in certain specific cases, it cannot explain the continuing and statistically observed fact of higher R and D/sales ratios in small firms in certain industries in the two Member countries for which data are available. Indeed, if there is a "threshold" problem in small firms, it is likely to arise as a result of growth based on technological capabilities eventually requiring the strengthening of production, marketing and management capabilities. (2)

52. But this analysis does not exhaust the subject. The phenomenal growth from very small beginnings of such firms as Xerox, Polaroid, Texas Instruments and Control Data Corporation are not signs of a tidy division of labour between small and large firms. The standard explanation for such phenomena is the conservatism, the weight of established interests and ways of doing things, and the "not invented here" attitude leading large firms to neglect opportunities for radical innovation; and it is probably true that, until the early 1960's, most large firms did not have an effective mechanism for evaluating and pursuing high risk, innovative proposals from outside sources. Whilst this may sometimes have been the case, it is an explanation that is not entirely convincing. The concepts of xerography and the Polaroid camera were, after all, offered to large firms not at all noted for the negative qualities cited above (i. e. IBM and Kodak). Another possible explanation is the extreme technological and market uncertainties associated with technological innovations - especially radical ones.

53. On the basis of a study of some thirty radical innovations, Professor Bright has advanced the following proposition:

> "The most important application of a new technology is not always that which was visualised first .... Technological innovations frequently gain their first foothold for purposes that were originally not thought of or were deemed to be quite secondary." (16)

"Mr. Ed. Gee, Director of Development at DuPont, recalled such cases as these in which a small market (of the order, say, of $ 1,000,000 per annum gross) was envisaged and in which DuPont encouraged production, since it was not worthwhile for them." (44)

57. Many such new firms are established on the basis of knowledge acquired by their owners elsewhere. In his study of new science-based firms in the Boston region, Roberts found that the most successful tended to be those with a high degree of technology transfer - in other words, those whose owners used their previously gained knowledge most directly. He also showed that, during the 1950's and early 1960's, a time lag existed of four and a half to six years between the level of research efforts in the MIT Instrumentation and Lincoln Laboratories and the levels of sales or employment of firms "spun off" by former research workers (19). There are many other areas in the U. S. A. where important clusters of new companies have been "spun off", including Palo Alto, San Diego, Minneapolis, Atlanta, Miami, Pittsburgh, Austin and Boulder. All these areas have a strong concentration of organised research activity, based in universities, or government or industrial laboratories. (47)

58. But although small firms do grow out of work done in university and government laboratories, perhaps too much emphasis has been placed on the university-based, scientific entrepreneur. Out of 22 firms started in the Stanford area, six emanated from the university, and the remainder from industry and not-for-profit institutes (47). For the Boston region, Roberts identified 202 new innovative firms of which 155 emanated from MIT. But of these 155, 105 emanated from the MIT Laboratories, the work of which has been oriented towards development and hardware, and which are not what would normally be defined as university laboratories. Furthermore, Roberts found that successful entrepreneurs were development oriented rather than research oriented, and that their average level of education was at the Master's and not at the Doctoral level (19).

59. All this suggests that new firms are more likely to come out of industrial or governmental laboratories than out of the universities. This is not to say that the universities have no role to play in creating new science based firms. On the contrary, the above evidence suggests they have made a significant contribution. But, when interpreting the U. S. experience in this field, and comparing it with their own, other Member countries might well bear in mind that conventional university departments have not necessarily been the main source of science-based entrepreneurship in the U. S. A.

entrepreneurs may be higher in the U. S. A. where the stock and graduation rates of Bachelors (and probably Masters) in Science is higher than elsewhere (115). Although European graduation rates at the Ph. D. level compare more favourably with the U. S. A., it must be borne in mind that about 70% of science-based entrepreneurs appear to have qualifications below this level.

Table 3. THE EDUCATIONAL LEVEL OF SCIENCE-BASED ENTREPRENEURS: A COMPARISON BETWEEN U.S. AND EUROPEAN SAMPLES

LEVEL OF EDUCATION	U.S.A.		EUROPE	
	No.	%	No.	%
Lower than University Level	9	14.3	5	6.8
First (Bachelor's) Degree ..	19	30.2	13	17.8
Second (Master's) Degree ...	24	38.0	40	54.8
Third (Doctor's) Degree	11	17.4	15	20.5
TOTAL	63	100	73	100

SOURCES: U.S.A. - E.D. Roberts, cited in Reference 106. Data are for entrepreneurs who have established firms.
Europe - Information supplied by European Enterprises Development Company, Paris. Data are for entrepreneurs who have asked for financial support.

63. Do differences between countries in science-based entrepreneurship reflect differences in cultural attitudes towards risk taking and change? If they do, they are not historically deep-seated: many large firms outside the U. S. A. still carry the names of the inventors and entrepreneurs who have created them over the past hundred years (e.g. Citroën, Olivetti, Rolls Royce, Siemens). And there are many contemporary examples of non-science-based entrepreneurship outside the U. S. A. in more traditional industries, shipping, retailing, tourism, etc. Thus, if there are differences in attitudes to entrepreneurship, they do not appear to be a generalised phenomenon, but specific to the entrepreneurship which has come to be called "science-based". Perhaps some clues could be found to the relevance of this factor in comparing the social and psychological characteristics of potential science-based entrepreneurs in different countries. In the U. S. A., Roberts has found that a high proportion had fathers who were self-employed, and that successful entrepreneurs are highly motivated towards achievement and only moderately towards power, whilst unsuccessful ones felt a low need

66. Management ability is also related to the success of new, science-based firms. Roberts has found that scientists and engineers who set up new firms often had followed courses in business management, and that successful entrepreneurs have been those who explicity recognised the importance of the management, marketing and personnel functions (19). And, of the European applicants to EED, 16% had followed some management experience, and about 20% had studied in the USA - almost equally divided between management and science studies. However, it is likely that most European scientists and engineers have had less exposure to management thinking and education than their U. S. counterparts.

67. Personal and company taxation is another factor advanced as having an important influence on the incentives and rewards for science-based entrepreneurship. A recent report to the U. S. Government made a number of recommendations concerning taxation in order to encourage such entrepreneurship (2). However, given the variety of taxation systems in the OECD area, it is impossible to make any generalisation as to their effects. And even in specific Member countries, there are disagreements between science-based entrepreneurs about the effects of taxation systems (107, 108).

68. Probably more important is the availability of venture capital for science-based entrepreneurship. The same U. S. report noted that regional differences in science-based entrepreneurship in the U. S. A. could be explained, to some extent at least, by differences in the degree of communication and linkage between venture capital sources and science-based entrepreneurs. Furthermore, it identified the following potential sources of venture capital available for science-based entrepreneurship in the U. S. A. : personal wealth; insurance companies, investment funds and trusts; corporate sources; investment bankers and underwriters (2).

69. Thus, the finance available for science-based entrepreneurs depends not only on the amount of capital available in a country, but also on the degree of confidence and comprehension existing between the scientific and banking communities, and on the degree of the latter's competence. The experience of the American Research and Development Corporation suggests that "venture capitalism" is a very special art (113). In the 21 years of its existence, it has reviewed several thousand proposals, and invested in 98 firms, the investment in general varying between $ 100, 000 and $ 1, 000, 000. Approximately one out of five of these investments lost money, but the Corporation has retained an interest in 43 companies, the value of which is now about 16 times their original cost. In Europe, the creation of similarly specialised institutions has been more recent, but a number have been created over the past five years (112). Their experience so far suggests that there

Table 5. PERCENTAGE OF NEW SCIENCE-BASED COMPANIES IN THE U.S.A. WHOSE GOVERNMENT SALES ARE A GIVEN PROPORTION OF THE TOTAL

PROPORTION OF GOVERNMENT SALES	ELECTRONICS		INSTRUMENTS		CHEMICALS, MATERIALS		TOTAL	
	ORIG.	NOW	ORIG.	NOW	ORIG.	NOW	ORIG.	NOW
0-1/3	50.8	41.5	46.9	44.4	72.7	69.7	52.3	42.5
1/3-2/3	10.2	23.1	6.2	25.0	9.1	9.1	12.0	27.1
2/3-3/3	39.0	35.4	46.9	30.6	18.2	21.2	35.7	30.4

SOURCE: See Reference 44.

72. Nonetheless, the impact of government markets on European science-based entrepreneurship appears to be much less strong. Table 6 shows that, for the sample of applicants to EED, nearly 66% concerned products for industry, commerce, agriculture and construction, and only about 10% products for government. But, as in the U.S.A., products for consumer markets are negligible.

Table 6. MARKETS FOR PRODUCTS OF EUROPEAN SCIENCE-BASED ENTREPRENEURS: A SAMPLE

TYPE OF MARKET	PERCENTAGE DISTRIBUTION OF PROPOSALS
Industry, Commerce, Agriculture, Construction	65.6
Research Institutes, Schools, Hospitals, etc.	18.7
Government Departments and Contracts	10.4
Services, Consultancies, etc.	5.3
TOTAL	100

SOURCE: EED.

successful product varies between 8 and 35%* and that R and D expenditures should not account for more than 10% of sales price, then the largest R and D projects found in the above studies (i.e. $ 3 million or more) would require a total sales volume of between at least $ 100 million and $ 400 million from the innovation.

77. There are some other estimates. On the basis of an examination of R and D patterns in U.S. industry, Scherer has concluded there may be a size threshold below which firms are disadvantaged because they cannot reap all R and D scale economies, spread risks or reach sufficiently large markets in exploiting their research results. But if such a threshold exists, it has probably been surpassed already by the several hundred U.S. firms with annual sales exceeding $ 100 million. ** On the other hand, Cottrell has estimated that a medium-sized computer project, with total R and D costs of $ 50 million, requires annual sales of about $ 200 million (102).

78. It should be noted that all these figures are well below the billion dollar range, which is the annual sales of many existing large firms. But one must also bear in mind that, in sectors where R and D projects are uniformly expensive and their commercial success uncertain, such a sales volume may be necessary in order to support a number of projects and thereby hedge against failure.

79. Are technological "thresholds" tending to increase over time? For large-scale technological systems this does appear to have been the case. Advances in such technologies as materials, communication and control, and reliability, have opened up increasing possibilities of developing ever more complex and expensive operational systems. This has been particularly true in relation to weapons systems, but also in such areas as telephone exchanges, power generating plant and jet transport aircraft. It is on spectacular areas such as these that public attention tends to be focussed. But there are no data which confirm that thresholds are increasing in all technological areas. It is significant to note that in the U.S. aerospace industry - which is largely concerned with large scale systems development - R and D expenditures became increasingly concentrated in the biggest firms between 1958 and 1967. But the same tendency was not observed in other U.S. industries; indeed, there is some indication that the trend was towards lesser concentration (135). It is also worth nothing that relatively small Member countries such as the Netherlands, Switzerland and Sweden still appear to be able to undertake a large share of the industrial R and D necessary to satisfy the requirements of a number of large and technologically powerful firms.

* These probabilities are derived from data presented in paragraph 123 of this report.

** Scherer made these estimates in 1965. Given the effects of inflation, the same estimates made today might be as much as 50% higher.

84. This conclusion tends to confirm one of the conclusions of a recent report of the U.S. Academy of Sciences on applied science and technological progress:

"... the most important invention in the pursuit of modern (as opposed to older) applied science is the big mission-oriented industrial or government laboratory. In fact, modern applied science can hardly be discussed without reference to these homes of applicable science. These institutions derive their power from three sources: 1) their interdisciplinarity and the close interaction between basic research and application; 2) their methodology for precipitating and organizing coherent effort around big problems; 3) their ability to adapt their goals to the requirements of their sponsors.

... Just as Basic Research and National Goals has as its primary institutional focus the university (at which most basic research is performed), so this study, possibly less explicit, has as its primary institutional focus the multidisciplinary mission-oriented laboratory, at which most applied research and development are performed." (52)

85. However, the evidence above identifies two further and very important functions of large firms in national innovative systems, namely:

- to create capabilities embodied in scientists and engineers who go out to start up their own firms in order to apply and exploit commercially the technological - and sometimes the market - knowledge that they obtained when working in large firms;
- to create demands for technologically sophisticated components, materials, services and equipment which sophisticated small firms can meet.

86. The addition of these further functions of large firms in the innovative process helps explain, amongst other things, the apparently conflicting observations that countries with relatively more large firms tend to have a relatively strong performance in technological innovation (see Annex A), but that - within these same countries - small firms have played an important role in the innovative process.

87. It is clear that the relationships between small and large firms in technological innovation are not stable or fixed for ever. While it is possible to observe some division of labour between firms according to their size, the small firms specialising in certain sectors - highly sophisticated, faced with few buyers - there is a continuous change in these relationships. While large firms generate many of the basic technologies, their personnel is liable to establish small volume production fields. These firms in turn, like other small established firms, may contribute further to the creation of technological know-how, and exploit it themselves. Or, when markets promise to be big, science-based entrepreneurs

that national or regional differences in the scale and the sophistication of markets have a very important - and sometimes determining - influence on national or regional patterns of industry's performance in technological innovation. The scale of such national or regional markets, it is argued, influences the extent to which firms can successfully amortise the fixed costs of developing, equipping for, and launching a technological innovation. The degree of sophistication of market demand, it is argued, determines the time at which local firms commercialise new products and production processes: market sophistication itself being determined by the level of income per head, and the consequent demand for new consumer products and labour saving equipment (53), and also by the nature of the requirements of government.

D. 2. The Empirical Evidence

91. But the empirical evidence suggests that there is in fact a weak relationship between the size and sophistication of national markets, and national performance in technological innovation. Table 7 shows, for ten industrially advanced Member countries, a very low correlation between national innovative performance and the size of the national market as measured by Gross National Product. Three countries with small national markets - the Netherlands, Sweden and Switzerland - all have a relatively strong performance in technological innovation.

