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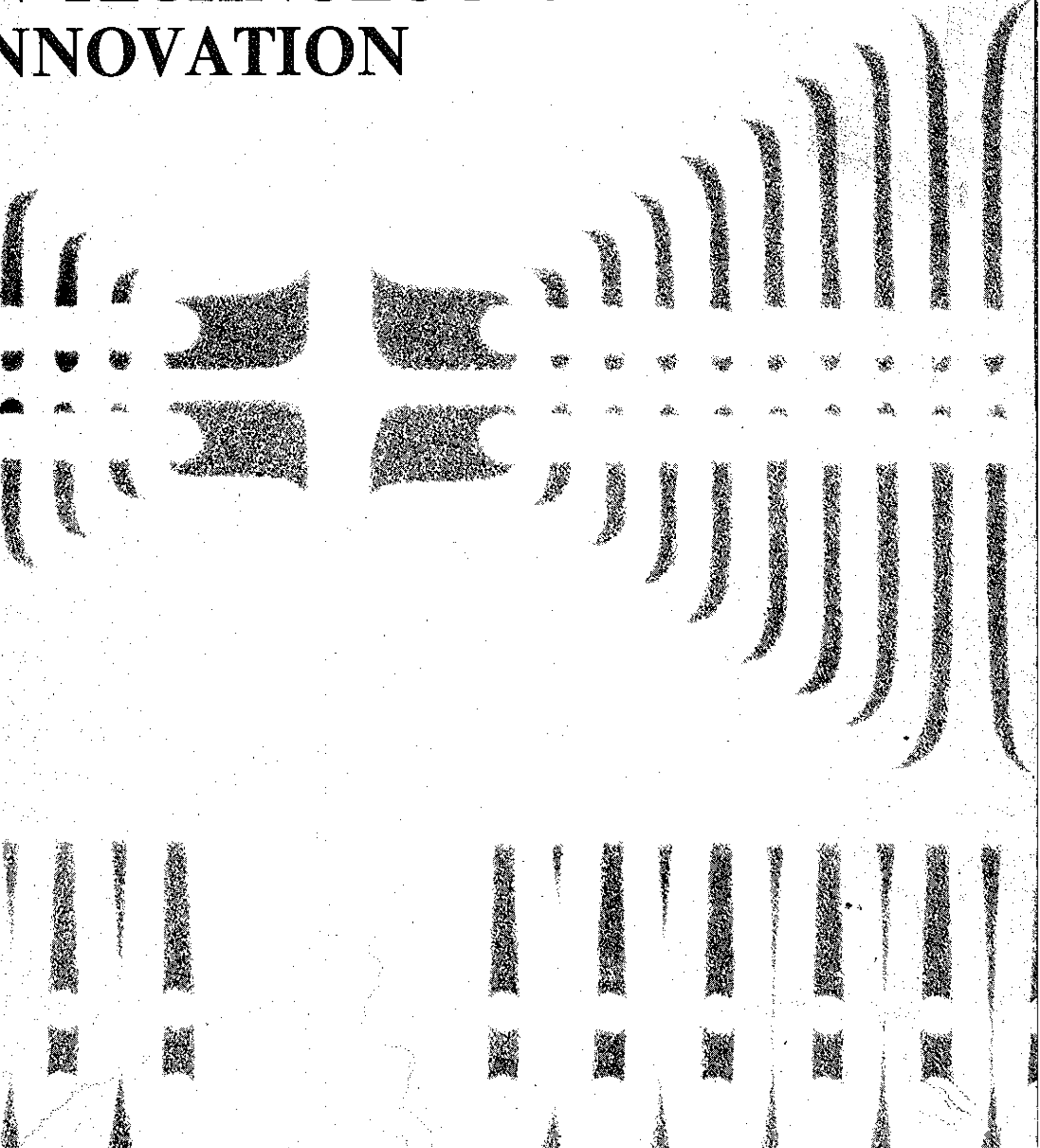

ORGANISATION FOR ECONOM PERATION AND DEVELOPMENT

The conditions for success in technological innovation

PARIS 1971

The Organisation for Economic Co-operation and Development (OECD), was set up under a Convention signed in Paris on 14th December, 1960, which provides that the OECD shall promote policies designed :

- *to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy ;*
- *to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development ;*
- *to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.*

The Members of OECD are Austria, Belgium, Canada, Denmark, Finland, France, the Federal Republic of Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

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.

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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.

According to the results of four empirical studies, between two-thirds and three-quarters of innovations are initially stimulated by a clear definition of market needs. However, the remaining technology-stimulated innovations include relatively more innovations of a radical nature, which provide the basis for a larger number of more minor innovations, oriented towards the satisfaction of well defined market needs.

Differences Amongst Industries

In spite of the relative concentration of R and D activities in a few industrial sectors, many other sectors of the economy benefit from science and technology, through being suppliers or customers of the research-intensive industries. According to a U.S. study, these research-intensive industries employ relatively large numbers of qualified scientists and engineers, not only in R and D, but also in production, marketing and general management. They also have relatively high proportions of total employment outside production and high levels of concentration; but they are not particularly capital intensive, nor are they relatively big consumers of raw materials.

Three factors have been put forward to explain the varying research-intensity of industrial sectors, namely, variations in technological opportunity, quality of management, and market opportunities. But there is no empirical evidence on the relative importance of these factors which may, in any case, be interdependent. Technological advances in materials, automation and informatics offer considerable opportunities for application in sectors which are not at present research-intensive. Managements in these sectors may themselves exploit these opportunities, which will otherwise be seized by the research-intensive industries themselves.

Industrial Structures

The empirical evidence suggests that both large and small firms play essential roles in the process of technological innovation, and that these roles are complementary, interdependent and ever changing.

They are complementary in that larger firms have tended to contribute most to innovation in areas requiring large scale R and D, production or marketing resources, whilst smaller firms have tended to concentrate on the supply of specialised but sophisticated components and equipment - often with large firms as customers. In addition, however, small firms have often made very major innovations, either because large firms have not had effective methods of evaluating and implementing radical proposals, or because major innovations often involve great uncertainties so that even the best managed of large firms may let important opportunities slip through their fingers.

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 company objectives. In particular, the definition of the appropriate mix of "offensive", "defensive" and "absorptive" R and D strategies.

The Role of Fundamental Research

Fundamental research undertaken mainly in the universities plays an essential role in the process of technological innovation. It enlarges the pool of knowledge from which innovative activities draw, and is an essential input into the training of manpower for applied research and development activities.

The experience of eleven Member countries suggests that strong links exist between national potentials in fundamental research and national strengths in technological innovation. Although the results of the world's fundamental research are, in narrow economic terms, a "free good", the effective absorption of the results of foreign fundamental research requires an indigenous fundamental research effort - certainly in the universities and, at higher levels of technological development, also in industry.

Furthermore, the transfer of knowledge between science and technology is mainly "person-embodied": in other words, it takes place through people talking to one another, or through people moving from one institution to another. Hence the importance of integrating the results of fundamental research rapidly into the teaching process, of university staff consulting with industry, and of university-based refresher courses for industrialists.

Conversely, strength in technological innovation also affects the quality of fundamental research. It leads to industrial growth and thereby induces greater demands for university education and research, either through direct, industrial financing of certain university activities, or through the sensitivity of governmental educational policy to industrial requirements.

THE ROLE OF GOVERNMENT

Government is not the primary agent for the generation and application of scientific and technological knowledge. This role belongs to the universities and industry. But experience has shown that government policy, when oriented towards well-defined objectives, can have an important influence on the resources, incentives and barriers related to the innovative process.

Objectives

However, no general policy prescriptions can be made which will be applicable in all countries, because countries differ in resources, [illegible] 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 high return projects, as well as the degree of internationalisation of participation in large-scale programmes in future.

Creating a Climate Favourable to Technological Innovation

When considering more general policies for the creation of a climate favourable to technological innovation, three key characteristics of the innovative process must be borne in mind. First, the outcome of innovative activities is uncertain, so that risk taking must be rewarded, and individuals and institutions must have the ability to adapt to new and unforeseen situations. Second, innovation often implies uncomfortable changes, so that pressures must exist for change, and its social costs reduced as far as possible. Third, the transfer of technological knowlodge is mainly "person-embodied", so that mobility and person-to-person contacts must be encouraged, both within and amongst institutions at the various stages of the innovative process.

These requirements suggest a number of objectives for government policy, such as:

- ensuring industrial competition, as the main pressure for technological innovation;
- ensuring equitable rewards for innovations, through the tax and patent systems;
- ensuring that regulations, codes and standards take account of both the social costs and benefits of the innovative process, as well as the flexibility and pluralism required for successful innovation;
- having active regional and manpower policies to deal with the changes in industrial and skill patterns brought about by technological change;
- using government procurement to upgrade the technical level of industry, and to couple technology more effectively to collective, social needs;
- encouraging the mobility of scientists and engineers, especially in and out of government laboratories;
- identifying policy measures to encourage science-based entrepreneurship;
- ensuring continued trade and capital liberalisation, thereby heightening the pressures and incentives for technological innovation in all Member countries, and maintaining the rapid, international spread of the benefits of new technology.

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.

policy makers concerned with productivity growth, the diffusion of existing technology - either indigenous or foreign developed - is clearly the most important part of the process. The mechanisms of the diffusion are the same either nationally or internationally: expansion of the innovating firm, licensing, independent re-development, the purchase of producers' goods, and the flow of scientific and technological knowledge - either written or embodied in people.

4. This explains, amongst other things, why there is no observed correlation between the proportion of national resources devoted to R and D and rates of growth of productivity. Productivity growth depends on the diffusion of both nationally and foreign developed innovations. But national R and D efforts are concentrated mainly at the inventive and innovative parts of the spectrum. As such, they reflect only a small proportion of the stock of innovations available for diffusion, and hardly any of the factors that affect the rapidity of the diffusion process.

5. It also shows the difficulty of separating the contribution of "technical progress" (i.e. the diffusion of innovations) to productivity growth from that of other factors. The diffusion of an innovation often requires capital investment. If it is a radical innovation, it may require changes in production methods, company organisation and the skill requirements of management and the work force: it will also offer many opportunities for improvement once in use. How effectively these changes are made and these opportunities exploited will depend on the level of education and the learning capacity of management and the labour force. Thus, the diffusion of innovation is intimately bound up with, and complementary to, investment, education, and management.

6. However, continued productivity growth requires more than the diffusion and effective use of existing technology. For any given production technique, there are ultimate limits on the productivity advances which can be attained by better education and training, improved management, economies of scale, and so forth. These limits are technologically determined and can be transcended only through technological innovation. Thus, continuing growth in productivity in the OECD area requires continuing technological innovation in order to increase the stock of technology on which the Member countries can draw. The mechanism through which this stock is increased is the continued competitive efforts by industrial firms to improve and change their products and production processes. Innovation - and especially radical innovation - is very closely dependent on invention and R and D, and is a risky, uncertain, and sometimes long-term activity.

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 <u>not</u> 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.

such a "beggar my neighbour" policy and to stop producing innovations. The OECD is perhaps the appropriate framework within which to say that the industrially advanced Member countries have some sort of collective responsibility to produce useful innovations as a basis for future economic growth.

C. THE FRAMEWORK OF THE REPORT

10. Given the multiplicity and complexity of the processes of technological innovation, any manageable framework of analysis is bound to be imperfect. One interesting possibility would be to consider the processes of technological innovation as a system of creating, coupling, transfer and use of information (141). But given the complexity of any consequent model in relation to the empirical information available, this possibility has been rejected.

11. Instead, the report adopts a much simpler hypothesis (or "model"), which assumes that technological innovation always requires the existence of three factors: first, a base of scientific and/or technological knowledge; second, an economic or social demand; third, a coupling agent which transforms the scientific and/or technological knowledge into goods and services which satisfy the economic or social demand.*

12. Furthermore, the report is divided into three parts which examine respectively the role of industry, of the universities, and of government in the process of technological innovation. This "institutional" presentation has the advantage that it enables one to see the role of government, in relation to those of industry and the universities, within the total innovative system. But it must be continually kept in mind that the process of technological innovation cuts across these institutional boundaries, and that the roles of industry, university and government in the innovation process are mutually dependent and interacting.