92. A higher, but still relatively low correlation, exists between national innovative performance and the level of sophistication of the national market, as measured by the level of income per head, and the level of government expenditure on R and D. But much higher correlations with national innovative performance exist for "supply" rather than "demand" factors, such as the number of large firms, the level of industrial R and D, and capabilities in fundamental research.

93. These statistics should not be overinterpreted. The indicators used are open to serious methodological and statistical criticisms, the total sample is too small, and the levels of correlation are highly sensitive to slight changes in the rankings. Nonetheless, in an important area where so little quantitative evidence is available, they do at least have the merit of questioning an aspect of current conventional wisdom. What they suggest is that the essential element in national innovative performance is less the size and intensity of national demand for technological innovation than the entrepreneurial, organisational and technological resources within a country that are capable of identifying and responding to market demands for technological innovation anywhere in the world. Firms and countries that have these capabilities appear to be able to overcome tariff and non-tariff barriers, as well as the barriers of distance, differing legislations and standards, in order to respond to

worldwide demands for technological innovation. Their task has no doubt been greatly facilitated by the liberalisation of trade and capital investments over the past few years, reflected in increasing interpenetration and interdependence amongst the Member countries in trade, direct investment and licensing (54).

94. This is not to say that existing barriers are unimportant. Overcoming them has its costs. For example, the OECD study on gaps in technology in plastics concluded that, although several countries had strong technological and market positions in plastics, European firms' profit margins had suffered, partly because of tariff and non-tariff barriers (55). Furthermore, there is some evidence for one European Member country which suggests that the financial and growth performance of firms in high technology industries has been lower than the average for industry as a whole (117). And OECD studies have shown that strictly national requirements have had an important influence on innovative performance in specific sectors, where governments have been important customers: for example, advanced electronic components, certain classes of scientific instruments, and electronic computers (34, 35, 36). It is worth noting that concern about technological disparities has tended to be focussed on sectors such as these, and not on sectors where market opportunities can be more readily met by firms of foreign origin.

D. 3. National Innovative Capabilities: The Underlying Factors

95. But what are the factors underlying national differences in innovative performance, as reflected in differences in strength in fundamental and industrial research and in the number of large firms - differences which in turn reflect entrepreneurial, organisational and technological capabilities? A thorough answer to this question would require a great deal of research. Here, we can only speculate. Sociologists might argue that these differences reflect differences in the degree of flexibility and outward-lookingness of the various societies. Historians of science and technology might point to the fact that different countries have traditionally been strong in certain fields of science and technology, and that many large firms of today grew out of specific innovations or innovative entrepreneurs. Economists might argue that the differences in national performance in technological innovation reflect differences in the degree to which industry has been exposed to competition - either within a large national market, or in world markets. Exposure to competition on a world scale forcing not only the necessary specialisation and familiarity with world markets, but also forcing firms to use more systematically the commercial opportunities offered by scientific advance.

96. Historians should no doubt examine these various hypotheses. But for policy makers it would be probably right to conclude that flexibility,

activities, and second because they have certain characteristics which differentiate them from the other corporate functions. These points are stressed by Professors Roberts and Marquis, members of the staff of one of the academic institutions with comprehensive research and teaching programmes on the management of research and innovation, namely, the Sloan School of Management at MIT:

"Because R and D is a very young corporate activity, the practices of R and D management are still in the infancy stage of development ... R and D suffers from a lack of standards of performance, a lack of a true understanding of its process, and a lack of an organised educational basis for its managers. This accounts for the fads, the "magic" techniques, the unfounded philosophies. Indeed, I believe R and D has more of the mystique about it than any other area of management." (56)

Marquis has suggested that, increasingly:

"Research management is not only the critical difference between a good organisation and an average one, but research is the most difficult to manage of all functional activities. There are three sources of this special difficulty. The first is the degree of uncertainty. Compare, for example, the certainty with which you can plan and schedule production or inventory or sales or cash flow compared with what you can do in new product development. The second source of difficulty is that you are managing a new kind of employee who views himself as a professional person. Scientists and engineers differ from other employees in their expectations, their values, their attitudes and their motivations. The third source of difficulty is measuring results when each research task is unique and never repeated. Even if you could measure results, the delay in the feedback loop is so great that it is hard to use knowledge of results as a basis for planning in the future." (57)

Marquis goes on to say that the body of knowledge on research management is derived from four sources: tradition, revelation, experience and systematic investigation of results, the last being the source the most in need of development.

99. This is neither the time nor the place to undertake a detailed and systematic review of the problems of managing research and innovation. A comprehensive review of R and D management practice in over 100 large U.S. firms has, in fact, already been published by Seiler (7). Little of a similar nature has been done in other Member countries. Nonetheless, some of the points emerging from written experience and systematic study are relevant to government policy makers insofar as they are involved, directly or indirectly, in innovative activities. They pertain to the problems that research and innovation pose to established organisations, and to current methods of programme evaluation. They also pertain to the fact that the objectives of industrial research and innovative activities must increasingly be fixed within a world-wide framework rather than a national or regional framework.

margin between price and cost gets narrower. At a relatively early stage in the development ... it becomes far more important that the principal managers be good administrators than that they be good innovators.

"... Quite understandably, we begin to get a preponderance of what, for the simplification of the concept, I will call administrative managers. They can exploit the innovation, but the skills they need and admire in themselves, in their peers, in their superiors and subordinates, are the skills of administration including leadership. Hence, the people they need and select are, in turn, predominantly administrative managers.

"... Often they have succeeded or displaced the original innovators and sometimes have suffered justifiable despair at the inability of the innovators to perform adequately the increasingly difficult administrative tasks. At the same time many an innovator fails to recognise how bad he really is as an administrator. His own experience and value systems simply do not qualify him to comprehend what is involved, how difficult it is to get the administrative management job done, and how justified the administrative manager is in his despair.

"As a consequence, from their own experience, the administrative managers have no basis on which to judge and respect the contribution that the innovator can really make. All they are able to see is his muddling and, too often, thoroughly inadequate ability to administer. So, they grow the organisation by accretion, adding the kind of products and services that flow naturally from the business one is already in, supplementing the markets in which one already engages, doing effective work in cutting costs and lowering prices - all essential, but unlikely to provide the step function in product and service necessary for dynamic growth.

"... Because they are efficient administrators, the net result is often constructive and results in the total organisation's being more effective, more profitable and more useful to society. But, at the same time, it makes the organisation still more complex and decreases the relative number of those who know how to innovate, and innovation gets increasingly harder. At some point, the growth rate slows down or falls below that of the industries in which the organisation exists." (66)

Furthermore:

"To handle the growth and increasing complexity, the organisation decentralises into groups, divisions, departments and branches: and the total job is divided up and cut into the size pieces that a good administrator can get his arms around. This is a logical and good management practice, but unless the general managers understand their jobs thoroughly, the company is in danger of its becoming no more than the sum total of the decentralised parts loosely governed primarily from a financial point of view at the corporate level.

persons in higher management to advance the cause of the entrepreneur and his venture. Even after the project had attained the status of an independent venture, the younger entrepreneurs reported capital support as being a major problem." (10)

104. Finally, problems can arise because, as we have seen, radical innovation involves the manufacturing and marketing functions in addition to the R and D function (2). Effective innovation requires effective "coupling" amongst these functions (63), which may prove difficult because of differences in motivation and in vocabulary and education, in addition to the inevitable preoccupation which manufacturing and marketing have with existing rather than future business.

105. So much for the difficulties posed by radical innovation, but how can they be overcome? Burns has argued, on the basis of empirical enquiry, that innovation is more likely to flourish in a framework which is "enterprise centred" rather than "management centred":

"In management-centred organisations the problems and tasks facing the concern as a whole are broken down into specialisms. Each individual pursues his task as something distinct from the real tasks of the organisation, as if it were the subject of a sub-contract. "Somebody at the top" is responsible for seeing to its relevance. The technical methods, duties, and powers attached to each functional role are precisely defined. Interaction within management tends to be vertical, i. e. between superior and subordinates. Operations and working behaviour are governed by instructions and decisions issued by superiors. This command hierarchy is maintained by the implicit assumption that all knowledge about the situation of the firm and its tasks is, or should be, available only to the head of the firm. Management, often visualised as the complex hierarchy familiar in organisation charts, operates a simple control system, with information flowing up through a succession of filters, and decisions and instructions flowing downwards through a succession of amplifiers.

"Entrepreneur-centred systems are adapted to unstable conditions, when problems and requirements for action arise which cannot be broken down and distributed among specialist roles within a closely defined hierarchy. Individuals have to perform their special tasks in the light of their knowledge of the tasks of the firm as a whole. Tasks lose much of their formal definition in terms of methods, duties, and powers, which have to be redefined continually by interaction with others participating in the task. Interaction runs laterally as much as vertically. Communication between people of different ranks tends to resemble lateral consultation rather than vertical command. Omniscience can no longer be imputed to the head of the concern." (62)

a system is particularly appropriate when entering technologies or markets radically different from the existing business. Members of such venture teams must be at home in an environment of uncertainty and rapid change (65, 66). One empirical study has been undertaken which compared the effectiveness of the "venture" system with the normal "functional" system of management for the development of a number of U.S. weapon systems, effectiveness being measured in terms of time and technical performance, and not in terms of cost and marketability (64). The results of the study were somewhat incon lusive, and not in any case necessarily applicable to commercially oriented innovations.

110. Other methods of coupling R and D, production and marketing exist:

"A successful pattern of technology transfer often involves people moving with ideas from research all the way through production, and organisation should make this easy. It is very difficult to transplant new ideas from one organisation to another. The development of new ideas should be left in the hand of the originating group until sufficient probability of success has been demonstrated. New ideas should not be transferred prematurely just because they lie outside the assigned tasks of the originating organisation." (52)

And when ideas must be transferred:

"... only in rare cases is it possible to effect this transfer by the simple exchange of "software" between the research organisation and operating component. The writing of reports is certainly not sufficient, nor is the giving of lectures and verbal exchange of information. Almost invariably the transfer of technology requires the demonstration of technical feasibility." (70)

111. Frequent personal contracts between research workers and the rest of the firm are also very necessary:

"An extremely important element in the conduct of applied science is to create circumstances that ensure the confrontation of scientists with practical problems ... The failure of fundamental work to yield practical results, or of applied research to solve the true barrier problems, too often results from the fact that experimenters themselves are never adequately confronted with the real practical problems that exist. These practical problems can be a stimulating source of fundamental research ... just as stimulation can come from the inner development of pure science. Such contracts are "even more necessary in large organisations than in smaller ones, for research on a broad front, serving a diverse technical clientele, generates a greatly expanded possibility of matching an industrial need to a technical capability." (70)

Even though he may sometimes be more distinguished for enthusiasm and ingenuity than for profound technical understanding, his courage and tenacity are frequently vital elements of successful innovation. We need to identify such individuals early in their careers, to encourage appropriate educational preparation, and to ensure an occupational environment that will enhance their contributions.

"It must be recognised, however, that many successful innovations have been accomplished without such zealots. Some very able and original technical people, who have contributed important innovations, are not especially vocal or persuasive. Infectious enthusiasm may impart courage when - as is frequently the case - courage is needed; but enthusiasm will not, of course, repeal a law of nature, if that is the road block that stands in the way of a successful innovation. The technical idea that has glamour or popular appeal or is easily explained and dramatized is not always the best idea, or the one most likely to lead to successful application in the long run." (52)

E. 2. Innovation and Evaluation

115. The choice ex ante, and the evaluation ex post of R and D of innovative venture, also creates new types of problems of management due to the relatively long-term time horizons and relatively high degrees of uncertainty involved. Effective definition and appraisal of the overall R and D budget appears to be as difficult for individual firms as it is for national governments:

"At the present time there are no known relationships between optimum R and D expenditures and another single variable that can be used to establish the research budget with a sufficiently reliable degree of accuracy. Thus the budgetary determination by top line officials in most cases is a matter of using broad gauges to see if the budget requests of research officers are reasonable. The more frequently applied guides are competitors' research efforts and the R and D spending/sales ratio." (7)

Some would argue that - as with national governments - the effective determination of the total R and D budget must depend on the identification of long-term objectives, and on the existing and the desired capabilities needed to achieve these objectives, and that it requires participation from all parts and all levels of the firm, together with an explicit consideration of attitudes towards risk and uncertainty (75).

116. Ex ante evaluation of long-term research programmes presents particularly difficult problems of evaluation. Not only do they generally present a higher degree of uncertainty than do other types of R and D programmes but, insofar as evaluation methods take into account the time value of money (e.g. through such techniques as Discounted Cash

"... Some of the observed problem areas (with regard to normative technological forecasting) are:

- the costliness of the inputs
- the dubious accuracy of the estimate
- the inflexibility of the methods
- the limited impact on managerial decision." (78)

118. Furthermore, a recent meeting of the European Industrial Research Management Association, at which were present both individuals involved in developing the methodology of technological forecasting, as well as practitioners from the larger European firms, concluded that:

"In companies whose markets were subject to short time scale of product life, long lead time in development, technological discontinuity between successive products, low predictability of markets and high competition, technological forecasting was very relevant but difficult to apply with success. Successful technological forecasting was a characteristic of more slowly moving industries." (149)

119. In other words, useful technological forecasting is most difficult to do in precisely those areas where it is most needed. This suggests that until we have a much greater understanding of the mechanisms of scientific and technological development, and of users' reactions to radical innovations, forecasting will continue to be empirical rather than scientific and deductive. As such, few would deny that forecasting is still both a feasible and necessary exercise in the evaluating of R and D programmes. It can improve insight into complex problems, and focus attention on critical areas where further questions must be answered (79). But, given the uncertainties involved, the judgment, experience and intuition of individuals will continue to have an important role to play, as will a thorough and critical evaluation of the assumptions underlying any forecast and the effects of changing them.

120. Empirical evidence confirms that proposals for R and D projects in industrial firms are rarely taken solely on the basis of numerically based models or evaluation techniques. Two persons concerned with the management of innovative ventures at DuPont have said the following:

"The choice (of ventures) cannot be properly made on the basis of numbers, weights, formulas, or some other short cut. It cannot be properly made by specialists. It must be made instead on the basis of <u>entrepreneurial</u> judgments." (65)

"Several criteria are used for appraising the value of the venture to the Company. One is the expected net return on investment over a period of years. Another is venture worth, which, in a simplified sense, is the forecast net cash position from operating the venture for a number of years and then liquidating all assets. While these criteria are useful,

Table 8. RESEARCH MANAGEMENT'S OPINION OF THE ACCURACY WITH WHICH FACTORS AFFECTING RESEARCH PROJECTS CAN BE ESTIMATED, 1964

Percentages

FACTOR	ACCURACY RATING					
	EXCEL-LENT	GOOD	FAIR	POOR	TOTAL-LY UN-RELIABLE	TOTAL
Cost of the research project	3.5	27.8	52.2	14.8	1.7	100
Cost of development if the research is successful ..	2.6	38.8	46.6	9.5	2.5	100
Probability of technical success	3.5	51.3	39.9	6.3	0.0	100
Time necessary to complete the research	0.9	18.6	50.4	24.8	5.3	100
Manpower requirements necessary to complete the research	2.6	34.2	53.5	7.0	2.7	100
Probability of market success	3.6	33.6	38.2	14.5	10.1	100
Time necessary to complete the development ..	1.8	34.5	41.8	17.3	4.6	100
Market life of the product if R and D efforts are successful	4.6	28.0	29.0	23.4	15.0	100
Revenue from the sale of the product if R and D are successful	5.3	36.0	28.9	27.2	2.6	100
Cost reductions if R and D efforts are successful ..	10.7	57.1	14.3	14.3	3.6	100

SOURCE: See Reference 7.

seek to reduce all the available data to a single composite figure of merit which can serve as a decision criteria ...

" - The treatment of uncertainty and likehood of success or failure is generally unsatisfactory ...

" - The methods proposed fail to recognise that project selection is a continuous process. ... a new project under review will, in a practical case, only be in competition with a very limited number of new or established projects. This is not to say that all projects in a given programme must not be subjected to regular assessment to determine their current value and load to related decisions. However, the time for doing this will be determined by the evolution of the project itself or of external events related to it ..." (81)

125. Nevertheless, the report goes on to say:

"All the methods evolved to date are still heavily dependent on intuitive estimation and the final decision rules must still be interpreted with considerable care so that experience and intuition is still the major factor involved. To put this matter in perspective, it must however be borne in mind that there is a fairly general feeling of dissatisfaction with the existing procedures for project selection. Virtually all research managers are highly interested in formal methods for this purpose although in fact freely admitting that they do not make much use of them. Furthermore, as projects become more complex, as the rate of technological advance increases, it is becoming increasingly difficult to make satisfactory intuitive decisions. More and more, the need is being felt for rendering explicit the implicit assumptions and hypotheses upon which intuitive decisions are based. However unsatisfactory the existing formal methods may be, the use of no method at all is likely to be even worse. It is felt, therefore, that it is very much worthwhile to devote effort to improving techniques and, perhaps even more importantly, to acquire experience in the application of such techniques; without this experience the essential feedback which will assist further development will be lost."

126. The report therefore goes on to discuss a number of general considerations which should be borne in mind when designing specific evaluation procedures, such as the rapid rejection of unsuitable projects, the information requirements for evaluation, attitudes to risk, sequential evaluation, the choice of decision criteria, and the implications for evaluation methods of the degree of advancement of the project.

E. 3. Innovation and Company Objectives

127. Both the appropriate organisational forms for innovation and the criteria used in evaluating research projects and innovative ventures

order to recognise the opportunities for industrial innovation that the market affords. A number of European firms have already demonstrated that this can be done successfully." (82) Operating in the U. S. A. will also ensure a strong technological and managerial feedback from the U. S. environment.

132. A firm can launch an innovation on world markets through a number of channels: exports, licensing, direct foreign investment and joint ventures. It may use more than one channel, and the mix will probably vary over time. The factors influencing the choice of channel include the relative weight of tariffs and transport costs in the value of the product, the managerial and financial resources at the firm's disposal, the size of the local market and the importance of local manufacture to its penetration, practices with regard to government markets, and the desired degree of control over further technological developments. Statistical evidence suggests that U.S. firms are increasingly launching their innovations in foreign markets through direct foreign investment (54). No equivalent data are available for firms in other Member countries.

133. Effective competition in international markets requires specialisation, and technology cannot be exempted from this requirement. However, technological specialisation may often be very different from conventional concepts of specialisation (for example, between wool or wine, or between electronics and agriculture). In areas of rapid technological change, where new market opportunities are continually opening up, there are ample opportunities for specialisation within sectors - between different sorts of aircraft, different sorts of electronic goods, different sorts of drugs, or different sorts of transportation equipment.

134. The fields chosen for specialisation will, of course, depend on the relative strengths and weaknesses of the firm, and on the possibilities of market penetration. But even in fields where other firms or countries appear to have a strong lead in an important broad area of technology, specialisation and concentration of effort can be rewarding. For example, in spite of the general U. S. lead in solid state technology, certain Japanese firms have been very successful through concentrating their efforts on this technology's use in electronic consumer goods (84). And at least one European firm has benefited from a concentration of effort:

"... by narrowing down the field by excluding all but silicon devices and by excluding all techniques other than diffusion and by limiting ourselves to a narrow range of powers required for the automative and aircraft industries, it has been possible, with a few technical men concerned in the work, to develop over a limited range quite a number of sophisticated devices and it has been possible to sell back to the largest corporation in the United States a license on one of them." (83)

total "style" of the firm with regard to technological innovation, including the appropriate organisational form and the criteria for evaluating R and D projects. Yet very little appears on the subject in the academic literature. Further thought on these problems may well be relevant to member governments, insofar as they are involved either directly or indirectly in industrial technological activities. It may also be relevant in relation to the policy objectives that member governments fix in areas with a strong scientific and technological component.

E.4. Conclusions

140. To sum up, R and D and technological innovation create new and sometimes difficult problems for management. This is partly due to the relatively recent growth of R and D and innovation as important management functions, and partly to certain unique characteristics which - as we have seen with regard to organisation and evaluation - may require adaptation or rethinking of conventional management practices. The prime requirement for the successful management of innovation would appear to be entrepreneurship - not only in individuals, but also in organisational forms capable of transmitting knowledge and information across functional and divisional boundaries and of responding rapidly to change, and in evaluation methods which take account of technological and market uncertainties and of the nature of the various stages of the innovation process.

141. This same entrepreneurial flexibility and openmindedness will be necessary for a real improvement in the techniques for managing research and innovation. Academic institutions can play an important role in advancing understanding of research and innovative processes, and in training innovative and entrepreneurial management - provided that they are closely coupled with the real problems and experience of those actually involved in research and innovation: this point will be returned to in Part IV of the report, concerned with government policy. Finally, the management literature, the activities of management consultants and of EIRMA and IRI*, together with the pressures of an increasingly open and competitive environment, will ensure that advances in this particular aspect of management technology - as with advances in other "software" and "hardware" technologies, will continue to be diffused internationally and rapidly.

* European Industrial Research Management Association, and the Industrial Research Institute, which is its equivalent in the U.S.A.

Part III

THE UNIVERSITIES

A. UNIVERSITY SCIENCE AND INDUSTRIAL TECHNOLOGY IN INDUSTRIALLY ADVANCED COUNTRIES

A. 1. National Scientific and Technological Capabilities

142. The relationship between science and technology has evolved, during the past 200 years, from independence to occasional links, and from there to mutual interdependence. This movement has been brought about by economic and military competition, as illustrated by the emergence of the German chemical industries in the 1860's and of many other science-based industries which followed, as well as by scientific and technological efforts induced by the Second World War. It has been accelerated by the increasing availability and applicability of scientific knowledge. These two converging forces still being at work, the trend towards closer links between science and technology is unlikely to diminish in the foreseeable future. Science and technology have drawn together in an increasing number of sectors, but by no means in all of them, nor indeed - to a satisfactory extent - in all countries. Hence there is much room left for further systematic application of science to practical tasks.

143. The aim of this part of the report is to attempt to shed some light on the concrete relations between science and technology in the industrially advanced countries of the OECD area. It has been suggested in earlier studies that the national strength in technology is linked to national strength in science. Countries with strong capabilities in fundamental science, it is argued, seem to be particularly capable of applying science to practical tasks as well. This thesis is often based on the history of science and technology in two countries, Germany and the United States. Can it be generalised to all countries?

144. It is difficult to find a universally acceptable indicator of national scientific capabilities. No single index is perfect. Two indicators

146. However, it does not necessarily follow that there is a direct causal link between national scientific and technological capabilities. Both could depend on other - perhaps sociological, economic or political - factors. In order to examine whether there are direct links between science and technology, further data are necessary. Therefore, the following two sections of this report will examine some of the available evidence on the two-way links between science and technology.

A. 2. Knowledge Transfer from University to Industry

147. Before presenting the data which attempt to examine how science is linked to technology, some general remarks are necessary. Discussions on science and technology cannot remain general for very long. They have to focus on the institutions which produce and use science and technology, that is to say, on university and industry. Science-technology links imply university-industry links. However, the basic objectives of industry and university are different, sometimes even contradictory. Until recently, all European countries assumed more or less explicitly that the main and certainly most noble task of a university was to pursue research and teaching for their own sake. In the United States, the university concept which developed during the 19th century was, at the beginning, not very different. American universities were not closely linked to society's requirements. This started to change with the land grant colleges which were established in 1862 as a help for American agriculture. As the land grant colleges developed into universities - which they were not at the beginning - the understanding grew that universities should not just be ivory towers, but should also be sensitive to society's needs and problems.

148. However, in most countries, the drawing together of university and industry has led to tension, illustrating how difficult it is to reconcile the growing interpenetration of science and technology with the differences between the aims of university and industry. Although this interpenetration is likely to increase, industry and university will probably never be fully integrated and tensions will hence subsist. One cannot even exclude a further increase of these tensions in extreme cases, up to the point of provisionally jeopardizing the whole system of industry-university links. In the United States as well as in other

in the 19th century, Russia had already given birth to many brilliant scientists and inventors, Chinese citizens had engaged in scientific research since the First World War, and thousands of Chinese studied science abroad between the two wars. These examples, as well as the Israeli experience, seem to indicate that - at least during the first half of the 20th century, national strength in science was not in every case linked to national strength in technology. But, in each of these cases, national scientific capabilities were very closely linked to Western European or U.S. science.

Table 9. SOURCE OF R AND D EVENTS, BY INSTITUTION

DISTRIBUTION ACCORDING TO "HINDSIGHT", IN %, OF ALL R AND D EVENTS

Dept. of Defense Laboratories	39
Federal Institutions (except Dept. of Defense)	2
Industry	49
Universities (incl. Contract Research Center)	9
Foreign	1
TOTAL	100

DISTRIBUTION ACCORDING TO "TRACES", IN %, BY TYPE OF R AND D EVENT

	NON-MISSION RESEARCH EVENTS	MISSION-ORIENTED RESEARCH EVENTS	DEVELOPMENT AND APPLICATION EVENTS
Research Institutes and Government	10	15	10
Industry	14	54	83
Universities	76	31	7
TOTAL	100	100	100

SOURCES: References 13 and 120.

science") played no noteworthy role in the development of the 20 weapons systems. It contributed only 0.3% of all R and D events, while applied research contributed 7.7% and technology 92%. In "institutional" terms, only 9% of all R and D events came from university (most of this, evidently, was applied research and development), 49% came from industry, and 39% from government laboratories. However, the apparent modesty of the university contribution was mainly due to the very short time period which the Hindsight investigators took into account: they started with 1940, and stressed that they had deliberately excluded the "pool of basic knowledge" assembled before 1940. In spite of this warning, carried out within the United States too, and only little of it in other countries? There are probably many reasons for this. One of the most important – the advantage for technological innovation of close, personal contacts between industry and university – will be discussed later on in section B. 2. of this part of the report.

155. On the basis of this evidence, it would appear that science does contribute to industrial innovation, and in some cases, it has become an integral part of the innovation process. However, whether the university always contributes 60% of all R and D events, as in the TRACES innovations, remains to be tested by other studies. Probably, a shorter time period than that of TRACES would reduce the proportion of relevant non-mission research events and hence of university science. But they might easily remain the largest single group of R and D events leading to any industrial innovation. Of course, much depends upon the sciences involved. It seems that some fundamental sciences – for example, chemistry – participate with a higher rate in industrial innovation than others. A study by the U. S. National Academy of Sciences on modern chemistry (121) investigated statistically the scientific publications which announced "practical discoveries" (inventions and innovations) in industrial chemistry. On the basis of the cited references, the basic research results leading to the "discoveries" were traced back to their origins. For example, publications related to 16 different industrial discoveries included 240 citations in all. Sixty-five percent of them referred to university research, 31% to industrial research, and 4% to other sources: a distribution which would tend to confirm the findings of TRACES. If the citations in the announcements of the practical industrial discoveries are broken down by the type of publication they refer to, the following distribution appears: 67% referred to fundamental science journals and books, 22% to applied journals, 10% to patent publications, and 1% to other sources. Possibly, university research in physics plays, on average, a less important role in the development of industrial technology, but this is one of the many questions which remain to be investigated.