D. SOME METHODOLOGICAL PROBLEMS

13. It is only over the past ten to fifteen years that technological innovation has been the object of empirical analysis and data collection,

* Although both scientific/technological knowledge and economic/social demand are necessary conditions for technological innovation, the initial stimulus leading to innovation can come from one or the other. This point will be discussed in greater detail in Part II, Section B.

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

to avoid this danger, to exploit fully information relevant to other Member countries, and to identify those features of the U. S. experiences which are fundamental to the innovative process. It has also identified, in Annex B to this report, areas where further data collection and analysis are necessary in a wide number of Member countries. Such information will be relevant not only to students of technological innovation, but also to policy makers; unquestioning imitation of others' policy objectives, and of methods of achieving them, may - after all - sometimes be just as unrewarding as unquestioning imitation in the development of a new product.

16. Because technological innovation has only recently been subjected to rigorous empirical enquiry, its measurement presents many statistical and conceptual problems. A number of indicators of performance in technological innovation have been used in OECD studies in the past: historical data on the origin of technological innovations; monetary receipts for patents, licences and technological know-how; patent statistics; trade or market shares in product areas with rapid rates of technological change. All of them have statistical and conceptual shortcomings, and can justifiably be criticised. However, they are the same indicators that have been used in important academic studies on technological innovation undertaken outside the OECD*, and some of them have been used in governmental reports as a guide to innovative performance.** Furthermore, Annex A to this report shows that, in making comparisons amongst ten industrially advanced Member countries, these four types of indicator give a similar, and statistically significant, picture of national performance in technological innovation.

17. The use of R and D statistics as indicators of innovative performance has also come in for a great deal of criticism over the past two years. It has been pointed out that R and D statistics measure only one part of the total input into the innovation process. Thus, from a policy point of view, R and D expenditures cannot be equated with innovative expenditures. But it does not necessarily invalidate the use for analytical purposes of industrial R and D expenditures as one indicator of performance in technological innovation. No doubt the relevance and the productivity of R and D can, and do, vary widely from firm to firm. But, between industries and between nations, empirical evidence shows a high correlation between industrial R and D expenditures and technological innovation. Across thirteen industries in the U. S. A., Table 1 shows that there is a high correlation between R and D intensity (measured as R and D expenditures divided by sales) and rates of technological

* See, for example, References 1, 4, 9, 13-16, 22-25, 28, 31, 33, 39, 64, 67, 70, 71, 86, 142.

** See, for example, References 2, 8, 17, 77, 87-89, 109, 120-122, 127.

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)	EXPECTED PERCENTAGE OF 1969 SALES IN NEW PRODUCTS (1966)
	1	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.

ucts as a percentage of sales). And Annex A to this report shows, across ten countries and corrected for differences in population size, a high correlation between national expenditures on industrial R and D and national performance in technological innovation.

18. Thus, there is no simple and uncontroversial measure of technological innovation. The indicators used by academics, by governments and by industrial firms are all imperfect measures of various parts of the innovation process. Yet these measures, taken together, appear to be mutually consistent. They will therefore be used - with suitable prudence - throughout this report.

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

marketable products, 17.5% to new components in products, and 24.7% to new or better production processes (4). In the U.K. the same pattern probably exists: in 1959-60, 37% of industrial R and D was directed towards new products, and 24% towards major improvements (5). However, in Japan, a government survey found that, in 1967, one tenth of Japanese industries' R and D was related to imported technology, and indicated that most industrial R and D was related to current production activities rather than to the development of entirely new products and processes (6). It would be useful to have similar information from a wider number of Member countries.

22. The following discussion of the role of industry will be divided into four parts: differences between industrial sectors, the influence of firm size, the influence of market size, and the implications of technological innovation for management.

B. DIFFERENCES AMONGST INDUSTRIES

23. Table 1 has shown, for the U.S.A. at least, considerable differences between industries in their "research intensity" (i.e. ratio of R and D to sales) and rate of new product innovation. The same pattern of research intensity has probably existed in the U.S.A. for a long period (20). And, although there are certain variations, a very similar pattern of research intensity exists in other industrially advanced Member countries (21).

24. In spite of this relative concentration of R and D innovative activities in a few industries, many other sectors of the economy nonetheless benefit from science and technology, through relations with research intensive industries as customers or suppliers, through inter-industry manpower mobility, through the "invasion" by research intensive sectors of other industries' markets, and through the acquisition of scientific and technological knowledge, proprietary or otherwise (22). Classic examples of inter-industry technology transfer include the penetration of the textile industry by the chemical industry, the contributions of the machinery and chemical industries to improvements in agricultural productivity, and the contribution of the computer to office administration, insurance and banking. Thus, although only a few industries may be research intensive, a much larger number make intensive use of science and technology. It is through this process of inter-industry transfer that technology makes its main contribution to economic growth.

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 <u>education</u> - 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 -

ary. Certainly, as Table 2 shows, studies of successful innovations in the U.S.A. and in the U.K. suggest that a considerably higher proportion of innovations is initially stimulated by need recognition (i.e. market and production need) than by recognition of a technological opportunity. But two of the studies equally suggest that radical innovations rely more heavily on technological opportunities, and tend to be more frequent in the research intensive industries (4, 86). This finding goes in the same direction as one of the results of a survey of R and D management practices in U.S. industry, namely, that a relatively higher proportion of proposals for R and D originate in R and D departments in the research intensive industries than in other industries (7).

Table 2. THE RELATIVE IMPORTANCE OF TECHNOLOGICAL OPPORTUNITY AND OF PRODUCTION AND MARKET NEEDS AS INITIAL STIMULI TO TECHNOLOGICAL INNOVATION: A COMPARISON OF THE RESULTS OF FOUR EMPIRICAL STUDIES

INITIAL STIMULUS	PERCENTAGE DISTRIBUTION ACCORDING TO FOUR EMPIRICAL STUDIES			
	CARTER AND WILLIAMS	GOLDHAR	LANGRISH	MYERS AND MARQUIS
Technological opportunity ..	27	33	34	23
Production and Market need	73	67	66	77
Total number of innovations studied	204	600(?)	84	567

SOURCE: Carter and Williams : Reference 116
Goldhar : Reference 145
Langrish : Reference 86
Myers and Marquis : Reference 4.

29. Furthermore, there is some evidence that technology-stimulated and need-stimulated innovations are complementary. Studies of patent statistics (25), and of innovations related to the catalytic cracking of petroleum (9), tend to confirm one of the conclusions of the "Hindsight" study, namely that:

"Advancing technology is made up of a number of precursor type events and a far greater number of pedestrian accomplishments. The

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.

33. The debate on the respective contributions of large firms and small firms to technological innovation continues. On the one hand it is argued that large firms are better able to spread risks; to mobilise interdisciplinary research teams and large scale efforts; to penetrate markets; to undertake fundamental research which will be relevant to their commercial needs; and to forecast, plan and (some would say) control the development of their markets. On the other hand, it is argued that small firms are able to take decisions more quickly; to integrate technological, production and marketing factors more effectively; to generate greater personal commitment and energies in relation to the success of a project; and to avoid resistance to innovation within the firm due to established practices and interests.

34. In order to unravel these conflicting conceptions of the role of large and small firms in the process of technological innovation, we shall first review the available empirical evidence, and then go on to suggest why and how their roles are complementary.

C.1. The Empirical Evidence

35. Industrial R and D tends to be concentrated in large firms. In nine OECD countries in 1963-1964, the four firms with the largest R and D programmes accounted for more than 20% of total industrial R and D, and for more than 45% in Italy and the Netherlands (26). In the U.S.A. in 1966, 471 firms with 5,000 or more employees reported 88% of total industrial spending (27). In France, it has been estimated that 77% of large firms undertake R and D, as against 54% for medium, and 32% for small firms (28).

36. Of those firms performing R and D, however, large firms do not always spend relatively more of their resources on R and D by comparison with medium and small sized ones. In the U.S.A., in 1966, large firms (i.e. more than 5,000 employees) did spend a high proportion of sales on R and D. But, out of 20 industrial sectors, small or medium sized firms spent as much, if not more than, large firms as a proportion of sales in the following sectors: drugs and medicines, other chemicals, non-ferrous and other metal products, communications equipment and electronic components, and scientific and mechanical measuring instruments (27). Even amongst large U.S. firms, Scherer and Hamberg have found no positive correlation between firm size and R and D expenditure as a percentage of sales. Indeed, the R and D/sales ratio tends to decrease with size in most industries, as does the number of patents taken out as a percentage of sales (42, 45).

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

And in the 1950's, the important discoveries by Professors Natta and Ziegler in the plastics industry were made in close collaboration with large chemical firms (1).

41. But although invention and innovation in the chemical industry has probably become more "institutionalised", it would be altogether wrong to conclude that all contemporary technological innovation is being tidily organised by large firms. Since 1945, important contributions to invention and technological innovation have continued to be made by small firms. Xerography and the polaroid camera were invented, developed and commercialised by individuals and small firms. In the computer field, those for office use were successfully commercialised by large, established firms, but there has been a phenomenal growth of new firms in scientific and special purpose computers (both large and small), and in software (34). In solid state electronics, the initial discoveries and inventions were made by large firms, but it was a group of new, small firms which successfully commercialised them and thereby have become large firms themselves. In the field of scientific instruments, firms with the best innovative and growth records have been those established since 1945 and concentrating exclusively on instruments (36).

42. Furthermore, one study has found that 34 new companies have been started by 44 former employees of one large electronics company in the Boston region. Thirty-two of these companies have survived and their sales in 1966 were approximately double the sales volume of the "parent" company which the employees had left (37). And an article in Fortune in 1968 showed that the 150 Americans whose personal worth is more than $ 100 million include technological entrepreneurs who have made their fortunes since the Second World War (38).

C. 2. The Division of Labour

43. At first sight, all this empirical evidence might appear to be both conflicting and confusing. It would perhaps be legitimate, and certainly would be prudent, to conclude that no generalisations can be made about the respective roles of large and small firms in technological innovation. But such a conclusion would not be intellectually satisfying, and certainly no guide to policy makers. And perhaps some generalisations can be made. The evidence - mainly from the U. S. A. - suggests that large firms tend to make a strong contribution to innovation in areas requiring large scale technological, production or market resources, and small firms in areas requiring sophisticated and specialised technological capabilities, but relatively small production and marketing resources.

44. Technological scale factors are important in sectors the products of which are highly complex systems, and where very high standards of

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).

opportunities will be in the first stage of the "product cycle", where economies of scale in production are relatively unimportant, where market shares of individual firms are volatile, rates of entry and of failure are high, and successful entry depends on scientific and technological capability (43). Computers, electronic components and scientific instruments are post-war examples of such areas, where the opportunities for new and small firms have at various times been great (34, 35, 36). When technologies become more mature, scale and efficiency in production techniques tend to become more important, the opportunities for small firms tend to diminish.

47. Empirical evidence tends to confirm the importance of the above factors. The relative contributions of small and large firms to technological innovation contain some elements of such a division of labour. Small firms can and do make significant contributions to technological innovation in areas where production is on a relatively small scale, where the number of customers is small but their technological sophistication high, and where development costs are low. Often firms develop superior technological capabilities in specialised areas:

"... a Massachusetts firm employing some 40 persons ... developed and now produces a crucial precision component for ballistic missile guidance systems. So skilled was this firm in its narrow art that a giant prime contractor was unable to duplicate the product, despite substantial expenditure of technical manpower and government funds in the attempts." (45).

48. In many cases, large firms are not interested in entering new ventures which do not offer big markets, and they leave these to smaller firms. In the computer industry, for example, small firms could establish themselves successfully in small markets where clients were sophisticated and where no mass production existed.