156. It must be added that the relevance of fundamental science to technological innovation goes beyond the mere transfer of R and D events from university to industry, as illustrated by TRACES. American experts, among others, noticed that a growing part of applied research was being performed by people whose training was in basic science (122). This may be because basic scientists are often of a higher intellectual calibre than applied scientists and engineers. Their contribution enriches the quality of applied science and also of development and helps to ensure that due attention is given to the work and the discoveries of the world-wide scientific community. Thus, industrial firms may have a direct economic interest to attract basic scientists into their innovation research teams (123). Possibly also, the increasing participation of basic scientists in applied research and technology indicates that it

by Langrish, these two factors explain the delay which occured in more than half of 84 investigated innovations in British industry: 33.0% "some other technology not sufficiently developed" and 23.0% "nor market or need" (86).

159. But in addition to this, it is probable that the thirty year cycle has often been due to the fact that the technological relevance of new R and D events has not been understood by, or not known to, the competent people or university. The diffusion of new knowledge was limited or deficient. University discoveries were not transmitted quickly enough to the student body or to industry, and it took years - sometimes a generation - before they found their way into handbooks, teaching programmes and finally industrial laboratories. It comes as no surprise that, in 22.0% of Langrish's 84 innovations, the factors listed as causing delay belong to this group: "potential not recognised by management"; 10% "resistance to new ideas"; and 4.0% "poor co-operation or communication". It should be possible to reduce the thirty year cycle in those cases where it is due to lack of understanding or communication.

160. The results of a study by F. Lynn suggests that the gestation period for military innovations has been shorter than for civil innovations (14). This has probably been due in part to the clearer definition of defence "needs" than is often possible for civil innovations, and possibly also to the greater time pressures related to military innovations. Equally important, however, may be the difference in the modes of knowledge transfer for the Hindsight and TRACES innovations. The thirty year time lag observed in the TRACES innovations suggests that most university created knowledge was transferred through university education and publications. In the Hindsight innovations, however, many transfers were based on informal person-to-person communication. There is no doubt, as we shall see, that such personal transfers are quicker and more efficient than the other channels of university-industry communication.

161. Most "person-embodied" knowledge transfers take place through university graduates who join industry as full-time collaborators, through consultancy work of university teachers, and through industrialists' participation in university courses. No comparable data are available on the relative importance of the different modes of knowledge transfers, neither within a country nor between countries; but data for the United Kingdom shows that all three methods are used by more than 70% of large companies (i.e. with more than 5,000 employees) (154). Nonetheless, the tensions which arise from the differing objectives, preoccupations and ideals of industry and university do create problems.

162. Thus, scientists prefer academic careers to industrial jobs in all countries. Complaints about this and related problems have been heard

were of professional rank. Of the 82%, 58% of the firms had long term agreements with consultants for occasional, one-day meetings, whilst 36% employed specialists for regular consultation in specific fields. Furthermore, most universities allowed staff to take an outside consultancy for at least 10% of their time, but rarely for more than 20%.

166. In this respect, it is very interesting to come back to the high correlation between the number of science Nobel prize winners and technological performance of OECD countries. In fact, the personal links between Nobel prize winners and technologically successful industries might add a second and more direct explanation of the close relation between the two in addition to the general links between national scientific and technological capabilities mentioned above. It is not secret that some Nobel prize winners performed the bulk of their research work in or for industry, or at least in close collaboration with industry. Unfortunately, no internationally comparative statistics on this are yet available. But on the basis of a few checks, one can tentatively suggest that in countries which excel in industrial innovation, Nobel prize winners tend to work nearer to industry than in countries with a smaller performance in industrial innovation. Since 1943, for example, Switzerland has received the same number of science Nobel prizes as France, although her population is only a tenth of that of France. Switzerland's performance in technological innovation is relatively higher than the French performance, and some of the four Swiss Nobel prize winners are known to have done their research in or for industry - which cannot be said of their French colleagues. Thus, the collaboration of first class scientists adds to industry's innovative capability. The latter in turn helps industry - in financial and substantive terms - to attract first class scientists.

167. Finally, another method of knowledge transfer from university to industry which has received publicity in recent years is the "scientific entrepreneur", the university scientist who commercially exploits his knowledge by creating a science-based firm. But the discussion in Part II of this report suggests that relatively few of these scientific entrepreneurs come directly from university; most were already from other industrial or government laboratories. Therefore, the knowledge transfer from university to industry through this method may be less important than was generally believed. Of course, this does not mean that this method of knowledge transfer should not be encouraged - quite the contrary.

168. In conclusion it should be noted that all the modes of knowledge transfer described above border on a problem that has not been mentioned thus far. Knowledge does not flow free of charge. Getting it requires some effort and, in this context, it is worth citing one of the conclusions of the recent U.K. survey of university/industry relations:

pointed out that they classified R and D events "on the basis of their technical content and motivation, independent of the organisation in which they occurred."

170. However, the university as a national "organisation" trains scientists who have to find employment. Obviously, this mere fact places industry in a position of influence, if not power, at least over a long time-period. Industry being an important employer of science and technology graduates in OECD countries, it is today widely accepted that universities should be responsive to industrial manpower requirements. Since university training is more often than not linked today to university research, any change in the one is likely after some time to bring about changes in the other as well. Hence, industrial requirements do affect not only the patterns of university training, but the patterns of research too. It would be interesting to know how much the numerous changes in science curricula and university research programmes of the past have been due to changing industrial requirements rather than to any independent dynamics of the development of knowledge.

171. Naturally, there are national differences in the way industrial technology is linked to fundamental science. Joseph Ben-David called some national types of university organisation - for example, the United States type - "entrepreneurial", stressing that they are more flexible and more responsive to industrial needs than other forms of scientific organisation (127). However, it it doubtful whether differences of national university traditions alone are sufficient to explain the large national variations which exist in scientific excellence and in the quality and strength of industry-university links. Such an explanation should perhaps be complemented by a differentiation of national industrial systems, for there are entrepreneurial and less entrepreneurial industrial traditions as well. To stimulate science and to create successful industry-university links requires an entrepreneurial industrial attitude at least as much as an entrepreneurial university attitude.

172. But this is not necessarily true in all cases. For example, it has been mentioned above that, during the first decades of this century, Germany was a leading scientific and technological power. At the same time, her university traditions were said to be rigid and not entrepreneurial (127). But between 1901 and 1939, Germany, with about 70 million inhabitants, received 36 science Nobel prizes, compared to 49 prizes accruing to the United Kingdom, France and the United States taken together. These three countries together had a population of about 230 million and university systems which, except for France, were supposedly less rigid. Did the intrinsic quality of their scientists, or the general prestige of science in their countries lag behind those of Germany? This is not likely.

try to get first-class scientists, wherever they are coming from. Therefore, full control is a relatively irrelevant form of industrial influence in the university system. "The permeation of academic policy by business principles is a matter of more or less, not of absolute, dominance." (129)

177. It is more promising to look for patterns of partial financing by industry and hence, partial influence on universities. One might suppose that the direct relevance of university science to industry would be visible in the patterns of university financing, at least in highly industrialised countries. However, this is not the case. Direct industrial contributions to university research are insignificant in the OECD area. They amount to 1.5% in the United States, 3.9% in the United Kingdom and 0.7% in France. The relatively highest contributions of industry to national university budgets are to be found in Spain (6.8%) and Ireland (5.1%) (130). Of course, this does not mean that in Spain and Ireland, university science is more relevant to industry than in, say, the United States. It seems rather to indicate that in technologically less developed countries such as those mentioned, industry is less capable in terms of scientific manpower and laboratories of carrying out the research that it needs, and that university research is inadequately supported, so that industrial contracts are eagerly accepted.

178. However, a much more significant picture of industry influences appears as soon as financial data become more precise and detailed. In the United Kingdom, industry seems to have an important influence on the direction of post-graduate research and training, since 20% of all funds for post-graduate research and 12% of the funds for training come from industry, contributions being higher in technology than in science, and higher in chemistry than in other sciences (125). This is certainly a more relevant figure than the 3.9% of all university funds in the United Kingdom contributed by industry. A closer look reveals that in many industrialised OECD countries, industry contributes considerably - not to the financing of the national university system, but to the financing of selected university departments, chairs and research institutions. Cases of open financial support for clearly defined university purposes have been reported from the big science-based companies of many countries, for example, the Netherlands, Germany, Italy, Switzerland, the United States. In many of these cases, it appears that industrial wishes are easier to articulate and to satisfy within relatively small regional groupings, because a political, economic and even personal framework for intimate co-operation between industry, university and government often already exists or can be easily created. For example, contributions of the four big Swiss pharmaceutical companies (all being located in the canton of Basle) to the University of Basle have a touch of local patriotism which both partners tend to cultivate.

182. To sum up, published evidence about industrial influence on the organisation of university training and research is so scattered that it does not yet lead to a complete picture for any single country. But it is certainly consistent with our main working hypothesis, namely, that first-class industrial technology has become one of the main stimuli of first-class university science.

B. TWO GENERAL CHARACTERISTICS OF EFFECTIVE UNIVERSITY/INDUSTRY CO-OPERATION

183. Thus far, two important characteristics of the university industry relations have not been discussed in great detail. The first characteristic is the uncertainty associated with scientific development and application, and the consequent need for a framework facilitating flexible, pluralistic and continuing communication between the universities and industry. The second characteristic is the "person embodied" nature of flows of information between university and industry, and the consequently strong, regional link between strengths of scientific and technological capabilities. Each will now be discussed in turn.

B. 1. Fundamental Research in Industry

184. A recent article reviewing the numerous case studies of innovation which have been made in the U. S. A. concluded as follows:

- innovation typically depends on information for which the requirement cannot be anticipated in definitive terms and therefore cannot be programmed in advance; instead, key information is often provided through unrelated research. The process is facilitated by a great deal of freedom and flexibility in communication across organizational, geographical, and disciplinary lines;
- the function of basic research in the innovation process can often be described as meaningful dialogue between the scientific and the technological communities. The entrepreneurs for the innovation process usually belong to the latter sector, while the persons intimately familiar with the necessary scientific understanding are often part of the former (48).

185. How do the universities and industry in the industrially advanced countries adapt to uncertainty and the requirements of meaningful dialogue ? It is reasonable to argue that an effective interface is no doubt created by the existence, on the one hand, of "fundamental" research in industry, which looks not only into the firm towards application, but also outwards towards the universities and standards of academic excellence;

Table 10. INDUSTRIAL, FUNDAMENTAL RESEARCH AND UNIVERSITY APPLIED RESEARCH IN NINE OECD COUNTRIES (1963-1964)

	(1) FUNDAMENTAL RESEARCH IN THE BUSINESS ENTERPRISE SECTOR AS % OF ALL R AND D IN BUSINESS ENTERPRISE	(2) APPLIED RESEARCH DEVELOPMENT IN UNIVERSITY AS % OF ALL R AND D IN UNIVERSITY	(3) FUNDAMENTAL RESEARCH IN THE BUSINESS ENTERPRISE SECTOR AS % OF ALL FUNDAMENTAL RESEARCH
Austria	9.8	46.3	27.6
Belgium	9.0	37.8	32.4
Canada	5.3	-	-
France	4.0	14.1	10.2
Italy	4.8	40.2	3.6
Netherlands	19.0	40.0	38.9
Norway	4.2	31.2	10.5
United Kingdom	4.9	15.5	24.3
United States	4.2	37.1	25.2

SOURCE: International Statistical Year for R and D, Paris, 1968, Vol. 2.
Gaps in Technology: Analytical Report; OECD, Paris, 1970.

Table 11. FUNDAMENTAL RESEARCH IN THE BUSINESS ENTERPRISE SECTOR AS A PERCENTAGE OF APPLIED R AND D IN THE HIGHER EDUCATION SECTOR, 1963-1964

Austria	51.9
Belgium	111.3
France	108.3
Ireland	1.0
Italy	63.8
Netherlands	128.6
Norway	34.7
Spain	22.2
United Kingdom	290.1
United States	164.4

SOURCE: See Reference 130.

Table 12. FUNDAMENTAL RESEARCH IN THE BUSINESS ENTERPRISE SECTOR AS A PERCENTAGE OF APPLIED R AND D IN THE HIGHER EDUCATION SECTOR IN THE USA

1954	97.0
1955	106.4
1956	130.4
1957	139.7
1958	146.0
1959	149.5
1960	151.0
1961	147.4
1962	168.3
1963	161.6
1964	164.4

SOURCE: Scientific Activities at Universities and Colleges, NSF, Washington, 1968, together with Ref. 130.

191. Table 14 summarises the results of three different investigations, from which it appears that personal contact between scientists and engineers (methods 2 and 3) is the method most often used to transfer knowledge, being found in about 80% of the observed cases. The two more classical methods of transfer seem to be much less important. Transfer by reading and studying (method 1) is certainly less efficient, whereas transfer through a few brilliant individuals (method 4) is perhaps not less efficient, but less widespread: the inventor who combines wide scientific and engineering competences seems to be relatively rare.

192. However, economic and military competition, although most prominent in establishing personal interaction between scientists and technologists, is not the only precondition of such interaction. There are other factors which can promote or hinder person-to-person communication. The prominence of personal contacts during the development of Hindsight innovations appears in a new light, if it is related to a second leading characteristic of the Hindsight scientists and engineers: their professional and educational similarity.

193. In fact, the educational level of most Hindsight performers was exceptionally high, since 90% of them were university graduates (10.5% Ph.D's; 22.5% M.S's; 57.0% B.S's). A large proportion of them graduated at the twenty or thirty leading universities of the United States which had strong links with the Department of Defense and which receive a large part of all government funds for research. Ninety-six percent of all involved scientists and engineers graduated in subjects which were already closely related to their later professional work in defence innovation and many were associated with university professors who performed defence research. Moreover, their age distribution was very similar; most of them were at the time of their main contribution to Hindsight innovations between thirty and forty years old, and many had left the university eight to ten years before this. The pattern emerging from these observations "seems to describe a very sophisticated guild. The value of the guild relationship in the transfer of technology was demonstrated over 200 years ago." (18)

194. Again, additional studies indicate that, at least in the United States, the value of the guild relationship based upon graduation in one of the few leading universities is not limited to military innovations. The study already mentioned on ten successful innovations of General Electric (128) reveals that 33 out of the 57 involved scientists and engineers - 53 of them American trained - graduated at the following thirteen universities:

Harvard University	5
MIT	4
University of California	4
University of Illinois	4
California Institute of Technology	3
Ohio State University	2
Cornell University	2
University of Wisconsin	2
Yale University	2
University of Michigan	2
Stanford University	1
University of Chicago	1
Columbia University	1

195. Thus, more than 60% of all the American trained performers came from a few "centres of excellence" which all belong to the top universities of the United States in terms of Ph. D. training and in terms of government-financed R and D programmes. Furthermore, it appears that these thirteen top universities are training only approximately 30% of all American Ph. D's. This suggests that first-class civil technologies require - just as military technologies in the Hindsight case - a more than proportionately high number of the best available brains. It is not unlikely that some of these scientists and engineers knew each other, or were known to the same professors even before entering General Electric. In this respect, it is revealing to see in Table 15 the high concentration of research and Ph. D. training in a few American universities. Naturally, such a concentration of first-class research, first-class training and government relations in a few places greatly facilitated the creation of a "guild" system with close personal contacts.

196. Several conclusions emerge from this. First, the importance of person-to-person contacts in the transfer of knowledge towards application, together with the guild-like nature of these contacts, help explain the close relationships between scientific and technological capabilities at the regional level. Until now, such person-to-person contacts have tended to take place within a national framework for reasons of geographical proximity, language and - most important - the largely national

and who are in contact with industry and government, seem to be the key figures in this "guild" or élite system. They are the most powerful professional group in the effective coupling of science and technology for both civil and military innovations. It would be very important to know to what degree similar patterns exist in other countries. There are indications that this is indeed the case in European countries as well, but the available data do not suffice to affirm this in a definite way.

199. Finally, it is clear that, given the importance of person-to-person contacts, a variety of sociological barriers can hinder effective university/industry relations. Educational systems in which the training of university scientists is rigidly separated, differences in social status between careers in industry and in the universities, ideological differences between industry and the universities, and excessive juridical and administrative regulation can all make the achievement of effective university/industry relations particularly difficult. And although no detailed and comprehensive evidence is available on such factors for a wide number of countries, one can think of specific countries in which they are especially important.

C. CONCLUSIONS AND IMPLICATIONS FOR POLICY

C.1. The Functions of a National Capability in Fundamental Research

200. The conclusions of this part of the report can be only tentative because they are based on insufficient empirical evidence. Nonetheless, such evidence as does exist is consistent with what follows:

- Fundamental research is an essential input into innovation because it enlarges the general pool of knowledge from which innovations draw (often in an unpredicted or unpredictable manner), and because it helps solve problems raised by more applied, innovation-oriented research.

- The close links observed between national strength in fundamental research and national performance in technological innovation exist because knowledge flows and the definition of needs between science and technology are largely "person embodied": that is, they happen through people talking together frequently or through people moving from one institution to another. These contacts and movements have tended to take place within rather than across national boundaries.

- Although results of the world's fundamental research may be a "free good", their effective identification, assimilation and on past efforts (133). And, even if one was able to calculate a historically based figure, its application in determining future levels of funding would cause problems; as has been pointed out in Part II, conventional methods of calculating economic returns are blunt instruments to apply to an activity whose economic pay-off is as long term, diffuse and uncertain as fundamental research. Thus, the use of this technique is probably not for the present, but advances in the management of R and D may eventually lead to some sort of application in the future.

204. Another approach suggested on the basis of the findings of the TRACES study might be:

"an analysis of needed innovations to determine their characteristics can help to identify key blocks of knowledge which might contribute to innovation. Such analysis coupled with forecast techniques could aid in recognising "breakthrough" barriers early. The history of magnetic ferrites is interesting ... progress was limited by lack of detailed understanding of the basic properties of ceramic materials. Studies in crystal chemistry and in the electrical and magnetic properties of a number of materials provided the knowledge which unlocked the barriers to successful application." (13)

205. However, this suggestion is made on the basis of a study of five innovations, and its application to the totality of government's fundamental research efforts would pose many difficulties. It would require considerable resources for planning and forecasting; it could lead to rigidities in funding in an area of great uncertainty; and, very often, the needs for innovation cannot be defined by government, but only by industry. Nonetheless, governments can take broader and more flexible measures to orient fundamental research towards innovation, for example, through influencing the output of higher education - and therefore the related fundamental research - in relation to industry's needs, or by orienting research and training grants towards broad areas of interest to industry.

206. But it must ultimately be recognised that, given the uncertainties associated with fundamental research and technological innovation, and given the "person embodied" nature of the links established between the two, the successful coupling between them (i.e. recognition of opportunities, definition of needs, flow of information) ultimately requires continuing, personal and pluralistic collaboration between the universities and industry. The views of both industry and government in the U.K. survey confirm this need (154).

207. But how can government help to meet it? Unfortunately, the most spectacular and successful government action to this end may be misleading. Governments have successfully brought together industry

It has been suggested in Part II of this report that national specialisation in technology will increase - a subject which will be taken up again in Part IV. We have also seen that the pace and direction of national technological efforts have an influence on the pace and direction of national fundamental science. Does this mean that choice and priorities in fundamental research should or do reflect patterns of specialisation in technology? Of course, fundamental research is, in general, less expensive than are technological activities, so that it is possible at the fundamental end of the spectrum to cover a wider field than in industrial technology. Given the inherent uncertainties in the direction and potential applicability of scientific advance, this would probably be a wise policy. Nonetheless, it is perhaps worth asking whether national "centres of excellence" in science will increasingly reflect national "centres of excellence" in technology; and whether scientific "centres of excellence" should be concentrated in a few universities, or spread amongst a great number according to discipline, given the growth of interdisciplinary research.

Part IV

GOVERNMENT

A. THE ROLE OF GOVERNMENT

A.1. Its Nature and Limitations

211. The reasons for government interest in the process of technological innovation have already been set out at the beginning of this report. They relate to the effective use of scientific and technological resources, industrial growth, international competition and - in a collective sense - to laying the basis for long-term growth of the OECD area as a whole. Yet these legitimate reasons for interest are not to be confused with government's rôle in the implementation of innovation. As we have seen, the main agents for the creation, transfer and application of scientific and technological knowledge are industry and the universities. Nonetheless, governments have a considerable - albeit often indirect - influence on the process of technological innovation. From the formulation of national objectives in such areas as education, industrial and commercial policy and defence, down to relatively mundane matters such as regulation, government action has an important influence on the availability and flexibility of resources for innovation, on the demands for new technology, and on the pressures, rewards and constraints on institutions and individuals engaged in various parts of the innovative process. Thus, although governments often do not have legal or technical responsibilities in many key parts of the innovative process, their actions (or lack of them) have an important influence upon it.

A.2. Its Objectives

212. Two factors complicate any government's attempt to formulate a policy for technological innovation. First, many government measures which impinge on the innovative process are not directly and primarily concerned with its promotion. Second, very little is known about the effectiveness of government measures - both direct and indirect - in improving the innovative process. Fortunately, Parts II and III of this

nonetheless an important input into the innovative process, and is an essential concern of science policy makers.

B. 1. Industrial R and D

215. Table 16 shows the money spent on industrial R and D in thirteen countries as a percentage of net industrial output at various periods during the 1960's: in other words, the proportion of industrial resources devoted to industrial R and D. With regard to R and D performed by industry, there are wide variations amongst countries, the proportion being considerably higher in the U. S. A. than in other Member countries. However, this figure includes for some countries important sums of government-financed R and D, the primary purpose of which is often not the development of technology for sale in world markets. R and D financed by industry is almost certainly more oriented towards the objective of penetration of world markets, and here the variations amongst countries are smaller, and the pattern very different. Indeed, in relative terms, the industrial R and D efforts of Japan, the Netherlands and Switzerland were of the same order of magnitude as those of the U. S. A.

216. With regard to trends in industry-financed R and D over time, the time periods for which data are available are too short to enable any definite conclusions to be drawn. Nonetheless, they do not lend complete support to the hypothesis that countries with relatively low levels of intensity of industrial R and D effort will tend to have rapid rates of increase, and vice versa. This may have been the case in Austria, France and Norway (countries where industry-financed R and D is relatively low, but increasing rapidly) and in the United Kingdom and the U. S. A. (countries where industry-financed R and D is relatively high, but stabilising), but it does not appear to have been the case in Italy (relatively low level and low rate of increase) or in Germany and the Netherlands (relatively high levels and high rates of increase).

B. 2. Government Financed R and D

217. Governments can influence the potential contribution of national R and D resources to technological innovation through the objectives it assigns to the R and D that it finances, the strength of this influence depending, of course, on the proportion of government-financed R and D in the national total - a proportion that varies amongst Member countries from about one-third to more than two-thirds. It has not been

possible to compile for this report data on the objectives assigned to government R and D in the Member countries. Nonetheless, the example of the United Kingdom suggests that it is possible to achieve quite rapid changes in the balance of objectives towards which government-financed R and D is mobilised. During the six-year period from 1961/2 to 1967/8, defence-oriented R and D increased (at current prices) at less than one per cent per year, and civil R and D by nearly 13%, of which industry-oriented R and D by more than 19%, with the result that civil R and D increased from about a third to a half of total government commitment, and industry-oriented R and D from 11 to 23% (91).

218. Governments can also increase the coupling between R and D and industrial needs through the influence that it has on the pattern of performance of R and D. Tables 17 and 18 show that, in countries with a relatively high level of R and D within government laboratories - Canada, France, Norway and the United Kingdom - the relative importance of such laboratories has tended to decrease over time, partly due to the switching of government-financed R and D into industrial laboratories, and - in Canada and the United Kingdom - to a relatively slow rate of increase in government R and D expenditures. This reflects the policy judgment that R and D feeds industrial innovation more effectively if performed in or closely linked with the industrial sector itself. Only in Germany, Italy and the U.S.A. has the proportion of R and D undertaken in government laboratories increased - but in Germany from a very low initial level.

219. However, Table 17 also shows that, in spite of these adjustments, the patterns of performance of R and D in Member countries have changed relatively little in absolute terms - and this in spite of the relatively rapid growth rates of national R and D expenditures in many countries (see Table 18), and in spite of the possibility - shown by the U.K. experience - of quite rapid shifts in the objectives of government financed R and D. This suggests that any policy for the radical re-orientation of patterns of national R and D performance must be conceived over a time span of at least five years.

B.3. Policy Measures

220. In trying to improve the effectiveness of R and D in relation to technological innovation, member governments' policies have often tended to concentrate on two areas: the reconversion of government laboratories and the encouragement of R and D within industrial firms. The drawbacks of government laboratories need not be spelt out at length here. They relate essentially to the drawbacks associated with isolating R and D tasks from changing requirements and opportunities, and from

the process of application and commercialisation. Member governments have taken a number of measures to overcome these weaknesses, including – as we have seen – the transfer of capabilities to industry, and also the carrying out in government laboratories of research of direct interest to industry: in the U.K. Nuclear Research Centre at Harwell, for example, about 20% of the research at present being carried out there is in association with industry (134).

221. However, one might also ask if there are areas where government research laboratories could provide inputs into the process of technological innovation better than other types of institutions. There may, for example, be areas where many firms would benefit from technological advance, but each to an extent insufficient to warrant mounting a research programme: standards, calibration, quality control, materials, and process engineering come to mind as possible examples, as do areas where government has a major role in defining technological requirements (e.g. public transportation, education, health, construction). But whatever the appropriate role of government laboratories in the innovation process, the importance of person-to-person contact and of the movement of people for technological innovation means that close links between government laboratories and industrial firms are essential, and that all possible means should be taken to ensure the mobility of scientists and engineers between government and industry. This point will be taken up again later.

222. Many member governments have also given loans – reimbursable in the case of commercial success – to industrial firms for the performance of R and D related to commercial, technological innovation. This practice began after the Second World War in the aircraft and nuclear industries and has been adopted over the past five years in a wider number of industries and countries (92). Loans given by government for industrial R and D have sometimes been very successful in promoting technological innovation (50, 92). When they have not, failure has often resulted not so much from technical weaknesses as from inadequacies in industrial structures of management, or from incorrect assessment of a potential market or the lack of ability to penetrate it.

223. Some member governments have also employed a more indirect method of encouraging industrial R and D by according fiscal advantages to firms' R and D expenditure. But information on the effects of these measures is available only for Canada. Here, fiscal measures introduced in 1961 led to a considerable increase in capital expenditures on R and D, some increase in current expenditures, and the initiation of R and D by firms who had previously had no R and D programmes. But Canada found that the programme was difficult to administer: firms with large

Table 19. QUALIFIED SCIENTISTS AND ENGINEERS: TOTAL STOCK AND EMPLOYMENT IN R AND D IN 8 COUNTRIES

COUNTRY	BELGIUM	CANADA	FRANCE	GERMANY	ITALY	SWEDEN	UNITED KINGDOM	U.S.A.
Qualified Scientists and Engineers as % of the Labour Force (1960/1)	0.65	1.30	0.70	0.65 (1.48)	0.65	0.70	0.70 (1.13)	1.80
QSE in R and D (1963/4) as % of Graduate Scientists and Engineers	21.00	28.00	24.00	20.00 (9.0)	16.00	23.00	34.00 (21.0)	37.00
QSE in R and D as % of the Labour Force	0.14	0.36	0.16	0.15	0.10	0.16	0.24	0.63
Graduate Scientists and Engineers in non-R and D as % of the Labour Force	0.51	0.94	0.54	0.50 (1.32)	0.55	0.54	0.46 (0.89)	1.17

NOTE: Figures in brackets include non-university engineers with post-secondary education; figures not in brackets exclude them.