"Big as their potential markets may seem to the small computer manufacturers, they are still too limited for IBM, in most cases, to have done more than preliminary probes. Where IBM has pushed further, most small manufacturers have retreated from its path." (46)

49. Scherer provides a similar example from the steel industry:

"The big steel companies, for instance, showed little interest in developing a new stainless steel sheet to meet the Atlas ICBM's needs, largely because they saw no prospect for high volume production in the project. A smaller firm was found to do the job." (45)

50. This explanatory framework is also consistent with the observation that smaller firms performing research often devote a relatively higher proportion of the resources to R and D than do large firms. This is

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)

innovation undertaken in the U.S.A. has said the following:

"One appreciates the non-rational nature of the innovative process when one notes that the more novel the invention is, the less orderly and predictable is the process." (48)

54. And there are some striking examples of incorrect assessments of trends in technologies and markets: the too optimistic assessment of nuclear energy, and the too pessimistic assessment of computers in the 1950's (49), the too pessimistic assessment of French consumers' reactions to transistor radios (50) and the equally pessimistic assessment of American consumers' reactions to portable TV (35). With the wisdom of hindsight, it is all too easy to see where the forecasts went wrong. But was the fault really that of the forecaster, or is it just that identifying and quantifying the relevent parameters in a radical technological innovation is very difficult? How much do we (or even can we) know now about the extra price passengers will be willing to pay for supersonic air travel?

55. All this is not to suggest that forecasting, planning and evaluation are not useful. As Dr. R. Charpie has said:

"... one thing we have learned. Hard though it may be to predict the markets where the idea is going to be successful, it is even harder to be successful if you don't try to do that, because this is no place to scatter your shots. You had better make up your mind you will develop appraisal criteria and stick to them. We missed Polaroid and Xerox, but we are still in business." (51)

But it does suggest that, given the uncertainties, even the best-run large firm with the most capable of evaluators, planners and forecasters may miss an opportunity to exploit a radical innovation. This fact, coupled with the heavy backlog in many large firms of research proposals which are not undertaken because of lack of resources (7), means that the small firm is essential to technological innovation, not only as part of the division of labour with large firms, but as a necessary mechanism for ensuring that - in conditions of great uncertainty - radical innovations will be brought to the market.

C.3. Inter-Firm Mobility

56. The roles of large and small firms in the innovative process are not only complementary, they are closely interdependent. Large firms are often the main customers for the innovations of small firms, and many small firms are started by scientists and engineers who previously worked for big firms. Thus, Scherer speaks of "the recent proliferation of small research-based new enterprises founded by big firm refugees" (45). Sometimes small firms are not built by "refugees" but are consciously fostered by big firms:

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.

60. This naturally raises the wider question of differences amongst Member countries in the creation and growth of new science-based firms and, in particular, of the differences between the U.S.A. and other Member countries. At the present time any discussion of these differences is bound to be speculative. No empirical, comprehensive and nation-wide study of science-based entrepreneurship has been made in any Member country. Considerably more studies have certainly been made in the U.S.A., and which give some important insights into science-based entrepreneurship, but which do not claim to be comprehensive. For Europe, virtually no empirical information of equivalent quality exists. This does not of course mean that new science-based firms have not been created or have grown. Indeed, the existing and widely held view that science-based entrepreneurship has not flourished in Europe may well reflect a lack of study of the phenomenon rather than a lack of the phenomenon itself! Some interesting information has been published by the United Kingdom's National Research Development Corporation, one of whose functions is the development of inventions, but the information is not sufficiently detailed to be useful for this report (109). However, information from the EED (European Enterprises Development Company, whose function is the support of science-based entrepreneurs in Europe), concerning more than seventy serious proposals for support, enables some degree of comparison, however imperfect, with the U.S.A.

61. As a starting point, it will be assumed that small science-based firms have flourished to a greater extent in the U.S.A. than elsewhere, that some of these firms in the U.S.A. have grown into large corporations to a greater extent than elsewhere, and that it is useful to examine some of the factors that have caused this state of affairs. Both this working hypothesis and the following discussion may prove to be wrong in the light of further study and analysis. But they may nonetheless serve the useful purpose of provoking such study and analysis.

62. Does U.S. science-based entrepreneurship reflect a superior <u>scientific and technological capability?</u> Table 3 gives a rough comparison of the educational levels of samples of U.S. and European science-based entrepreneurs. Given the difficulties of matching the equivalence of degrees in different Member countries, it suggests a remarkable similarity in the educational profile of science-based entrepreneurs on the two sides of the Atlantic: relatively few without university education, between 15 and 20% with a Ph.D., and about 70% with Bachelor's and Master's degrees. Further data on European science-based entrepreneurs suggest that they move in the same technological areas as their U.S. counterparts: highly specialised, with a strong element of electronics and instrumentation, and selling to sophisticated (mainly industrial) customers (114). But the potential supply of science-based

uation 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

equivalent data are available for other countries.

64. Given the mechanism through which new science-based firms are created, attitudes towards mobility are clearly important. It is generally felt that scientists and engineers are more mobile in the U.S.A. than elsewhere, but there are no hard data enabling the comparison of mobility rates. Nonetheless, it is interesting to note from Table 4 that, in spite of the observed similarities in their educational characteristics, the previous work experience of the samples of U.S. and European entrepreneurs is radically different. In Europe, a much lower proportion come from government laboratories and the universities, and a higher proportion from industry, than in the U.S.A. Given the particular characteristics of the Boston region, the U.S. sample may be heavily weighted towards government and the universities. Nonetheless, these data suggest that the lack of mobility of European scientists and engineers employed in the universities and government laboratories (but not in industry) may be a hindrance to the formation of new, science-based firms. This point will be returned to in Part IV of this report, concerned with government policy.

Table 4. THE ORIGINS OF SCIENCE-BASED ENTREPRENEURS: A COMPARISON OF U.S. AND EUROPEAN SAMPLES

Percentages

INSTITUTION	U.S.A.	EUROPE
University	23.6	3.7
Industry	18.0	77.0
Government and Quasi-Government Laboratories	55.9	7.4
Private Non-Industrial Laboratories ...	2.3	11.9
TOTAL	100.0	100.0

SOURCES: Same as Table 3.

65. Related to the question of mobility is the degree to which industrial firms encourage their scientists and engineers to "spin off" and create their own firms specialising in the supply of sophisticated components, etc. As we have seen, this has been common practice in a U.S. firm such as DuPont. One European scientific entrepreneur has argued that practice in European firms is often less liberal, and that this has hindered the creation of new, science-based firms (111).

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

must be made to create closer links between the scientific and banking communities, to train venture capitalists, and to channel more funds to science-based entrepreneurship.

70. Differences in the market environment may also influence the incentives and the opportunities for science-based entrepreneurship. By comparison with those of the U.S.A., the markets of other countries are smaller and less technologically sophisticated.* But the experience of certain European science-based entrepreneurs shows that these difficulties can be overcome (110). Because the products that they sell often have a high value-to-weight ratio, and are often unique propositions, tariffs and transport costs are not insuperable barriers. And many have succeeded in selling specialised and technologically sophisticated products on the U.S. market.

71. But there do appear to be differences between Member countries in the role that the government market plays in stimulating science-based entrepreneurship. Roberts notes that most of his sample of U.S. science-based entrepreneurs began as government contractors, but that after four to five years about 40% of their turnover was in the commercial market - government contracts enabling the products of new science-based firms to move down cost and learning curves to the point where they can be competitive in commercial markets (19). In another empirical study of U.S. science-based entrepreneurship, Shimshoni also found that the government market played a role, but not at all to the dominant extent implied by Roberts' sample. Table 5 shows for three sectors the importance of the government market both when the firms started and now. It shows that, in their initial phase, 39% of new firms in electronics, and 47% in instruments, sold more than two-thirds of their production to government. However, the equivalent percentage for chemicals and materials was much lower (18%), and about half the new firms in electronics and instruments began with less than one-third of their sales to the government. Furthermore, about 36% of the firms did not eventually succeed in selling more than one-third of their output on commercial markets.

* For a fuller discussion of the role of markets, see the following Section D on the influence of national market size and sophistication.

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.

73. In conclusion, it must be stressed again that much of this discussion of Member countries' experience in science-based entrepreneurship is speculative, given the absence of sound information. But it does suggest three key sets of factors which should be examined: the mobility of university and government scientists and engineers, the availability of venture capital, and the market environment. Overcoming bottlenecks in these areas will depend largely on action by the scientific and banking communities, coupled with a general upgrading of management competence. But government may also have a role to play. This point will therefore be discussed again in Part IV of this report.

C. 5. Technological Thresholds

74. Concern with the promotion of technological innovation has been one of the reasons given by certain member governments for adopting active policies for promoting industrial regroupings. It goes beyond the remit of this report to examine all the implications of this trend. Here, we can only examine briefly some of the points relevant to technological innovation. We have seen that large and small firms have complementary, interdependent and dynamically evolving roles in the processes of technological innovation. But, from the point of view of policy, it is important to ask how large is large, and is it getting larger?

75. The only reasonably comprehensive data on the cost of industrial R and D projects and innovative ventures have been collected in the U. S. A. by Seiler in a survey of R and D in over 100 large companies (7), and by Myers in a survey of 567 successful innovations in five industries (4). They show that the majority of R and D projects and innovations are not very costly: 73% of R and D projects and 65% of the innovations cost less than about $ 120, 000. These figures suggest that many innovations require relatively small R and D inputs, and draw largely on existing and widely available scientific and technical knowledge. On the other hand, the data confirm that the size of R and D projects tends to be bigger in bigger firms, and that relatively costly innovations require relatively more inventive and R and D inputs. And 14% of the R and D projects cost more than $ 240, 000, and projects in some of the larger firms more than $ 3 million; in addition, 12% of the innovations cost more than $ 1 million.

76. Simple arithmetic shows that these data reconcile what are sometimes presented as conflicting viewpoints. Thus, although most R and D projects and innovations in industry are relatively inexpensive, a relatively high proportion of financial resources are devoted to relatively costly R and D projects and innovative ventures. And if one assumes that the probability of R and D expenditures leading to a commercially

... between 5 and 50% 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.

to conclude that technological thresholds are increasing, given - as we have seen - the greater requirements for manufacturing investment and marketing as the technology of a product area matures. But, at the same time as technology in certain product areas is maturing, new product areas are emerging where scale requirements are often less important. For example, although the thresholds for entry into EDP computers have increased considerably over the past fifteen years, the present-day thresholds for entry into certain specialised computers and software services is probably still quite low. Thus, the more rapid commercial exploitation of science and technology means not only that scale requirements in a given product field are likely to increase more quickly, but also that a greater number of technological opportunities are likely to emerge where scale requirements are not important in the early stages.

81. However, it is possible that the pressures for increased scale do not come from the R and D part of the innovation spectrum, but - given that selling on world markets is today a necessary condition for successful innovation - from the resources required to penetrate beyond national or regional boundaries. Insufficient evidence is available to test the validity of this hypothesis.

82. Thus, given the enormous variety in the threshold requirements in different sectors of technology and the speed with which they change over time, few generalisations can be made about the thresholds necessary for effective industrial innovation. The costs of developing large-scale systems is probably increasing, and the initial penetration of world markets may sometimes require considerable resources, so that industrial regroupings may sometimes be necessary for effective technological innovation. But size is no universal panacea. Section E of this part of the report will show that a particular effort is required to maintain large firms innovative.

C. 6. Conclusions

83. After this review of the influence of firm size on technological innovation, the main conclusion relevant to policy makers would appear to be that complementary, interdependent and dynamically evolving relations exist between firms of different sizes in their contribution to technological innovation, larger firms tending to concentrate on areas requiring larger scale technological, production or marketing resources, smaller firms specialising in sophisticated technological areas requiring smaller production and marketing inputs, and often drawing upon technological and market knowledge obtained by scientists and engineers with previous work experience in large industrial or government laboratories.

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

may be re-absorbed again by large firms. As the new technological opportunities appear, so new small firms will then be established in other sectors, repeating the process described above.

88. This leads on to what is perhaps the most important policy conclusion, namely, the need for extreme flexibility in any rational system in order to be able to change and adapt rapidly to the opportunities and requirements of technological advance. This depends largely on the flexibility of industrial structures, which is a subject which goes beyond the scope of this report. But the mobility of scientists and engineers is also very important; not only because - as is sometimes argued - it is good to have fresh minds on a problem, or because mobility is one means of ensuring the diffusion of technology, but mainly because mobility is a learning and adaptive process whereby scientists and engineers find the institutional framework where they can best exploit commercially their knowledge. There is one reason why solid state scientists and engineers left the Bell Laboratories in the 1950's when an anti-trust ruling restricted AT and T's role in the manufacture of semi-conductors. It is also why scientists and engineers leave universities, government laboratories and large firms to set up their own firms. Once scientists and engineers find the appropriate institutional framework, they may well become much less mobile. Project Hindsight found that the scientists and engineers who made important discoveries in U. S. defence technology were markedly <u>less</u> mobile than the average for the industry (18).