SOURCE: Gaps in Technology: Analytical Report, OECD, Paris.
International Statistical Year, Volume 1, OECD, Paris.

C. 2. Existing Patterns

230. No comprehensive and reliable data exist on present patterns of technological specialisation amongst the Member countries. Indeed, it is doubtful that there ever could be, since it would be necessary to collect a vast variety of date, technology by technology, product group by product group, which would probably be out of date by the time it had been compiled. Nonetheless, existing patterns of industrial R and D give some broad indications of existing patterns of specialisation, with the drawback that the industry classifications are often too broad and that specialisation takes place within them, and with the reservation that R and D is not the same thing as technological innovation.

231. Table 20 shows for twelve Member countries the percentage of total national expenditures on R and D in industry undertaken by various industrial sectors. The Table is arranged so that, if all industrial sectors were included, the column for each country would add up to 100%. Thus, by looking down the columns for each country, one can identify the first three sectors in which industrial R and D is concentrated: these sectors are marked with parallel horizontal lines. Similarly, by reading across the rows for each industry, one can identify countries where this industry accounts for a relatively large share of total, national industrial R and D; these countries are marked with vertical lines. Thus, closed boxes show industrial sectors in which countries undertake a large R and D effort, relative both to the total national industrial R and D, and to the proportion in the same industry in other countries.

232. The figures confirm the predominance of the electrically and chemically based industries in industrial R and D in all the advanced Member countries; these two industries are always amongst the first three in national totals, with the exception of chemically based industries in Sweden (although Swedish R and D in the drug sector is relatively strong). The aircraft and missiles industries rank in the first three in Canada, France, Sweden, the United Kingdom and the U. S. A.; the machinery and metals industries in Germany and Sweden; ferrous metals in Austria and Belgium.

233. Three factors appear to influence patterns of specialisation in industrial R and D:

- First, <u>access to raw materials</u>, which accounts for the higher proportion, relative to other countries, of industrial R and D resources in paper, petroleum and non-ferrous metals in Canada, and in paper in Norway and Sweden. But, even in these countries, raw material-based industries rarely account for a large proportion of total industrial R and D.

- Second, government policy objectives, which account in large part for the importance of aircraft and missiles in Canada, France, Sweden, the United Kingdom and the U.S.A., and which have a strong influence on the total level and deployment of industrial R and D.

- Third, the creation of technological capabilities in relation to competition in world markets and which accounts for the relatively high levels of industrial R and D in chemicals in Belgium; chemicals, electrical and mechanical in Germany; transportation in Italy; ferrous metals, electrical and shipbuilding in Japan; machinery in Sweden; chemicals in Switzerland. If detailed enough data were available for the Netherlands, they would probably show a similar concentration in electrical and chemicals.

C.3. Implications for Government Policy

234. These data suggest that certain Member countries have already achieved a high degree of technological specialisation linked to competition in world markets. And the importance of this requirement is being stressed in reports to certain member governments:

"The size of France and the resources available impose natural limits to the number and the size of the technological operations that can be undertaken ... In general, industrial profitability cannot be achieved in the totality of an industrial sector. An essential element of industrial strategy will therefore consist in choosing, within each sector, the areas where French industry has the best chance of being competitive." (89)

"Britain thus faces the same problem - how to adjust industrially (to international technological competition) as do many other countries of medium or small economic size ... If there were anything like a law of averages, we should not expect any longer to contribute more than, at most, about ten per cent of the world's new technical knowledge." (87)

235. However, in examining what would be ideal patterns of specialisation, Member countries often tend to eye with envy the patterns of specialisation existing in other countries. In Belgium, relatively specialised in heavy chemicals, a government report has stressed the relatively low levels of R and D effort in the electrical, mechanical and synthetic chemical industries, where it was felt that there were particularly favourable growth prospects (88). In France and the United Kingdom, both relatively strong in aerospace, the government reports cited above call for stronger efforts in the mechanical industry, and similar, though non-official thoughts, have been expressed concerning the U.S.A. (97). On the other hand, in certain countries without strong technological efforts in aerospace, some have argued

239. However, the two approaches may in fact be complementary, the former being concerned with the shorter term, and the latter with support to education, science and technology as the longer term basis for potentially new patterns of specialisation. Both approaches are reflected in policy recommendations and actions. Thus, in France, comprehensive criteria have been developed for the support of science and technology, taking into account "externalities", as well as technological and market opportunities (98). As a general principle, it has been recommended that France be "active" in some fields in science and technology, whilst only "vigilant" in others (89). At the same time, financial support is given to projects of both a short- and a longer - term nature. In Canada, it has been suggested that specialisation be based on the specific requirements of Canada with regard to climate, size and population patterns. Efforts in fundamental research should be "active" in areas where Canada has scientists of outstanding quality, and in areas related to Canada's needs - and "vigilant" in other areas as a hedge against unforeseeable change, and as a means of effectively absorbing the results of foreign science (99). Furthermore, the Canadian Government is actively encouraging foreign based multinational firms to specialise by establishing in Canada full responsibility for the total corporate requirements of selected product lines in research, development, design and manufacture (93).

240. It is worth stressing, in conclusion, that successful specialisation ultimately depends on industrial firms' technological and entrepreneurial capabilities, and the opportunities open to them in world markets. Governments can stimulate patterns of specialisation, and in the longer term open up options for the establishment of new patterns. But given the way in which the market economy functions, together with the uncertainty and need for flexibility associated with scientific advance and technological innovation, they cannot impose patterns of specialisation. In the framework of a multinational, economically integrated region, a country has strong economic reasons for specialising in certain sectors if it can thereby complement the patterns of specialisation of its other, national partners. However, without such a framework, some governments might feel that too great a degree of technological specialisation would lead to too great a dependence on foreign technology in other areas.

D. LARGE-SCALE TECHNOLOGICAL PROGRAMMES

241. Governments do have an important influence on patterns of national technological specialisation - as well as on the total deployment of national scientific and technological resources - through the support that they give (or do not give) to large-scale scientific and technological programmes involving the commitment of considerable human and financial resources. In the past, many such programmes have been

245. This evidence does not, of course, imply that government-financed projects have not had an important influence on technological innovation in specific sectors, nor that these sectors are technologically or economically unimportant. But it does suggest the validity of at least one, and possibly both, of the following hypotheses: first, it has been possible to specialise in economically advantageous and intellectually stimulating sectors, other than those heavily influenced by large scale government projects, and which have often been those oriented directly towards competition in international markets; second, the innovations and advances in skills coming out of large scale projects have effectively been diffused internationally - in other words, their "pulling effects"* have, to some extent at least, become international.

246. Whether these hypotheses will hold in future depends on the relative importance that one attaches to technological advances coming out of large-scale programmes by comparison with those resulting from an alternative use of scientific and technological resources. It will also depend on the degree of "internationalisation" of participation in all the stages of large-scale technological programmes. It is probably reasonable to predict that the greater the degree of internationalisation, the smaller will be the temptation to start what might often be sub-optimal efforts.

D. 3. Some Decision Parameters

247. As government reports have stressed, national decisions to participate in large-scale programmes merit careful preparation and analysis (88). In many respects, the parameters that must enter into the decisions are similar to those relevant to industrial firms when deciding their strategies for research and innovation. Given available resources, objectives and the world technological and market environment, should the project aim to cover a broad front, or should it be specialised? If it is to be specialised, is specialisation to be based on a strong existing capability, and - if not - how is the capability to be created? Further, should the research and innovation strategy by offensive (i. e. first in technology and in the market), defensive (i. e. second but more effectively in the market with one's own developed technology), or absorptive (i. e. more effectively into the market on the basis of technology developed elsewhere)? Given the inevitable technological and market uncertainties, an offensive strategy implies the definition of national policy towards high-cost, high-risk but high-return projects; a defensive strategy implies the definition of a programme aiming at the exploitation of a competitive advantage once the technological

* In French, "les effets d'entraînement".

E.2. The Managers of Innovation

251. The increasing scope of technical change suggests another important requirement for educational policy, namely, to train not only the creators of new science and technology, but also the managers of technological change. But what are the educational characteristics of "innovators"? Unfortunately, the available statistics do not give any guidance. The data in Annex A to this report show a relatively low correlation between national innovative performance and most national educational characteristics, with the possible exception of graduate scientists and engineers as a percentage of the labour force. Furthermore, Table 21 shows, for six European countries, no clear relationship between national innovative performance and various educational characteristics of chief executives of industrial firms. * These statistics should not, of course, be overinterpreted, but they do at least suggest that there is no established or easy solution to the training of innovative management.

252. One solution is to make innovative managers out of scientists and engineers with previous experience in R and D. Casual observation, but no hard statistics, suggests that this is one of the main source of managers of innovation. But is a scientific training and experience in R and D adequate in an area where, as we have seen, economic, social and behavioural factors are often as important as technical factors, and where there are often few laws established - and numbers available - which enable innovative decisions to be reduced to the kind of hard calculus with which scientists and engineers are mostly familiar? Another potential source of innovative managers is business education, which is being considerably expanded in certain Member countries. Here again, however, one must recognise that the long time-spans and uncertainty associated with technological innovation often render conventional management techniques inapplicable. Thus, to be effective, both these solutions imply teaching and research efforts focussed specifically on the management of innovation, and on the encouragement of entrepreneurial abilities.

253. This is the view of industry in the United Kingdom (154), and of one recent conference on education for innovation held in the U.S.A. (153). But the conference went further and criticised many aspects of contemporary engineering education, arguing that too great an emphasis on the acquisition of knowledge and the skills of analysis - coupled with too great a degree of specialisation - can kill the abilities of creative synthesis and design in response to practical needs, which are the essence of engineering.

* This confirms more fragmentary evidence collected during the OECD sector studies on technological gaps.

This problem, like the others mentioned in this section, is both vast and complex. Given the scope and the resources available for the preparation of this report, they cannot unfortunately be analysed in detail here.

F. A FAVOURABLE CLIMATE FOR TECHNOLOGICAL INNOVATION

254. The policy areas discussed above are widely recognised as having a strong influence on the processes of technological innovation. But it is important to stress that, through a wide variety of policy measures on the faces of it quite unconnected with technological innovation, government has an important indirect influence, since these policies create incentives for, or barriers to, the innovation process. When examining the influence of such policy measures, certain key characteristics of the innovative process must be kept in mind.

255. First, the activities undertaken in relation to it involve a high degree of uncertainty with regard to their outcome. This is true of all stages of the innovation process. The outcome of fundamental research is uncertain in that a hypothesis may be proved or rejected, or that new fundamental knowledge may or may not be relevant to a practical application. Development work and engineering involve uncertainties in that full-scale products and plant may not perform as expected from calculations and experiments in the laboratory. And there are similar uncertainties when launching an innovation, in that one often cannot predict the reactions of potential customers and potential competitors. Given this uncertainty, risk taking must be rewarded, and individuals and institutions must have the flexibility to adapt to new and unforeseen situations.

256. Second, innovation implies change, be it changes in scientific theory, engineering practice, the skill requirements of management and labour, forms of organisation, or the habits of users. But change is uncomfortable both for individuals and institutions, so that pressures must exist for change, and its social costs reduced as far as possible.

257. Third, the transfer of technological knowledge is mainly "person embodied". In his study of 567 successful innovations in U.S. industry, Myers found that personal experience and personal contacts were responsible for three-quarters of the information inputs to these innovations (4). This means that the effective transfer of technological knowledge requires the encouragement of personal mobility and person-to-person contacts, both within and between institutions involved in various parts of the innovation process.

F.2. Taxation

260. Systems of personal and company taxation are not the primary cause of differences between countries in innovative performance. They cannot be manipulated to create a technological capability in a country where none exists. Yet they may have an important influence on the effectiveness with which this technological capability contributes to technological innovation through the rewards and growth possibilities they offer to those who contribute to successful innovation. Thus, a recent report to the U.S. Government made a number of recommendations with regard to such factors as the carrying forward of losses and stock options, designed to encourage the growth and viability of small, science-based firms (2), and similar, though non-official, suggestions have been made in the United Kingdom (95). But it is difficult to make recommendations applicable to all countries. There is no comprehensive evidence on the influence of various types and levels of taxation on the effectiveness of the innovative process. And given national differences in taxation systems and in deficiencies in the innovation process, there is no single policy which would automatically recommend itself to all Member countries.

F.3. Regulations, Codes and Standards

261. Government-imposed regulations, codes and standards also have an important influence on the process of technological innovation, although very little empirical analysis has been published on their precise effects. Nonetheless, given the characteristics on the innovation process, it is highly likely that rigid and detailed regulation is likely to stifle technological innovation: it has been argued by the U.S. railroad industry, for example, that Federal regulations governing railroad car design have tended to freeze technology and to prevent significant design change (96). Thus, regulatory practices should probably be continually revised in the light of technological possibilities, and should specify performance and design characteristics, leaving open the possibility for industry to respond with the most appropriate technical solution.

F.4. Government Procurement

262. As sizeable customers for the products of many industries, governments have an important influence on the pressures, incentives and barriers to innovation through their procurement practices - in other words, through their influence not on technology itself, but on the market to which technology can respond. By acting as enlightened and forward-looking customers, governments can reduce some of the very considerable uncertainty which, as we have seen, is associated with the market for technological innovation. However, as a recent report to the French Government has stressed, it is important to maintain

in one laboratory? Is normal civil service status for scientists in government laboratories compatible with the effective exploitation of a nation's scientific and technological capability? Could not juridical and administrative practices be adapted so that research workers could move more freely in and out of government laboratories?

266. There is also the question of what knowledge a research worker can use when he leaves a government laboratory. In certain Member countries, he must comply with a "technological embargo", forbidding him to use for an important length of time knowledge acquired whilst working for government (35). This can be a great drawback to the firm that eventually hires him. It can also be an important brake on the emergence of new science-based firms. We have seen earlier in this report that successful science-based firms "spun off" from quasi-governmental laboratories at MIT are precisely those where the degree of knowledge transfer is the highest. A more liberal attitude by certain member governments towards knowledge transfer - person-embodied or otherwise - could lead to a greater commercial return from existing technological capabilities. Furthermore, it is worth noting that science-based entrepreneurs in Europe and the U.S.A. have often been exposed to industry or to industrial management education. Could not more be done to inform research workers in government laboratories of the opportunities open to them in large firms and small, and of relevant aspects of innovative management?

F.6. Science-Based Entrepreneurship

267. Indeed, the whole range of policies influencing the emergence of new, science-based firms could be a profitable field of study and action by governments. This has already been done in the U.S.A., where new science-based firms appear to have flourished (2). It has not been done elsewhere, where much less appears to be known about the phenomenon. Part II, Section C.4 of this report has attempted to identify some of the differences between Member countries. These suggest that, in addition to the taxation question on which the U.S. report concentrated, it would be necessary to examine the mobility of university and governmental research workers, the availability of venture capital, and government procurement practices with regard to new, science-based firms.

F.7. International Economic Integration

268. International economic integration (in the sense of the lowering of barriers to the entry of foreign markets and to the international mobility of the factors of production) heightens competition, allow advantages of scale and specialisation, offers more channels through which science and technology can be exploited commercially, and increases the speed

272. It goes beyond the scope of this report to examine this problem in detail. Suffice it to say here that, given the OECD growth targets established for the 1970's, and the continuing pressures of industrial competition, the pressures for technological change will be as strong in the future as they have been in the past. Furthermore, the competitive industrial system has shown considerable strength in harnessing technology to society's needs, once these needs are clearly articulated into a market. The policy challenge of the future will not be to stifle technological change, but to make the innovative system more sensitive to social requirements.

F.9. Conclusion

273. The relative brevity of this discussion of the factors affecting the climate for technological innovation should not be interpreted as an indicator of their importance in the innovation process. Rather, it reflects the past concentration of science policy makers on the scientific and technological aspects of innovation. This is not altogether surprising, since science policy has been mainly the province of scientists, and scientific research is the one part of the innovative process for which solid and comparable data are available. Factors affecting the climate of technological innovation are often conditioned by both policy measures that ostensibly have little to do with technological innovation and by deep-seated institutional, social and political attitudes to innovation and change. In future, however, a greater understanding of the influence of these factors, and of related policy measures on the innovative process will be required. And this probably implies a greater involvement of social scientists and the social sciences in the formulation of science policy.

G. SPECULATIONS

274. The main conclusions of the report have already been set out in the Summary at the beginning. Here we shall therefore restrict ourselves to a few speculations on the role of government policy.

It is above all clear that technological innovation is conditioned by both technological and non-technological factors. Certainly, the support of scientific and technological activities is essential for technological innovation. But the support of follow-up activities is also necessary for effective application, as are attitudes to risk-taking and experimentation; the existence of pressures and rewards, and the non-existence of barriers. It is also clear that the various parts of the innovative process are intimately, if indirectly, linked. For example, the relationship between capabilities in fundamental research and the pressures of industrial competition may be indirect, tenuous and difficult to identify, but they nonetheless appear to be real.

the ample information and analysis available on science policy and technological innovation in the U. S. A. But is the U. S. A. the only successful model that deserves examination, or even the most appropriate one? The information presented in this report shows that there are other countries, with much smaller resources and markets, and much lower levels of government involvement, which also have a strong performance in technological innovation. A more detailed analysis of these countries' experience and policies would be particularly valuable.

279. Science and technology are important in so many aspects of industrial society that many decisions about them inevitably involve political considerations, as well as the scientific, technological and economic factors on which this report has rigorously concentrated its attention. The interaction of technology, economics and politics has been brought out very clearly in C. Layton's recent review of European technological co-operation (100). In particular, the policy implications of economic integration, industrial structures, technological specialisation and participation in large scale programmes are both important and intimately linked; J. Defay has argued that policies with regard to access to government markets have had an important influence on the development of industrial structures - both within and across national boundaries (101). And A. Cottrell has said the following:

"For any single country with a GNP of no more than, let us say, 5% of the gross world product, it is either economically and industrially unrealistic to aim at a goal of being second to none in all sciences and technology. What should it do instead? Aim at excellence in a limited number of selected fields? Link up with other countries to form a larger technological and economic community? But these require deliberate, major, national decisions." (102)

280. But, although technology and technological innovation have been, and will continue to be, subjects of political concern, innovation is an intimate and endogenous factor with modern economy systems. Policies related to technology cannot continually be divorced from economic considerations. Indeed, some have argued, such as S. Rolfe, that technology and its economics have wider political implications:

"One interpretation of economic history would argue that at least since the Middle Ages man's technological capabilities have outpaced his social and political organising ability. The compass, the gun, the steam engine, the jet, the computer ... are no more than stations along the technological way; more will come. So too have there been political way stations - the city state, the duchy, the confederation, the nation state, and now haltingly in several areas, common markets. As technology for trade ... pressed then prevailing political boundaries, those boundaries have historically expanded to incorporate and use the new dimensions technology made possible." (103)

ANNEXES

Annex A

NATIONAL PERFORMANCE IN TECHNOLOGICAL INNOVATION IN TEN COUNTRIES: ITS RELATIONSHIP TO OTHER NATIONAL CHARACTERISTICS OFTEN ADVANCED AS BEING IMPORTANT IN THE INNOVATION PROCESS

Introduction

In Book III of the Secretariat's Analytical Report on Technological Gaps, an attempt was made to measure ten Member countries' performance in technological innovation (139). Six statistical indicators were used to measure such performance, namely:

I. The Location of 110 Significant Innovations Since World War Two

II. Monetary Receipts for Patents, Licences and Know-how (1963-64)

III. The Origin of Technology Imported by Japan (1960-64)

IV. Number of Patents Taken out in Foreign Countries (1963)

V. Export Performance in Research-Intensive Industries (1963-65)

VI. Export Performance in Research-Intensive Product Groups (1963-65).

Each of these indicators has limitations on conceptual or statistical grounds, and these were described in detail in Book III of the Analytical Report. This is to be expected when an attempt is made to define and measure a social phenomenon, such as technological innovation, for the first time. Similar problems of direct and accurate measurement exist in many other branches of the applied social sciences.

Despite the limitations, when these six indicators are corrected for differences in country size (see Table A. 1) there is statistically a high degree of concordance* in each country's rankings. The actual

* i.e. a high degree of agreement between the rankings of the six indicators.

rankings approximate to 70% of a perfectly concordant ranking. There is statistically only a 1% probability that this degree of concordance could occur by chance. This means that it is highly probable that the six indicators give an accurate picture of the ten countries' relative performance in technological innovation.

Consequently, from Table A. 1, a composite ranking of the six indicators of the ten countries' performance in technological innovation has been calculated (see Table A. 2). This composite ranking was then correlated with the same ten countries' rankings according to a number of national characteristics which are often advanced as being important factors affecting innovative performance.

Table A. 2. METHOD OF OBTAINING THE COMPOSITE INDEX OF TEN COUNTRIES' PERFORMANCE IN TECHNOLOGICAL INNOVATION FROM TABLE A. 1

COUNTRY	COLUMN 1 SUM OF SIX COLUMN B INDICATOR RANKS	COLUMN 2 RANKING OF COLUMN 1 i.e. COMPOSITE INDEX RANKED
Belgium	48	8
Canada	51	9
France	39	6
Germany	21	2. 5
Italy	44	7
Japan	52	10
Netherlands	22	4
Sweden	23	5
UK	21	2. 5
USA	7	1

The results of these correlations are presented in Table A. 3. They suggest a relatively high degree of correlation between national performance in technological innovation and strength in fundamental research (as measured through numbers of science Nobel Prizes, and of Physical and Chemical Abstracts), the presence of large firms (as measured through the number of firms with annual sales of more

Table A. 3. (Cont'd)

V. Composite Index minus Germany, Italy and Belgium	-	6	5	-	-	7	3	4	2	1	-	-	-
W. Average Number of Years' Schooling of HLM	-	2	6	-	-	4	5	7	3	1	-	0. 29	n. s.
X. Average Number of Years' Schooling of STP's	-	2	6	-	-	3	5	7	4	1	-	0. 11	n. s.
Y. Composite Index minus Italy and Belgium	-	7	6	2. 5	-	8	4	5	2. 5	1	-	-	-
Z. HLM with University Degree as a Percentage of Labour Force	-	2	4. 5	3	-	8	6	7	4. 5	1	-	0. 49	n. s.

NOTES AND SOURCES:

A : A composite ranked index of six national characteristics advanced as being of importance in the innovation process (source: Table A. 2).
B : As above, adjusted to include Switzerland.
C : Size of market represented by GNP (source: OECD).
D : R and D expenditures per capita financed by business enterprise (source: OECD).
E : Total per capita expenditure on R and D (source: OECD).
F : Expenditure per capita on R and D performed by business (source: OECD).
G : Expenditure per capita on R and D financed by government (source: OECD).
H : Number of large firms represented by the number of firms with annual sales of $500m or more per million population (1964-65) (source: Fortune).
I : As above, but with firms with sales of $250m or more (source: Fortune).
J : Research and development manpower as represented by total number of Q. S. and E. in R and D per 10, 000 population (source: OECD).
K : Research and development manpower as represented by total number of QSE in industry per 10, 000 population (source: OECD).
L : As above, but QSE and technicians in industry per 10, 000 population (source OECD).
M : Income per capita, 1966 (source: OECD).
N : Nobel prizes in chemistry, physics, medicine and physiology, 1943-67, expressed per head of manufacturing population (source: QUID, Plon, Paris).
O : Scientific abstracts, 1961-62, expressed per head of manufacturing population (source: Promotion and Organisation of Fundamental Research, OECD).

Ranking of Educational Characteristics (P - Z):
(source: OECD)

P : Number of graduates and equivalent as a percentage of the total labour force.
Q : Number of graduates and equivalent in pure science only, expressed as a percentage of total labour force.
R : Number of graduates and equivalent in engineering, expressed as a percentage of total labour force.
S : Combined number of graduates in science and engineering, expressed as a percentage of total labour force.
T : Composite index minus Germany, as data was unavailable.
U : Average number of years of formal schooling of the total labour force.
V : Composite index minus Germany, Italy and Belgium, as data was unavailable.
W : Average number of years of formal schooling of high level manpower (ISCO major classifications 0 + 1).
X : Average number of years of formal schooling of scientific and technical personnel (ISCO minor groups 00, 01, 02, 0X).
Y : Composite index minus Italy and Belgium.
Z : Higher level manpower with university degrees and equivalent as a percentage of the labour force.

Annex B

EMPIRICAL STUDIES ON TECHNOLOGICAL INNOVATION: THE PRESENT SITUATION AND SOME FUTURE NEEDS

I. THE PRESENT PATTERN OF EFFORT

Two facts will have become apparent to those who have read the foregoing report. First, the overwhelming majority of empirical studies on technological innovation have been undertaken in the USA. Second, there is ample room for further fact finding and analysis on the processes of technological innovation.

About 50 per cent of the papers, studies, reports, books, etc. cited in this report have been written by U. S. citizens about the USA, and a further 20 per cent wholly or partly financed with funds from U. S. sources. Recently, Professor A. Rubenstein made a survey of the level of effort of "research-on-research", which showed the rapid increase of teaching and research in the field during the 1960's (143). He found that, in 1968, 53 U. S. universities were engaged in research projects related to policy aspects of science and technology, as against 20 foreign (i. e. non-U. S.) universities. He also found that 34 U. S. industrial firms and 12 U. S. government agencies were engaged in similar research, as against 9 foreign (i. e. non-U. S.) firms and associations.

II. FURTHER STUDIES AND THEIR RELEVANCE TO POLICY

In spite of its existing high level of academic effort, it is in the USA that the need for further study of the economic, social and policy aspects of science and technology has been most clearly recognised. As has already been mentioned in the report, Roberts has stressed the need for further empirical research on the management of research and innovation, in order to destroy the mythologies surrounding it and becomes evident when an analogy is made with an area where considerable efforts have been made to collect empirical data related to science and technology - namely R and D statistics. There can be little doubt that the existence of thorough and comparable data on R and D has had an important - through often indirect - influence on science policy formulation in the Member countries. Yet this influence would not have been so great - and would even have been thoroughly misleading - had it been based solely on the data collected by the U. S. National Science Foundation.

IV. THE ROLE OF GOVERNMENT

Governments can - and do - influence both directly and indirectly the level and direction of research and teaching related to problems of science policy and technological innovation. As we have seen, a number of U. S. Government agencies support such activities, and the National Science Foundation publishes periodically an exhaustive list of <u>Current Projects on the Economic and Social Implications of Science and Technology</u>. And during the course of preparation of this report, the Secretariat has run across a number of research and teaching programmes in other Member countries. This information tends to confirm what has been said earlier about the relative balance between the USA and the rest of the OECD area, but shows in addition that levels of effort vary widely from country to country (many new programmes have been established in the UK over the past four years), and that some of the programmes enjoy government support. Given the potential returns from a better understanding of the interaction between science, technology and the economy, science policy makers in a wide number of Member countries should perhaps review the adequacy of their support for research on technological innovation - or even science policy in general.