89. However, high mobility rates are probably both more likely and more necessary in new sectors with high rates of technological advance. They are more likely because rapid advance is normally accompanied by the growth of new firms which are less likely than big established firms to establish contractual or instutional constraints on mobility. They are more necessary because rapid technological advance goes hand in hand with the opening up of new opportunities, with high levels of uncertainty, and with difficulties in prediction and planning. In such circumstances, higher levels of mobility are likely to ensure that larger numbers of avenues and possibilities are explored, and that a greater number lead to commercial exploitation.

D. THE INFLUENCE OF THE SIZE AND SOPHISTICATION OF NATIONAL MARKETS

D. 1. The Theoretical Framework

90. We have already stressed in this report the importance of the demand - or the market - for technological innovation. It is often argued

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

Table 7. RANK CORRELATIONS, FOR 10 COUNTRIES, BETWEEN NATIONAL PERFORMANCE IN TECHNOLOGICAL INNOVATION AND SOME OTHER NATIONAL FACTORS ADVANCED AS BEING IMPORTANT IN THE INNOVATIVE PROCESS

SOME FACTORS ADVANCED AS IMPORTANT IN INNOVATIVE PERFORMANCE / STATISTICAL RELATIONSHIP BETWEEN THESE FACTORS AND NATIONAL INNOVATIVE PERFORMANCE FOR 10 COUNTRIES	"DEMAND" FACTORS			"SUPPLY" FACTORS					
	SIZE OF NATIONAL MARKET AS MEASURED THROUGH GNP	SOPHISTICATION OF NATIONAL MARKET		QUALITY OF FUNDAMENTAL RESEARCH		INDUSTRIAL R AND D		NUMBER OF LARGE FIRMS	
		LEVEL OF INCOME PER HEAD	LEVEL OF GOVERNMENT FINANCED R AND D PER CAPITA	NOBEL PRIZES 1943-1967, PER HEAD MANUFACTURING POPULATION	SCIENTIFIC ABSTRACTS 1961-1962 PER HEAD MANUFACTURING POPULATION	INDUSTRY PERFORMED R AND D PER CAPITA	INDUSTRY FINANCED R AND D PER CAPITA	WITH SALES MORE THAN $ 250 MILLION PER CAPITA	WITH SALES MORE THAN $ 500 MILLION PER CAPITA
Rank Correlation	0.18	0.45	0.59	0.92	0.67	0.87	0.79	0.65	0.87
Degree of Statistical Significance ..	Not significant at 5%	Not significant at 5%	Not significant at 5%	1%	5%	1%	1%	5%	1%

NOTE: The ten countries included are: Belgium, Canada, France, Germany, Italy, Japan, the Netherlands, Sweden, the U.K. and the U.S.A. If Switzerland, with a high level of national performance, were included in the analysis, the only "demand" side factor to become statistically significant would be level of income per head; the correlations with size of national market, and with level of government-financed R and D would be reduced still further. On the "supply" side, the correlations with quality of fundamental research already include Switzerland; and, if Switzerland were included in the analysis of industrial R and D, the correlation with industry-financed R and D would increase considerably.

SOURCE: See Annex A.

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,

strong industrial competition are all necessary conditions for success in technological innovation. Scientists and engineers - and capital - must be sufficiently mobile to adapt to the changing requirements and opportunities of technological advance, and - in conditions of great uncertainty - to keep open multiple possibilities of commercialising technology. Market integration brings the advantages of increased competition, greater opportunities for exploiting economies of scale and possibilities for specialisation, and more equal opportunities for all countries. Within this framework, national policies for technological innovation will be bound up with strong capabilities in fundamental and industrial research, and the ability to match these capabilities with the demand for technological innovation in world markets. These points will be taken up again in Part IV of this report, which will discuss the role of government. In the meantime, however, it is necessary to discuss the implications of technological innovation for management.

E. INNOVATION AND MANAGEMENT

97. In discussing the implications of technological innovation for management, it is necessary to stress once again that technological innovation is more than R and D. Not only - as we have seen - does innovation require resource inputs in production and marketing as well as in R and D (2). The study of 567 U.S. innovations concluded:

"Perhaps the most general overall implication of the findings (of the study) is that the management of technical innovation is much more than the maintenance of an R and D laboratory which is productive in technical output. In this study only a small fraction (21%) of the successful innovations were based primarily on the recognition of technological potential, and for even fewer did the major information input evoking the idea or solving the problem involve experimentation or analysis in the firm's laboratory. The management of innovation is a corporate-wide task, and is too important to be left to any one specialised functional department. The R and D staff can make its full contribution to the total process of innovation not only by effective problem solving, but by building its competence, knowledge and personal contacts to contribute to the generation of new ideas and to the evaluation of proposed adopted innovations. In this way it can participate fully in the overall corporate strategy for technical innovation." (4)

Perhaps this conclusion needs to be tempered by another finding of the study, namely that the number of innovations involving R and D tended to be the larger and more radical ones. But it does serve to situate and define the role of industrial R and D in the total innovative process.

98. R and D and technological innovations raise some difficult problems for management, first because they are relatively young corporate

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.

100. Myers' study has shown that much industrial R and D has for objective the improvement of existing products, the widening of market applications and the development and improvement of related production processes. (4) Furthermore:

"With reasonable foresight and close collaboration between marketing and research, (such innovative activities) can be carried out effectively without really major decisions having to be made by the Board and the short and medium term future of the company provided for, but there is also the requirement for new products for the longer term." (58)

A recent report to the U. S. Government corroborates this finding and shows that, because of sales decline and price erosion of older products, a firm - in addition to making relatively minor innovations - must successfully launch new products if it is to maintain its growth targets, and that these new products will sometimes be based on radically new technologies or radically new markets for the firm (2). But it is precisely the launching of such new products which creates the greatest challenges and the greatest difficulties for management.

101. Both Schon and Wormald see a fundamental tension between the nature of the established firm and the nature of radical innovation (59, 60). Established firms seek a certain kind of ordered, foreseeable, plannable change - neither surprise nor revolution. Yet radical innovation often goes hand in hand with uncertainty with changes in scientific theory, commands changes in concepts in marketing, or requires radical changes in production equipment; it forces established firms to undergo major change. Bright emphasises the differing requirements of four stages of radical innovation: scientific (i. e. search for knowledge), engineering (i. e. reduction to practice), entrepreneurial (i. e. introduction to society), and managerial (optimisation of usage). He points out, only in very few cases has one man spanned these four stages, each of which "requires a different type of skill and knowledge, may involve some changes of attitudes and values, and requires the manipulation of very different types of resources". (16)

102. The difficulty of maintaining innovation in large organisations has been described by P. Haggerty, the President of Texas Instruments - a highly innovative firm that only recently was small but has now become very large. His experience merits extensive quotation:

"As the organisation grows, it gets more complex. Hundreds and then thousands of people are involved, often in multiple locations. The number of customers grows. Operations expand into many states and often into many countries ... To exploit the invention or innovation fully and to get broad distribution, the price must come down. The 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.

managers develop in a decentralised organisation, their innovations are ordinarily restricted to the entity for which they have responsibility or, at most, narrowly and obviously beyond it. Hence, though the organisation as a whole may have far more of the tools and the opportunity and the skilled people needed for innovation, the exposure of any one manager is restricted, and he simply fails to see the larger opportunities to solve problems which are the right scale for the whole corporation or a large part of it." (61)

Finally:

"... when one must choose between the hazy and uncertain high risk future associated with a major innovative effort and the hard, tangible, quantifiable future of exploiting present technological and commercial possibilities, the temptation is almost irresistible to press hard on the latter and postpone the former. If one is an administrative manager whose accomplishment is unquestioned, the necessity for choice may not even suggest itself.

"If an innovative effort is to be of such significance that, if it succeeds, it really will have a major impact on a big company - a true breakthrough strategy - then at some critical time in its development the risk will be very large and the general management must understand both the risks and the potential rewards ... If management does not understand, the resources applied simply will not be adequate and the strategy will fail, and no innovation will result, not because it wasn't potentially there, but because the management simply lacked the comprehension and the courage to proceed." (61)

103. But technological innovation can also create problems for senior management:

"Managements are thus confronted with tasks which are more and more frequently difficult, unfamiliar, entirely new in their experience and demanding technical expertise which belongs more and more exclusively to the young, recently qualified - and junior - manager." (62)

And this situation is not always recognised. Even in the U.S.A., an empirical study by Roberts of innovative ventures in a large company found that:

"... The young men received less encouragement than the older men, they were given less latitude for independent action, had less say in formulating the judgmental criteria for the venture, experienced less co-operation between their venture and the company, experienced a good deal of trouble in securing capital support for their project, and had a lower level of sponsorship for their project - sponsorship being a term used to describe the supportive actions taken by a person or 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)

showed that almost all the inventive and innovative events in the development of six complex weapons systems in the U.S.A. took place in an "adaptive" environment in contrast to an "authoritarian" environment (64). Of course, the description of "management/authoritarian" systems and "entrepreneurial/adaptive" systems is to some extent caricatural, and the distinction between them artificial. Some functions may be best performed within the framework of a "management" system, whilst others may require a mixture of both. But the evidence suggests that, whilst new science-based firms tend to be strong on entrepreneurship and weak on management, the reverse danger exists in large established firms.

107. For this reason, industrial firms are adopting organisational terms which respond to the requirements of radical technological innovation. At Texas Instruments, for example, there is not only the top management's commitment to technological innovation:

"... we have made a serious attempt to institutionalise it by developing a system for the management of innovation. This consists of a formal statement of business objectives, a detailed summary of the strategies which will be followed to attain these objectives, and a series of technical programmes in such functions as research and development, manufacturing and marketing, with emphasis on the invention and innovation required ...". (61)

108. This system ensures that all parts of the organisation are aware of the corporate goal of technological innovation, and of its implications for them. It also has the necessary integration of efforts across the boundaries of existing business. Furthermore, with regard to the implications of decentralisation:

"Every manager must understand that the frequently enunciated management rule that responsibility and authority always go together is just not so. The right rule is that responsibility and authority must always go together to the maximum extent possible, but in a decentralised organisation the span of responsibility practically always exceeds the span of authority, and each manager has an authority which extends only to his own decentralised unit, but a responsibility which extends across the corporation."(61)

109. The inevitable preoccupation of large firms with existing business, together with the difficulties of getting across functional and divisional boundaries, have led some firms - such as DuPont - to create a system of so-called "venture management" (65,66). The essence of this system is that the implementation of new ventures leading to radical technological innovation is separated from the existing business. One person is made fully responsible for the project, in charge of a full time team, thereby creating the advantages of the "small firm" environment, namely commitment, flexibility, rapidity and incisiveness in decision taking. Such

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)

long-term and uncertain activity, few now argue that the industrial scientist should in general be left complete freedom to choose his field of enquiry:

"The best atmosphere for applied laboratories is characterised by internal freedom under strong leadership. Success in applied research is seldom achieved by authoritarian methods, e.g. by directives from the head. Consensus must be developed at many levels by discussion and argument conducted in an atmosphere of mutual intellectual respect. Each level must have considerable freedom in the use of resources allocated to it. Multiple forms or layers of administrative control are especially stultifying. Lines of scientific communication must be as short as possible - and not necessarily congruent with administrative organisation." (70)

113. That R and D can be managed and coupled with other corporate activities emerges from an empirical study into the productivity of 1,300 research scientists and engineers in eleven laboratories (industrial, university and governmental) (71). The results of this study confirm that R and D tends to be a long term process: R and D groups tended to be most productive after four or five years' existence. They also show research workers tended to be more productive to the degree that they value intellectual freedom to pursue their own ideas. However, research workers also tended to be more productive to the degree that they do not focus on one stage of the research process,* to the degree that they had more than one area of specialisation, and to the degree that a number of outsiders were involved in shaping their objectives.