V. AREAS FOR FURTHER STUDY AND ANALYSIS

There follows a list of subjects, grouped under a number of broad problem areas, which - on the basis of the foregoing report - would appear to merit further data collection and analysis. Methods of undertaking research on the various subjects might vary from the development and testing of sophisticated models, through the collection and analysis of statistical data, to detailed, descriptive case studies. The value of the research would often be increased considerably, if national projects could be co-ordinated with similar projects undertaken in other countries, thereby increasing the range of data available for analysis, as well as increasing the possibilities of variation of the parameters involved.

13. The Objectives of Research and Innovation: products and processes; improvements and changes; offensive, defensive and absorptive strategies; government, industrial and consumer markets (21, 127-139, 247-248).

14. The Functions of the R and D Laboratory in the Innovative Process (97); the Management of R and D Scientists and Engineers (109-113).

15. Organisation for Innovation - Definition of the Organisational Characteristics of Successful Innovative Firms: the administrative and entrepreneurial functions (102, 104-109); the interfaces amongst R and D, production and marketing (110-111).

16. The Educational, Sociological and Psychological Characteristics of Successful Innovative Management (63, 251-252); the Role of Entrepreneur in Large Organisations (103, 114).

17. The Evaluation of Research and Innovative Ventures - Existing Methods, their Utility and Desirable Future Developments: the overall R and D budget (115); long term, exploratory research (116); R and D projects and innovative ventures (120-126); project control; evaluation of the output of R and D and innovation (16-18); success rates of research projects and innovative ventures (123).

18. Research, Innovation and Company Objectives: existing methods and their utility (127); the role of technological and market forecasting (52-54, 117-119); the world environment - implications for specialisation, R and D and market strategies (131-139); examples of successful strategies.

D. <u>Fundamental Research, the Universities and Technological Innovation</u>

19. The Contribution of University/Fundamental Research to Technological Innovation (149-156).

20. Patterns of Knowledge Flow from University to Industry: flows of qualified scientists and engineers (157-158, 161-163); consultancy (164-166); person-to-person contacts (160) - the sociological and educational foundations of these contacts (189-199).

21. Industry's Influence on Patterns of University Research: university training and research financed by industry (174-176); manpower requirements (170); technological specialisation and scientific specialisation (210).

Annex C

REFERENCES AND BIBLIOGRAPHIES

C.1. REFERENCES

1. C. Freeman: The Plastics Industry: A Comparative Study of Research and Innovation, National Institute Economic Review, November 1963; see also Stocking and Mueller: The Cellophane Case, American Economic Review, March 1955.

2. Technological Innovation: Its Environment and Management, U. S. Department of Commerce, January 1967.

3. McGraw Hill: Surveys of Business Plans for Research and Development Expenditures, New York.

4. S. Myers: Technology Transfer and Industrial Innovation, National Planning Association, Washington, 1967. This study has been revised and published recently under the title Successful Industrial Innovations, National Science Foundation, Washington, NSF 19-17, Washington, 1969.

5. Federation of British Industries: Industrial Research in Manufacturing Industry, 1959-1960, London, 1961.

6. Japan Economic Journal, 10th October, 1967; Arimasa Baba: National Policy of Research and Development, paper read at the International Seminar on R and D Planning, Council for Industry Planning, Tokyo, 4th-6th April, 1967; written communication from the Japanese authorities.

7. R. Seiler: Improving the Effectiveness of Research and Development, McGraw Hill Book Company, New York, 1965.

19. E. Roberts: Entrepreneurship and Technology, in The Human Factor in the Transfer of Technology, MIT Press, 1969; also, with H. A. Wainer: New Enterprises on Route 128, in Science Journal, December 1968.

20. N. Terleckyj: Research and Development: Its Growth and Composition, National Industrial Conference Board, New York, 1963.

21. OECD: International Statistical Year for Research and Development, Volume 2, Statistical Tables and Notes, Paris, 1968.

22. Patterns and Problems of Technological Innovation in American Industry, report by A. D. Little to the National Science Foundation, U. S. Department of Commerce, September 1963.

23. W. Gruber, D. Mehta and R. Vernon: The R and D Factor in International Trade and International Investment of United States Industries, Journal of Political Economy, February 1967.

24. W. Gruber and R. Vernon: The Technology Factor in a World Trade Matrix, paper presented at the Conference on Technology and Competition in International Trade, USA, 11th and 12th October, 1968, and sponsored by the Universities-National Bureau Committee for Economic Research (to be published).

25. J. Schmookler: Invention and Economic Growth, Harvard University Press, 1966.

26. OECD: International Statistical Year for Research and Development, Volume 1, The Overall Level and Structure of R and D Efforts in OECD Member Countries, Paris, 1967.

27. National Science Foundation: Research and Development in Industry, 1966, Washington, 1968.

28. J. C. Morand: Recherche, Progrès technique et dimension des entreprises, Doctoral Thesis, Université de Nancy, 1968; also, Les grandes entreprises ne font pas plus de recherche que les petites, in Le Monde, Paris, January 1969.

29. E. Mansfield: Industrial Research and Technological Innovation, Norton Press, New York, 1968.

30. OECD: Gaps in Technology: Pharmaceuticals, Paris, 1969.

31. J. Jewkes, D. Sawers and R. Stillerman: The Sources of Invention, St. Martin's Press, London, 1958.

45. F. M. Scherer: (same as Reference 42).

46. Moody's Survey of Computers, New York.

47. V. Danilov: The Spin Off Phenomenon, in Industrial Research, May 1969.

48. W. Price and L. W. Bass: Scientific Research and the Innovative Process, in Science, USA, 16th May, 1969.

49. OECD: Technological Forecasting in Perspective, Paris, 1968.

50. P. Aigrain: Some Factors Inhibiting Technological Innovation in France, paper presented at a meeting of the National Academy of Sciences, Washington, 1968.

51. R. Charpie: The Business End of Technology Transfer (same as Reference 41).

52. U. S. National Academy of Sciences: Applied Science and Technological Progress, report to the Committee on Science and Astronautics, U. S. House of Representatives, Washington, 1967.

53. R. Vernon: International Investment and International Trade in the Product Cycle, in Quarterly Journal of Economics, USA, May 1966.

54. See section on Trade, Investment and Technology in Gaps in Technology: Analytical Report, OECD, Paris, 1969.

55. OECD: Gaps in Technology: Plastics, Paris, 1969.

56. E. Roberts: The Myths of Research Management, in Science and Technology, USA, August 1968.

57. D. Marquis: The Knowledge Base for Education of Research Managers, paper presented at the 19th National Conference on the Administration of Research, published by the Denver Research Institute, University of Denver, USA, April 1966.

58. E. Osmond: Making the Most of One's Own Resources - Research and Development (same as Reference 16).

59. D. Schon: The Fear of Innovation, in International Science and Technology, USA, November 1966.

72. H. Ansoff: Corporate Strategy, Penguin Books, London.

73. P. Drucker: Managing for Results, Pan Piper Books, London.

74. E. Ward: The Consultant's View (same as Reference 16).

75. "Les crédits de recherche dans les entreprises des Etats-Unis ne sont pas attribués rationnellement", in Le Monde, Paris, 22nd July, 1969.

76. D. G. Marquis (ed.): Second Report of the MIT Research Programme on the Management of Science and Technology, MIT, Sloan School of Management, USA, October 1967.

77. R. Isensen: Factors Affecting the Growth of Technology - as seen through HINDSIGHT, paper presented at the NATO Defense Research Group's Seminar on Technological Forecasting and its Application to Defence Research, United Kingdom, 12th-14th November, 1968.

78. E. Roberts: Exploratory and Normative Technological Forecasting: a Critical Appraisal (same as Reference 77).

79. T. Garrett: Illustrations of Technological Forecasting Techniques in Britain (same as Reference 77).

80. M. Baker and W. Pound: R and D Project Selection: Where We Stand, IEEE Transactions on Engineering Management, December 1964 (cited in Reference 78).

81. European Industrial Research Management Association: Project Selection and Review, Report No. 1 of Working Group No. 6, Paris, 1969.

82. R. Vernon: An Outsider's View of the Technological Gaps Report, in OECD Observer, Paris, May 1968.

83. W. Arrol: The Technology Gap Between the United States and Europe, in Conference Papers, Volume IV, European Industrial Research Management Association, Paris.

84. M. Ibuka: Managing Product Development for Growth (in Reference 35).

85. K. Pavitt: Technological Innovation in European Industry: The Need for a World Perspective, in Long Range Planning, U.K., December 1969.

98. General Strategy for Resource Allocation at the National Level, paper presented by the French Delegation to the Fifth Meeting of Senior Economic Advisers, Economic Commission for Europe, 14th June, 1967.

99. See discussion during examination of Canadian Science Policy, OECD, Paris, 1969.

100. C. Layton: European Advanced Technology, George Allen and Unwin, London, 1969.

101. J. Defay: Technological Collaboration in Europe, speech delivered at the meeting of the Federal Trust, London, 16th September, 1969.

102. A. Cottrell: Technological Thresholds, lecture given to the National Academy of Engineering Sciences, Washington, 24th April, 1968.

103. S. Rolfe: The International Corporation in Perspective, Conference Working Paper No. 1, The Atlantic Council, Washington, 1969.

104. A. L. Stinchcombe: Social Structure and Organisations, in J. G. March: Handbook of Organisations, 1965 (cited in Reference 62).

105. E. C. Berkeley (cited in A. Peccei: The Chasm Ahead, MacMillan, U. K. , 1969).

106. La Route 128, in Le Progrès Scientifique, No. 134, Paris, October 1969.

107. P. Curry: How Entrepreneurs Exploit Technology (a) (same as Reference 16).

108. C. Saunders: How Entrepreneurs Exploit Technology (b) (same as Reference 16).

109. J. Duckworth: Technology Transfer, National Research Development Corporation (same as Reference 16).

110. R. Hogarth: Problems in the Marketing of Innovations, in European Business, January 1969.

111. P. Della Porta: An Alarm for the Giants in Successo, No. 11, Italy, November 1968.

127. J. Ben David: Fundamental Research and the Universities: Some Comments on International Differences, OECD, Paris, 1968.

128. G. Suits and A. Bueche: Cases of Research and Development in a Diversified Company (same as Reference 52).

129. T. Veblen: The Higher Learning in America. A Memorandum on the Conduct of Universities by Business Men (1918), American Century Series, New York, 1957.

130. Volume 2 (same as Reference 26).

131. Business Week, USA, 19th October, 1968, p. 58.

132. Das Soziale Ansehen von Naturwissenschaft, Technik und Ingenieurberuf in der Gegenwartsgesellschaft, Bericht zu einer Soziologischen Untersuchung des Forschungsinstituts für Soziologie der Universität zu Köln, von H. Schmelzer, Düsseldorf, 1968, VDI Information, No. 17.

133. I. Byatt and A. Cohen: An Attempt to Quantify the Economic Benefits of Scientific Research, Science Policy Studies No. 4, Department of Education and Science, H. M. S. O., London, 1969.

134. N. Vichney: La Conversion du Centre nucléaire de Harwell, in Le Monde, Paris, 9th October, 1969.

135. R and D in the Aircraft and Missiles Industry, 1957-68, National Science Foundation, NSF 69-15, Washington, May 1969.

136. The Urban Transportation Planning Process: In Search of Improved Strategy, OECD, document T/DAS/CSI/840, December 1969.

137. The Management of Innovation in Education, CERI/OECD, Paris, 1971.

138. Growth of Output in OECD Countries, 1960-1980, OECD document CPE/WP2(69)25, Paris, 29th October, 1969.

139. See volume on Technological Innovation in Gaps in Technology: Analytical Report, OECD, Paris, 1970.

140. G. Ray: The Diffusion of New Technology: A Study of Ten Processes in Nine Industries, National Institute Economic Review, London, May 1969.

C.2. BIBLIOGRAPHIES

The amount of literature now available in the area of R and D, innovation and associated fields is so extensive that an attempt to compile a comprehensive bibliography would require resources beyond the scope of the Secretariat. Consequently, the following list indicates some of the available bibliographical sources.

1. L. K. Caldwell: Science, Technology and Public Policy: A Selective and Annotated Bibliography, 1945-65, Institute for Public Administration, Indiana University, 1965: an annotated bibliography of more than 1,000 books in twelve broad subject categories.

2. Bibliography on Technological Forecasting, Economic Commission for Europe, Switzerland, November 1969: 300 references.

3. Program on Technology and Society: Accessions Lists: an annotated bibliography under various categories issued periodically, Harvard University.

4. Robert E. Johnston: Technical Progress and Innovation, Oxford Economic Papers, Vol. 18, No. 2, U.K., July 1966: a general bibliography comprising 90 references.

5. E. Mansfield: Technological Change: Measurement Determinants, and Diffusion, an article in Appendix Vol. II, The Employment Impact of Technological Change, of a report on Technology and the American Economy, February 1966: contains about 80 references.

6. E. Mottur: The Process of Technological Innovation: A Conceptual Systems Model, National Bureau of Standards Report, U. S. Department of Commerce, Washington, March 1968: 600 references which provide a comprehensive and detailed general guide to the literature.

18. A Select Bibliography on Industrial Research, 1944-1964, Reference Paper 1, Centre for Industrial Development, Department of Economic and Social Affairs, United Nations, New York, 1964.

19. R. Havelock: Bibliography on Knowledge Utilisation and Dissemination, Centre for Research on Utilisation of Scientific Knowledge, Institute for Social Research, The University of Michigan, Ann Arbor: about 3,500 titles.