114. Finally, a number of writers stress the important role of the individual entrepreneur in technological innovation. Burns goes so far as to argue that the innovative process is in principle identical with the function of the classical entrepreneur, and that the task of organising industrial science is simply to facilitate technical entrepreneurship (62). Schon suggests that the entrepreneur becomes the champion of an idea, who is totally committed, who accepts by risks of failure, but who will use every means to succeed (68). Charpie says that he is likely to be non-conformist and technically rather than managerially oriented (69). However, the U.S. National Academy of Sciences has taken a more measured view:

"The technical entrepreneur, a missionary - the man who carried the torch for a new idea - is often the catalyst of technical progress.

* Effective scientists ... did not limit their efforts either to the world of pure science or to the world of application, but were active in both." (71)

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

Flow), longer term projects will tend to receive relatively low priority. Some research directors think this is only right and proper:

"... it is preferable to use the DCF method for longer term projects, otherwise a too optimistic result will be obtained." (58)

But others would argue that such evaluation techniques are inappropriate when considering long-term exploratory or fundamental research in the firm (16). The characteristics of such research are often very low probability of success, relatively low cost, very high pay-off if successful, but pay-off only in the long term - up to thirty years according to the evidence presented elsewhere in this report. Given these characteristics, together with the inevitable arbitrary nature of numerical assessments of probability of success and of pay-off, evaluation techniques such as DCF may be unnecessarily blunt instruments to apply to exploratory research. It is perhaps for this reason that industrial firms such as DuPont do not use sophisticated accounting techniques to evaluate their programme of exploratory research, but are content to observe that support of fundamental research has paid off in the past, and thus continue to support fields of "relevance and promise" to their business.

117. For radical innovations, the evaluation of market and technological trends also presents many pitfalls. Paragraphs 52 to 54 have shown how difficult it often is to make an ex ante assessment of the nature and extent of the market for radical innovations. And a recent review article by Roberts has pointed - rather severely perhaps - to the limitations of present methods of technological forecasting:

"Exploratory technological forecasts are largely based either on aggregates of "genius" forecasts (e.g. the DELPHI technique) or on the use of leading indicators or other trend line approaches. The practitioners of economic forecasting, in contrast, long ago recognised the need for multi-variable systems analysis and cause effect models to develop reliable predictions.

"... The empirical "research-on-research" of the past decade has now produced an impressive basis of understandings of the influences on scientific and technological progress (76, 77). Surely it is important to begin to embody these findings into the development of improved exploratory technological forecasting models.

"Normative forecasting is at the opposite extreme on the sophistication scale, fully utilizing Bayesian statistics, linear and dynamic programming, and other operations research tools. Here, despite the uniqueness, uncertainty and lack of uniformity of research and development activities, each of the designers of normative techniques has proposed a single-format wholly quantitative method for resource allocation.

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, yet a substitue for good judgment." (66)

121. Furthermore, in a review of formal R and D project selection methods in fifty organisations, Baker and Pound found that few were employing formal selection processes that were described in papers published by their own employees (80). One reason for this may well be that accurate ex ante assessments of the costs, duration and probabilities of technical and commercial success of R and D projects are very difficult. One empirical study in the U. S. A. found a weak relation between initial estimates and outcomes. (150) And a more recent study in the U. K. came to the same conclusion, with the additional findings that initial estimates tended to underestimate cost and duration, and that there was no evidence of an improvement in the accuracy as projects approached completion, nor as experience in making such estimates accumulated. (151)

122. Seiler also throws some interesting light on selection procedures used in over a hunderd large U. S. firms (7). He himself lists more than fifty factors which could be taken into account in evaluating an R and D project, many of which are difficult to quantify and involve great uncertainty. He found that only slightly more than half of the firms employed project selection methods which were quantitative in the sense that weights or values were assigned to the several factors affecting each project - quantitative methods being more readily employed in development oriented firms and less readily in research oriented firms. He also found that 80% of the research managers felt that there were important qualitative factors which could not be expressed quantitatively, but only assessed subjectively - the percentage being higher for firms involved in relatively more complex or research oriented projects. Finally, he obtained research managements' opinions as to the reliability of estimates of a number of factors which must enter into project appraisal. Table 8 shows the percentage of responses indicating excellent, good, fair, poor and totally unreliable. They suggest that it is easier to predict accurately the costs and the time horizons of development than of research, the benefits of new production process than of new products, and technical success rather than commercial success.

123. The uncertainties related to industrial research and innovation can be illustrated by the results of a number of U. S. studies. These results are not completely consistent, but nonetheless point in the same direction:

- for 120 firms, it was found that at least 50% and often more than 60% of R and D projects never resulted in commercially used products or processes (11);

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.

oriented R and D, and 70% of expenditures on product-oriented innovation, were for products which proved to be commercially unsuccessful, and that 30% of new products launched on the market proved to be unsuccessful (10);

- for the U.S.A. as a whole, it has been estimated that some 10,000 new products are developed each year, of which 80% die in infancy: and that, of the remaining 2,000, only about 100 both incorporate significant scientific or technological advance as well as satisfy an economic need (12).

124. Some take these high "failure" rates to illustrate bad research and innovation management. Others argue that they simply reflect the high technological and market uncertainties inherent in research and innovation. At whatever point between these two extreme views the truth lies, the inadequacies of existing, formal management techniques are reflected in a recent report of European industrial research managers, members of the European Industrial Research Management Association (EIRMA):

"The extensive literature on possible methods for project selection would lead one to anticipate finding a certain number of papers dealing with how the proposed methods have worked out in practice. This is unfortunately not the case.

"... It seems that the general feeling is that the methods proposed to date possess a number of shortcomings which considerably affect their practical utility ...

"... The long-time span of most R and D projects is not reflected in the proposed procedures. Most profitability methods treat an innovation project as though it were equivalent to a normal capital investment ... A normal capital investment is usually a one-shot go no-go decision. The stakes are generally high from the outset and there is rarely the opportunity to reverse the decision before at least a major part of the funds are committed. The situation is quite different for the R and D component of an innovation project. It normally extends over a relatively long period of time, during which the comparative situation may be subject to rapid change which may in part be due to the interaction of the project itself with the environment. Technical, economic, political and social changes may be involved. Thus the assessment of an R and D project is not a once-for-all exercise leading to a definitive conclusion but must be continually updated, especially in the light of technological achievements within the project itself and of changing technology elsewhere ...

" - There is no adequate treatment of multiple objectives and conflicting criteria. In essence, all the quantitative methods proposed 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

will depend on the firm's objectives, and the perceived contribution of research and innovation to them. One U.S. report has said that these objectives should be set on the basis of "directional planning", which attempts to answer such questions as "what business are we in?", "what should we be in?" (2) A comprehensive and detailed discussion of the elements of directional planning go beyond the remit of this report. Suffice it to say that it is an exercise as difficult as it is necessary (72, 73, 74).

128. Company objectives and innovation strategies will be unique to each firm, depending on its strengths, weaknesses, and the opportunities open to it. These, in turn will depend on its history and its environment. Within the OECD area there are considerable differences amongst the Member countries in historical and environmental factors related to R and D and to technological innovation - as well as rapid change in relevant environmental factors - which influence what will be the appropriate R and D strategy for industrial firms.

129. The most important environmental factor is the increasingly open - indeed worldwide - framework within which strategies for R and D and technological innovation must be conceived. This is not only because no one country can hope to produce all the scientific and technological knowledge relevant to innovation, nor only because markets wider than national markets may be increasingly necessary to amortise the fixed costs of launching innovations. It is also because increasing liberalisation and interdependence means that competition through technological innovation is conducted less and less within a national framework, and more and more within an OECD-wide framework. The OECD sector studies have shown that successful innovative firms are precisely those which introduced their innovations in a wide number of Member countries, and which increasingly conceive their strategies within an OECD wide framework.

130. This trend has obvious and important implications for the R and D and innovation strategies of industrial firms: what markets to penetrate, how to penetrate them, what areas to specialise in, and what R and D strategy to follow? These are important but difficult questions to answer. In this report, one can do no more than sketch what appears to be some of the relevant factors.

131. With regard to markets, one generalisation is probably valid: successful innovating firms have all succeeded in penetrating the U.S. market. The importance of this market arises not only out of its size and homogeneity, but also out of the earlier and more intense demand for technological innovations resulting from high living standards and sophisticated government requirements. Vernon argues that "it may be necessary to establish an operating subsidiary in the United States in

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)

greater care in deciding the elements of an R and D strategy, especially in areas where technological change is rapid, and important new generations of products are being developed (63, 85). Should the firm adopt an "offensive" strategy, aiming to be the first to the market with a new product generation? If so, success will require strong R and D, considerable insights and creativity in science, technology, manufacturing engineering and marketing, and close coupling amongst them, together with access to a market environment receptive to technological innovation. It also entails the acceptance of big risks, but the possibilities of big pay-offs. If successful, it will probably lead to the successful penetration of world markets.

136. Or should the firm adopt a "defensive" strategy, aiming to follow-the-leader to the market with a product developed with its own technical resources? If so, success in the penetration of world markets will require accurate knowledge of market developments, short lead-times for development and commercialisation, and the effective integration of improvements in design, performance or cost by comparison with the original product conception.

137. Finally, should the firm adopt an "absorptive" strategy, through imitating the product conception of the leading firm, and concentrating technical resources on cost reduction and design improvement? If so, success in penetrating world markets will depend on the possibilities of obtaining and absorbing technologies developed elsewhere, and on factor cost or managerial advantages.

138. Once again, individual firms may adopt a "mix" of all three strategies, varying between product fields and over time. Clearly, the appropriate mix will depend not only on the firm's own resources, but also on its external environment. Some people might argue that, in newly emerging technologies over the past ten to fifteen years, U.S. firms have tended to follow "offensive" strategies, European firms "defensive" strategies, and Japanese firms "absorptive" strategies. Yet the examples of nuclear energy, jet transport aircraft and consumer electronics do not seem to support such a generalisation. Others might argue that the possibilities of following "absorptive" strategies will diminish as firms' horizons and operations become more international. Yet, as we have seen, there is a continual proliferation of small, high-technology firms, generally strong in technology and weak in financial resources, which – in the initial stages at least – may not be equipped to penetrate international markets, and from which technology can therefore be bought.

139. Even if it is not possible to generalise at this stage, the implications of the external environment for research and innovation strategies are very important. Eventually, as we have seen, they determine the

ing 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

numbers of science Nobel prizes. Both these indicators have, it will be recalled, already been used in J. Ben David's report for the OECD on fundamental research (127). Data on science Nobel prizes are a simple and easily available but controversial indicator. In fact, they have several shortcomings which might reduce their reliability: the relatively small number of Nobel prizes which have been distributed, the fact that some prizes are awarded to scientists who have emigrated from their country of birth and education and, finally, the long period which sometimes elapses between a major scientific discovery and the attribution of a Nobel prize to reward it. Thus, one should not over-interpret small statistical differences in the attribution of Nobel prizes to different countries. However, since most internationally leading scientists are consulted before the selection of new Nobel prize winners, one can reasonably assume that numbers of science Nobel prizes indicate to some degree national strength in fundamental science, as seen by the scientific community itself, at least over a certain period of time.

145. Hence, it is relevant to note that between 1901 and 1939, Germany received 36 prizes, while 19 were awarded to the United Kingdom, 17 to France, and only 13 to the United States. This figure is the more revealing as Germany during the same period was universally recognised as a leading power in military and civil technologies. But the distribution of science Nobel prizes changed radically after World War Two. For the period from 1943 to 1967, the United States moved to first place with 57 prizes, followed by the United Kingdom with 24 and Germany with only 11 prizes. France had dropped to fifth place with 4 prizes. This can be interpreted as a movement of the centre of fundamental research from Continental Europe to the United States. During the same period, the United States emerged as the leading technological power as well. Furthermore, Table 7 and Annex A to this report suggest a strong relationship, for eleven Member countries, between national performance in technological innovation and national strength in fundamental science, as measured through science Nobel prizes and Scientific Abstracts. In other words, the experience of eleven countries suggests that national strength in science tends to go together with national strength in technology. *

* The parallelism of national scientific and technological capabilities in many industrially advanced countries - at least since the Second World War - is not a universal law of history. Although this parallelism may from now on become a major feature of the industrially advanced countries, one should not forget that, until recently, some countries succeeded in creating and maintaining a first class scientific capability which - at least for some time - was not reflected in any comparable technological capability. For example,

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.

from industry and government be restored have become stronger in recent years. Thus, the economic and political pressures which promote closer industry-university links have simultaneously stimulated counterforces. The speed with which science and technology will draw together will depend on the relative strength of these two forces, and on the degree to which they can be reconciled.

149. This being said, we can return to the empirical evidence which suggests that university science is indeed linked to industrial technology. Most of this evidence is recent, perhaps because the widely accepted ideal of university independence did not facilitate studies on industry-university links. One of the first studies relevant to the problem was "Hindsight" (120), and more recent evidence has been provided by "TRACES" (13). Both studies have been criticised for lack of statistical reliability and for a partisan approach. It may be true that any study on U.S. military innovations performed by the United States Department of Defense might be expected to underline the importance of Department of Defense and industrial laboratories in the innovative process. Also, it is not altogether surprising that a study on civil innovations performed by university scientists and financed by the National Science Foundation ("TRACES") came to emphasise the necessity of fundamental research for technological innovation. However, these differences are due to different perspectives, and nothing permits one to suggest that, within their self-imposed limitations, they have wilfully given way to biases. Certainly, "Hindsight" and "TRACES" are not the last word on the subject. But they can be used as valuable and complementary sources of information on science-technology links. It is likely that in most innovations, the contribution of university science will be found to range, in quantitative terms, in between the upper and lower limits marked by "Hindsight" and "TRACES". These upper and lower limits appear in Table 9 overleaf.

150. In order to understand Table 9, one must go along with the assumption that every innovation can be considered an integrated system including many different R and D events. Hence, an innovation can be statistically dissected into its main R and D components in order to compare the importance of fundamental science, applied science and development, or to weigh the contributions of industry, university and government. There are, inevitably, statistical and historical pitfalls in such an approach. It is difficult to select objectively a reasonable time period preceding every innovation, to identify all relevant R and D events, or to find their origin.

151. Project Hindsight (1966) investigated 20 major American weapons systems developed since 1945. Its results influenced - and partly biased - the discussions on science-technology links up to today. According to Hindsight, "undirected" research (very roughly equivalent to "fundamental

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, innovation were exclusively an industrial problem, without any noteworthy contribution from university research.

152. However, at the end of 1968, TRACES challenged this conclusion. TRACES is a reply to, and a continuation of, Hindsight. Hindsight was limited in space and time: it covered only relevant military "events" since 1940, whereas TRACES goes beyond these two limitations. It investigates five economically and socially important non-military innovations which were neither financed nor programmed by government: magnetic ferrites, video tape recorder, oral contraceptive pill, electron microscope, matrix isolation. The relevant scientific events that TRACES covers go back to the middle of the 19th century. In some cases, the time-period taken into account is ten times as long as the periods in Hindsight. The results of TRACES differ accordingly from those of Hindsight: of the 341 key events which led to the five selected innovations, 70% were "non-mission research" (as compared to 0.3% in Hindsight), 20% "mission-oriented research", and 10% were development and application. Of the non-mission research events, 76% originated in universities. Altogether, 60% of the relevant R and D events represented in five recent major innovations came from universities. Thus, TRACES sees innovation as a result of two parallel, both indispensable sources: mission-oriented research which works towards a preconceived goal, and a large pool of general knowledge, originating mainly in the university and, in number of events, more important for innovation than mission-oriented research.

153. In all five innovations, the R and D events occurred according to similar and very revealing time patterns. Ninety percent of all non-mission research events were completed ten years before the innovation, but - and this is just as important - 10% occured later. Thus, some "undirected" and unplanned events, which were indispensable for the final innovation, appeared in the years immediately before it. In other words, without continuous non-mission research, most of which was being carried out at the university, and without the general pool of knowledge which it created, the five innovations would not have been possible. TRACES distributed the key R and D events according to major scientific disciplines. Several disciplines contributed to each of the five innovations: cross-fertilisation between these different disciplines was one of the main preconditions of technological success. It appeared, finally, that some areas of scientific specialisation contributed more R and D events to the five innovations than others.

154. All, or almost all, of the fundamental scientific knowledge integrated into those five innovations was available to anyone, irrespective of its place of origin - in this case, mainly the U.S.A. Why, then, was almost all relevant development work leading to the five innovations being

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

this is the case, leadership in science-based technologies, far from being an industrial problem only, may be less and less possible without strength in fundamental science.

157. Certainly, the intensity of the links between science and technology vary considerably amongst academic disciplines and industrial sectors. A recent report on university/industry relations in the United Kingdom found that it is the high technology industries which also have the highest proportion of qualified scientists and engineers in senior management, have most contacts with the universities, and make most use of university consultants (154). The same report found that university departments' contacts with industry tend to be higher in pharmacology, chemistry and physics than in biological sciences, biochemistry and mathematics. And Marquis and Allen have found, through an analysis of citations in the technical literature, a greater dependence on science in nuclear engineering, electronics, and metallurgical engineering, by comparison with mechanical engineering (147). Where the links between university science and industrial technology are strong, the mere imitation of already known, but sophisticated, technologies has become so difficult that it requires scientists of no less calibre than those who were necessary to invent the technologies the first time. In such sectors, the possibilities of developing new technologies without fundamental science cannot be very great either.

158. Scientific knowledge gets transferred into industry through a number of channels: essentially, personal contacts, teaching and publications. "TRACES" presented statistical data which shed some light on the length of the transfer process. All five investigated innovations reveal a time cycle of about 30 years between most non-mission research events and their technological application. The number of non-mission research events per decade reached a maximum between the twentieth and thirtieth year before the innovation, after having been quite high in the preceding decade - that is, between the thirtieth and fortieth year. "TRACES" explains this regularity as an aspect of the "educational cycle" which lasts 20-30 years, and suggests that "most inventors rely heavily on information created in the previous generation". In other words, industrial innovation is, or was, to a considerable degree based on university research performed one generation earlier, the results being transmitted to the second generation through the traditional channels of university education and scientific publication. The length of this time lag lends itself to different interpretations. In some cases, the time for the immediate utilisation of new non-mission research discoveries was not ripe, because there was no market need for the products which could develop from those R and D events. In other cases, the new R and D events were useful only in combination with other scientific discoveries which were not yet known. According to a study

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

even from the United States. Despite considerable attention from management, scientists and engineers remain one of the most disgruntled group on industry's payroll." (124) And in the United Kingdom only between 10% and 15% of all science Ph.D's go into industry (higher in chemistry and agriculture, lower in biology and biochemistry), and only 32% to 35% of all technology Ph.D's (higher in chemical engineering) (125). Neither sets of proportions are tending to increase, although the percentage of first degree university graduates who join industry is higher than the percentage of Ph.D's, and is increasing.

163. This is a matter of concern to the United Kingdom authorities, who consider the reluctant attitude of scientists towards industry as an obstacle to the development of technological innovation. In the present state of our knowledge, it is not possible to say whether the flow of good scientists and engineers into United Kingdom industry is high or low compared to that in other countries. Contrary to what is sometimes believed, nothing proves that the proportion of U.S. scientists joining industry is much higher. Unfortunately, no U.S. flow data on this subject are available, but some stock data are quite suggestive: the NSF has estimated that, in 1968, about 60% of all Ph.D's in science and engineering were employed by universities, 25% by industry and 13% by government (155). Nevertheless, some experts believe, on the basis of personal experience, that good scientists find their way to industry more easily in some OECD countries - for example, in the United States or in Germany - than in others. This is a popular explanation of some aspects of the United States' performance in industrial technology. But there is no solid statistical basis to support this view.

164. How important is the consulting of university scientists by industry in different OECD countries? Here again, there is much opinion, but only few data are available. For example, well informed people say that in Germany few important university scientists or technologists are without some industrial contact. In the United States, outside consulting by university teachers has been accepted as a public service, sometimes even as a function of universities. In 1963, 54 American universities - including all leading institutions - answered a questionnaire regarding their policy towards faculty consulting (126). It appeared that faculty consulting increased during the years before 1963. All 54 universities permit their faculty members outside consulting. Twenty-one out of 54 universities permit their members the use of university space for outside consulting, 18 universities permit the use of university equipment, 28 accept leave of absence, and 20 universities permit the utilisation of graduate students for consulting purposes.

165. However, industrial consulting by university staff is also widely practised in the United Kingdom. Eighty-two percent of firms responding to a recent survey employed university consultants, over half of whom

were of professional rank. Of the 62%, 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:

establish links between university and industry. ... The major difficulty in the way of closer collaboration is lack of mutual understanding and appreciation, and this was seen not only as a criticism of the opposite side, but as something in which personal failure had to be acknowledged. ... Essentially the main bar to improving collaboration is lack of time on both sides which can be devoted to all the various worthwhile activities which will improve mutual understanding, and most of which have a pay-off in the long term ..." (154).

Industry must be more than a passive receiver of university knowledge. It must and can create an efficient and complex network of influences stretching out into the university. These influences, which will not be discussed, are in some respect the "counter flows" to the knowledge transfer process described above.

A.3. Industry's Influence on University Research and Training

169. Until recently, most OECD work on fundamental research has concentrated on the internal workings of the fundamental research system and the consequences of this system on other parts of society. Little is known about the ways through which external, especially economic, factors have influenced this fundamental research system. However, the facts which are known suffice for a coherent working hypothesis. To outline this, one should take up again briefly the argument pursued through the preceding sections. First, statistical analysis suggests that national scientific and national technological capabilities are correlated. Second, the investigation of five important industrial innovations (TRACES) suggests that this correlation has most probably resulted from direct links between university science and industrial technology. The present chapter suggests that in a framework of international or national economic competition, it is the demand of industrial technology which tends to influence strongly the production, structure and flows of university knowledge. This includes fundamental science, which does not necessarily contradict the results of TRACES, according to which 76% of all R and D events in five innovations were due to "non-mission research". In fact, there is no "objective" border between fundamental and applied science or between mission and non-mission research. The differentiation makes sense only with regard to the motives and immediate tasks of the individual scientist or the research groups involved, and these motives and tasks can be indifferent to the overall direction and tendencies of university science in a given country. Moreover, the motives of those who organise and finance research can be very different - for example, much more "practical" - than the motives of the scientists who perform it, perhaps without any application in mind. The authors of TRACES were aware of this difference. They

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.

173. It is difficult to find a better explanation for the relative excellence of German science than the needs of industrial technology, although this is probably not the only explanation. * If technological needs were so much higher in Germany, it was because Germany felt heavily the pressure of international economic competition. Similar arguments would be valid for Switzerland and Holland, which are scientifically and technologically relatively strong countries, and which have competed for a long time in international markets.

174. What are the ways in which industrial demands on the university system are articulated? The dearth of relevant statistics is again quite acute. Only the United Kingdom has so far done a detailed survey (154). Perhaps this is not entirely fortuitous. Industry and university in some countries treat this problem discreetly, due maybe to the reverence in which university independence is still held. Hence, the following remarks do not claim to be a comprehensive picture of industrial influence on university systems in the OECD area. They are, at best, pieces of a puzzle the greater part of which has still to be assembled.

175. There are many direct and indirect methods of influencing the universities for the benefit of industrial technology. A full integration of national industry and university systems might at first sight seem the most effective way of putting fundamental science into industrial service. Although this will not happen on a large scale, isolated cases of close integration of industry and university do exist. Some big American firms are known to finance some of the smaller, less famous universities which probably formulate their research and teaching programmes in accordance with the needs of their sponsors.

176. However, this is no real answer to industry's needs, since these "sponsored" universities do not appear to attract many first class scientists. This is one conclusion that can be drawn from a recent study on ten important civil innovations in the electrical, electronics and chemical fields, and which have been developed in General Electric's laboratories in the United States (128). The key personnel who carried out the R and D leading to those ten innovations were 57 scientists and engineers of all ages and disciplines. Four of them came from abroad; of the remaining 53, only five graduated from the university which seems to have special links to General Electric. Evidently, technologically leading firms cannot rely on a strategy of full control of one university; they must

* Germany during that period profited from a considerable "braindrain". It was the "catchment area" of many of the most brilliant Central and East European scientists, which might somewhat reduce the value of the population comparison with France, the United Kingdom and the U.S.A.

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.

179. There are, in addition, more subtle and indirect ways by which industry influences university research programmes. Through consulting with industry, university staff may be influenced in their choice of research topics: in the U.K. survey already mentioned, industry estimated that 17% of university consultants were influenced "significantly" in this respect, and 44% "marginally" (154). In addition, when industrialists join universities on a full-time or part-time basis, their research interests and preoccupation are bound to reflect to some extent at least their previous industrial experience: the same U.K. survey found that 45% of university staff had had at least one year of post-graduate experience,* and such university/industry links are also said to be very close in the Netherlands. The pattern of university research is also influenced by the use of industrial lecturers in the universities (especially at post-graduate level), and by students doing their Ph.D's in collaboration with industry. It would be useful to have data on the intensity of such links for a number of countries in addition to the United Kingdom.

180. Furthermore, in some countries, people who are in industry or who are at least well aware of industrial needs, play an important role in the conduct of the universities. For example, the 2,100 universities and colleges of the United States are governed by boards of trustees who are often chosen for their fund-raising or managerial capacities. Therefore, an estimate that businessmen constitute 70% to 80% of the 30,000 trustees of the United States comes as no surprise (131). This is not to say that American trustees run their universities for business interests. But since American trustees are well informed of industrial research and manpower needs and of employment possibilities for graduates, it can reasonably be suggested that industrial viewpoints do have some influence on the formulation of university policies, although this influence should not be overestimated.

181. Apart from these direct ways of influencing the university system, there are methods which are less direct, but not necessarily less efficient. Since governments are by far the biggest financial source of all national university systems, government support which takes industrial interests into account represents the most important "indirect" influence which industry can hope to exert on the university system. Thus in some countries, Switzerland for example, the competent political authorities see to it that industry is represented on the university governing boards or on the consulting bodies which deliberate on university policy, whilst at the same time respecting the essential freedom of university research and teaching.

* Less than 25% in bio-sciences; between 25 and 35% in chemistry, geology, mathematics, pharmacology and physics; nearly all in engineering.

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;

attains standards of academic excellence but which also looks towards application. With all their limitations, available R and D statistics give some interesting clues as to the nature of this interface.

186. Table 10 shows that, in the industrially advanced countries, fundamental research performed by industry accounts for more than a quarter of all fundamental research in all countries with strong innovative performance and, for more than 4% of industrial R and D, most of this fundamental research is concentrated in the chemical and electrical industries. The apparently small figure of 4% of industrial R and D should not blind one to the fact that this involves considerable sums of money for some countries. In the U. S. A. for example, industrial fundamental research expenditures approach $ 600 million, which is too high a sum to be spent for prestige reasons alone. And the quality of industrial fundamental research appears to be high: the results of TRACES show that industry was responsible for 14% of non-mission oriented events (i. e. fundamental research events). Indeed, such high standards appear to be the price of the entrance ticket to the academic science club.

187. Table 10 also shows that university applied research in advanced Member countries accounts for between 16 and 46% of all university research. These figures must be interpreted with caution, since they are very sensitive to the place of performance and the definition given to medical research, and to certain "fringe" institutions. Nonetheless, it is tempting to relate the relatively low levels of applied university research in France and the United Kingdom to often-voiced criticisms that the academic community does not take sufficient interest in industrial problems.

188. But it may be mistaken to put too much emphasis on the importance of applied research in the universities. Table 11 shows that the ratio of industrial fundamental research to university applied research tends to be higher in countries with higher levels of technological development - a tendency confirmed in Table 12 which shows that the same ratio has been increasing over time in the U. S. A. This suggests that the key component in the industry/university interface is the recognition by industry of the potential contribution of fundamental science to industrial innovation, rather than the performance of "applied" research in the universities.

B. 2. Person-to-Person Contacts

189. The existence of the interface between university and industry does not, in itself, explain the strong regional links between scientific

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.

mental research results are available to anyone who can use them, irrespective of where they were discovered. Why, then, this close regional relationship? The fundamental reason would appear to be that knowledge gets transferred, and needs defined, through person-to-person contacts, which tend to take place within rather than across national boundaries.

190. Hindsight reveals the critical importance of informal person-to-person communication (18). Table 13 illustrates that personal contacts, although important in all R and D activities investigated by Hindsight, were higher in technology than in science. However, even of the scientific "events" in the 20 weapon systems, 45% became known to the responsible scientists through personal contacts with other scientists. In applied science and development, informal personal contacts were the dominant way of knowledge transfer. One could reply to this that it was mainly the secrecy surrounding all weapon developments which explains why the R and D structure in this case was based upon oral communications. Therefore, it is important to note that other studies confirmed the results of Hindsight for civil innovations (48).

Table 13. METHOD OF KNOWLEDGE TRANSFER OF R AND D EVENTS LEADING TO THE 20 WEAPONS SYSTEMS

Percentages

MODE OF TRANSFER / CATEGORY	PERSONAL CONTACT	PUBLICATION OR REPORT	SEMINAR OR SYMPOSIUM	TOTAL
Science	45	53	2	100
Technology				
a) New Materials, Concepts, Functions	64	33	3	100
b) Design Technique	79	21	0	100
c) Manufacturing Techniques	77	23	0	100

SOURCE: See Reference 18.

191. Table 11 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:

SCIENTISTS AND TECHNOLOGISTS ACCORDING TO THREE STUDIES ON CIVIL INNOVATIONS IN THE USA

METHOD OF KNOWLEDGE TRANSFER	NUMBER OF EVENTS ACCORDING TO		
	(1) SUITS/ BUECHE	(2) FREY/ GOLDMAN	(3) TANENBAUM
1. Indirect (No direct dialogue between originators and users of new scientific knowledge)	8	5	25
2. Passive Availability (Scientists take no initiative to stimulate dialogues, but are open to approach by technologists seeking their advice)	28	17	43
3. Direct Participation (Two-way partnership between scientists and technologists in joint workshop groups or interdisciplinary project teams)	38	18	40
4. "Gatekeeper" Approach (Coupling by direct action through "Gatekeepers": a few gifted, very competent scientists interested in practical application of science)	14	2	6

SOURCE: See Reference 48.

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 TRAINING OF Ph. D's IN UNITED STATES UNIVERSITIES

There are in the United States approximately:
2, 100 universities and colleges. Of these,

100 perform more than 93% of all university R and D
21 perform more than 54% of all university R and D
10 perform more than 38% of all university R and D

(Figures for 1964)

100 receive 88. 7% of all federal R and D funds and train 90. 7%
50 receive 69. 9% of all federal R and D funds and train 69. 2%
20 receive 45. 4% of all federal R and D funds and train 42. 8%
10 receive 29. 6% of all federal R and D funds and train 25. 3%

of all Ph. D's

(Figures for R and D funds refer to 1966,
PH. D. figures to 1964-1965)

SOURCE: Financement et exécution de la recherche fondamentale dans les pays Membres de l'OCDE, Document DAS/SPR/69.19, 14 avril 1969; Reference 18.

basis of "guild"-forming institutions, namely the universities. Regional links between science and technology are likely to exist as long as these are the main characteristics of the information transfer process.

197. This is not to say that all scientific and technological information flows are nationally based. On the contrary, there are diverse and very well developed mechanisms for international knowledge flows amongst scientists and amongst technologists. However, knowledge flows between scientists and technologists seem to be funnelled mainly on a national basis. The one institution tending to break this national framework is the multinational firm which established R and D laboratories, or scientific links, in a number of countries.

198. Second, the backbone of U. S. university-industry relations appears to be excellence - or, better, the organisation of excellence in about twenty leading universities. The university professors who carry out the relevant research and graduate training in those twenty universities,

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

transfer across the science/technology interface certainly has a cost. In particular, the assimilation of the results of foreign science requires an indigenous fundamental research capability, and the transfer of knowledge between fundamental science and technological application requires active efforts by both industry and the universities.

201. Thus, national capabilities in technological innovation must be matched by equivalent capabilities in university research, which:

- may lead to scientific discoveries which eventually become important inputs into technological innovation;
- create an awareness and a capacity for assimilation of scientific discoveries made elsewhere in the world;
- transmit knowledge to industry through the teaching process and a variety of others;
- enrich the quality of applied research, and help in the solution of problems raised by applied research;
- provide skills and resources for the performance of applied research and development.

At the same time, national capabilities in technological innovation influence the pattern and strength of fundamental research through the demands it induces for more knowledge and skills from the universities.

C.2. Coupling Fundamental Research to Industrial Innovation

202. Of course, governments finance fundamental research for purposes other than the promotion of technological innovation. Yet, insofar as this is one of the reasons for supporting fundamental research, it must be recognised that national fundamental research capabilities and national innovative capabilities form part of the same national system, so that policies related to them cannot be entirely divorced, the one from the other. This is a fine sounding concept, but what does it mean in practice? Here, we can only raise some questions, rather than give comprehensive answers.

203. Given that fundamental research does have an impact on technological innovation, one immediate reaction - especially in times of budgetary constraint and of fashions in "advanced" management techniques - might be to attempt to calculate the economic return from past national fundamental research efforts as a guide to future levels of funding. However, as a recent British publication shows, a formidable amount of data collection would need to be done before one could calculate returns

on past efforts (155). 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

and the universities when - as in the defence and space fields - government itself has been the main agent in the definition of technological targets and has distributed considerable funds to universities and industry to achieve them. Although this same method may be applicable in other areas of direct government responsibility (e.g. education, health, public transportation), it is not necessarily relevant in the many sectors where technological targets are set by a myriad of industrial firms within the framework of international economic competition.

208. In such sectors, the most important policy measures taken by governments to heighten the requirement for close university/industry relations have been those related to increasing the pressures of industrial competition and, thereby, the pressures on industrial firms to utilise more effectively knowledge and skills emerging from the universities; it is no accident that concern about university/industry relations has followed international, economic liberalisation. In cases where this requirement is not being met in a satisfactory manner, government can have an important role to play as a catalyst or "impresario" in creating the framework within which regular contacts take place between university and industry. As we have seen, person-to-person contacts are the essence of effective collaboration. This, government can encourage through a number of mechanisms, ranging from the financing of "concerted actions" - in other words, research programmes which university and industry undertake jointly, to the establishment of institutions or mechanisms through which scientists and engineers from the universities and industry can meet - and have an incentive to meet - continually and informally. The effectiveness of this latter method should not perhaps be understimated. Studies undertaken in the U.S.A. suggest that, within firms, and even within the same building, patterns of personal communication depend very much on such mundane factors as geographical proximity, and that special efforts must be made to create the required communication patterns.

C.3. Centres of Excellence and Specialisation

209. It should be noted that, if the U.S. experience is any guide, university/industry relations would be more accurately described as relations between industry and a relatively few centres of academic excellence. The same may be true for other Member countries, but insufficient empirical evidence is available to verify it. If this has been true in the past, it does not necessarily have to be true in future. But the established fact must certainly be borne in mind when considering future policies concerning "mass" higher education.

210. Furthermore, it is worth speculating on one of the factors which will influence the emergence of centres of academic excellence in future.

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 role 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

together with strength in technological innovation: strength in fundamental research coupled with a capability in industrial R and D, orientation towards competition in world markets, and flexible structures and methods that ensure that multiple channels are kept open for the creation, transfer and application of technology. These characteristics indicate at least some of the objectives to aim for. The nub of the policy problem is how to attain them, given that they are all part of an interrelated system. This report cannot pretend to solve this problem. Nor can it suggest a neat, packaged policy for innovation that would be relevant and applicable to all Member countries; differences in resources, objectives and environments amongst countries make this impossible. It can only try to identify and discuss some of the relevant policy areas - often asking questions rather than answering them.

A. 3. The Need for Information

213. However, in all Member countries, the effectiveness of any government policy for technological innovation will depend in large part on government's knowledge of the strengths and weaknesses of the nation's innovative efforts. This in turn will depend on the degree of personal and formal contacts between government and the scientific and technological communities, as well as on the quality of statistical information available on the nation's scientific, technological and innovative efforts. Science policy makers clearly have an important role to play in fulfilling both of these requirements. In many Member countries, industrial scientists and engineers participate in advisory bodies concerned with science policy. And administrators responsible for science policy have played an important role, not only in the collection of R and D statistics, but also in collecting data relevant to national innovative performance. *

B. THE LEVEL AND DEPLOYMENT OF R AND D RESOURCES

214. Although - as has been stressed throughout this report - technological innovation is more than R and D, and although the role of R and D in innovation has sometimes been overemphasised in the past, it is

* Performance in world markets in product areas with rapid rates of technological change, monetary receipts and payments for technology, patent statistics, coupled with more detailed analysis in specific sectors: see, for example, references 2, 52, 87, 88, 89.

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

Table 16. EXPENDITURES ON INDUSTRIAL R AND D AT A PERCENTAGE OF NET INDUSTRIAL OUTPUT IN 13 MEMBER COUNTRIES

COUNTRY	R AND D PERFORMED IN INDUSTRY AS A PERCENTAGE OF NET INDUSTRIAL OUTPUT				R AND D FINANCED IN INDUSTRY AS A PERCENTAGE OF NET INDUSTRIAL OUTPUT			
Austria	0.4	(1963)	0.8	(1966)	0.4	(1963)	0.8	(1966)
Belgium	1.5	(")	n.a.		1.5	(")	n.a.	
Canada	1.3	(")	1.6	(1967)	1.1	(")	1.3	(1967)
France	2.0	(")	3.1	(")	1.3	(")	1.8	(")
Germany	1.9	(1964)	2.5	(")	1.6	(1964)	2.1	(")
Italy	0.9	(1963)	1.0	(")	0.9	(1963)	1.0	(")
Japan	2.9	(")	2.7	(1967/8)	2.9	(")	2.7	(1967/8)
Netherlands	2.4	(1964)	3.2	(1967)	2.3	(1964)	3.2	(1967)
Norway	1.0	(1963)	1.4	(")	0.8	(1963)	1.1	(")
Sweden	2.4	(1964)	2.4	(")	1.8	(1964)	1.9	(")
Switzerland	n.a.		2.8	(")	n.a.		2.9	(")
United Kingdom	3.2	(1964/5)	3.3	(1966/7)	2.0	(1964/5)	2.1	(1966/7)
U.S.A.	7.0	(1963)	6.0	(1966)	3.3	(1963)	2.8	(1966)

SOURCE: International Statistical Year, OECD, Paris.

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

Table 17. TRENDS IN THE SECTORS OF PERFORMANCE OF R AND D IN TWELVE COUNTRIES

	1959				1960				1961				1962			
	BE	GOV	ED	O	BE	GOV	ED	O	BE	GOV	ED	O	BE	GOV	ED	O
Austria																
Belgium																
Canada	35	50	13	2					34	53	13	-				
France																
Germany																
Italy																
Japan	64	13	19	4	68	16	17	2	67	15	17	2	64	16	19	2
Netherlands																
Norway																
Sweden																
United Kingdom									64	27	5	4				
U. S. A.	77	13	8	2	77	13	9	1	75	13	9	3	73	13	10	4

	1963				1964				1965				1966			
	BE	GOV	ED	O	BE	GOV	ED	O	BE	GOV	ED	O	BE	GOV	ED	O
Austria	63	9	26	2									65	10	25	-
Belgium	72	11	16	1					70	10	18	2				
Canada	40	44	16	-	43	39	18	-	42	35	22	1	40	33	24	3
France	50	36	13	1	49	37	13	1	53	33	13	1	54	34	12	-
Germany					66	3	20	11								
Italy	62	8	30	-					59	10	30	1				
Japan	64	14	20	2	64	15	20	2	59	15	24	2	61	13	23	2
Netherlands					56	3	20	21								
Norway	51	21	25	3												
Sweden					67	15	18	-								
United Kingdom					66	25	7	2					69	22	7	2
U. S. A.	73	13	11	3	70	15	12	3	70	15	12	3	69	15	13	3

NOTE: BE = Business Enterprise
GOV = Government
ED = Institutes of Higher Education
O = Other

SOURCE: International Statistical Year for R and D, OECD, Paris.

Table 18. RATES OF CHANGE OF FINANCING AND PERFORMING R AND D IN TWELVE COUNTRIES

SECTOR / COUNTRY AND PERIOD		PERCENTAGE ANNUAL RATE OF CHANGE (CURRENT PRICES)				
		SOURCE OF FUNDS		SECTOR OF PERFORMANCE		TOTAL EXPENDITURE ON NATIONAL R AND D
		GOVERNMENT	INDUSTRY	GOVERNMENT	INDUSTRY	
Austria	1963-66			21	21	21
Belgium	1963-65			13	11	13
Canada	1959-65	11-12	15	6-8	18	14
France	1963-66	20	20	16	23	19
Germany	1964-67	16	15	26	14	14
Italy	1963-65	14	5	23	5	10
Japan	1959-66	21	17	18	17	19
Norway	1963-67	20	17	10	16	17
United Kingdom	1961/2-1966/7	3	7	2	8	6
U. S. A.	1960-66	8	8	11	7	8

SOURCE: International Statistical Year for R and D, OECD, Paris.

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

and established R and D programmes did not benefit from the scheme, nor did small or growing firms which were not in a profit-making position: in 1963, only 44% of firms performing R and D were able to claim benefits (93, 94).

224. The lesson to be drawn from these government measures to promote R and D in industry is somewhat obvious: namely, they promote technological innovation when R and D is the bottleneck in the innovative process, otherwise they do not. This may be the case in certain countries, industries or projects at certain times. But it is relevant to note that a recent report to the U. S. Government considered and rejected measures to give more favourable tax treatment to all industrial R and D. (2) Similarly, a report to the French Government recommended that government loans given to industry to promote innovation should not be restricted to the R and D part of the process (89).

225. And a report to the U.K. Government raised some broader questions concerning the balance of national resources in R and D by comparison with resources in other parts of the innovative process (87). It pointed out that scientists and engineers engaged in R and D have alternative uses in later stages of the innovative process (i. e. production and marketing), and in the process of diffusion of innovation; and that it is important to ensure a balanced deployment of scientists and engineers throughout this process. Table 19 gives a rough indication of the pattern of use of scientists and engineers in R and D and in other functions in eight Member countries in the 1960's. It shows that the United Kingdom has a higher proportion of scientists and engineers employed in R and D than other European countries, and that the U. S. A. has the highest level of scientists and engineers in R and D, and probably in other parts of the process of innovation and diffusion.

C. NATIONAL SPECIALISATION IN SCIENCE AND TECHNOLOGY

C. 1. The Imperative

226. Discussions over a number of years have shown member governments' continuing concern with priorities and choice in national scientific and technological activities. Reasons advanced for this concern have included the limited human and financial resources available for scientific and technological activities by comparison with the opportunities for advance that science and technology offers, and the increasing scale requirements for effective scientific and technological activities. But there is one other very important reason. A more open and liberalised world, together with growing R and D activities in a wider number of

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.

countries, and changing patterns in the relative sizes of Member countries' R and D efforts, have meant greater opportunities for all countries to absorb and benefit from the results of foreign R and D, and - for many countries - the need to concentrate resources in sectors if they are to achieve international levels of excellence.

227. National choices and priorities in science and technology therefore imply some degree of specialisation within the worldwide framework of scientific and technological development. It should be borne in mind, however, that specialisation in science and technology is of a particularly dynamic and changing nature. It is possible over time to create scientific, technological and entrepreneurial capabilities. And in sectors of rapid growth and rapid technological change, where new market opportunities are continually opening up, there are ample opportunities for specialising within such sectors.

228. One argument sometimes offered against specialisation relates to the interdependence of scientific fields, and the multidisciplinarity and uncertainty associated with technological advance. Given these characteristics, it is argued, national specialisation may lead to a loss of inputs necessary for technological advance. But against this it can be argued that an increasingly open and liberalised world means that knowledge and skills can be transferred and bought across national boundaries more easily. Furthermore, there is some empirical evidence which shows that successful innovations have already in the past relied heavily on inputs of foreign knowledge. In a study of the history of successful innovations in the United Kingdom, J. Langrish identified 158 important ideas used in 51 innovations. Of these ideas, approximately one-third were generated within the firms making the innovations, one-third came from outside the firm but within the United Kingdom, and one-third originated in foreign countries (86). Thus, even in a Member country with a relatively large R and D effort, successful innovations have in the past relied to a considerable extent on imported knowledge.

229. Of course, the absorption and use of foreign knowledge does not happen automatically. It requires not only an indigenous scientific and technological capability, but also some sort of system of "technological intelligence" in the main science - and technology - producing areas of the world. These requirements must ultimately be met by industrial firms themselves. But government can have some influence in the longer term through acting in such areas as the teaching of foreign languages, the opportunities afforded for research, study and travel in foreign countries, and - more generally - through stressing that science and technology is a worldwide rather than a national phenomenon.

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, access to raw materials, 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.

Table 20. PERCENTAGE OF NATIONAL, INDUSTRIAL R AND D UNDERTAKEN IN SELECTED INDUSTRIAL SECTORS IN TWELVE COUNTRIES

INDUSTRIAL BRANCH / COUNTRY AND YEAR	AUSTRIA 1963	BELGIUM 1963	CANADA 1963	FRANCE 1964	GERMANY 1964	ITALY 1963	JAPAN 1963	NORWAY 1963	SWEDEN 1964	SWITZERLAND 1965*	UNITED KINGDOM 1964	U.S.A. 1964
Paper	0.1	1.0	6.8	0.1	n.a.	n.a.	1.1	7.3	4.3	n.a.	0.3	0.6
Petroleum	0.1	0.9	5.8	4.2	32.0	2.3	0.9	0.5	0.1	n.a.	2.0	2.5
Chemicals and Drugs	18.8	40.0	16.1	13.6		23.1	25.3	15.7	9.3	61.2	11.2	9.6
Stone, Clay and Glass	1.7	5.0	1.0	1.7	0.9	0.6	2.1	1.9	1.2	n.a.	1.7	1.0
Ferrous Metals	14.4	8.7	1.7	1.8	n.a.	3.8	5.7	9.6	5.4	n.a.	2.2	0.9
Non-Ferrous Metals	2.7	5.6	5.0	3.0	n.a.	1.3	2.5		1.1	n.a.	0.9	0.6
Non-Electrical Machinery and Metal Products	5.1	7.3	6.3	n.a.	18.1	7.1	5.7	13.2	19.1	31.0	7.7	8.8
Electrical and Instruments	n.a.	17.0	24.6	26.0	28.2	25.3	26.0	16.2	23.0		21.9	23.3
Aircraft and Missiles	n.a.	1.4	15.7	22.5	n.a.		n.a.	n.a.	18.6	n.a.	28.4	38.2
Motor Vehicles and Parts	12.1	-		5.4	n.a.	18.6	6.9	n.a.	6.1	n.a.	6.0	n.a.
Shipbuilding	0.4	0.4	n.a.	n.a.	n.a.		3.2	n.a.	0.7	n.a.	0.6	n.a.

* Expenditures include R and D undertaken by Swiss-based firms in countries other than Switzerland.

| | = Industries in which the country devotes a relatively high proportion of its R and D resources by comparison with the same industry in other countries.

‾‾ = Industries in which the country devotes a relatively high proportion of its R and D resources by comparison with other industries in the same country.

☐ = Industries in which the country devotes a relatively high proportion of its R and D resources by comparison with other industries and other countries.

SOURCE: International Statistical Year for R and D, OECD, Paris.

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

that such efforts would be an important stimulus to national performance in technological innovation.

236. Thus, the (technological) grass tends to appear greener on the other side of the (national) fence. This may be right, or it may be wrong, depending on the circumstances in specific countries. To some extent at least, it is understandable. Individuals, working parties and officials are, in general, more aware of shortcomings in their own countries than in others, and it is easier to recommend efforts in areas where technological and market successes have been established than in areas where they have not. But although it may be understandable, it may not always be wise, since successful technological specialisation often consists in doing what others are not doing. And perhaps broad recommendations about whole sectors of industry or technology are not a sufficient basis for policy, given the ample opportunities which - as we have seen - exist within various sectors.

237. Some would go so far as to argue that implicit or explicit international comparisons may have led to a strong concentration of scientific and technological activities in the same and often spectacular fields, perhaps to the neglect of possibilities of marrying advanced technology to more "traditional" activities. Recent experience in coupling modern technology to shipbuilding, in using aeronautical experience in the development of high speed ground transportation systems, and in applying modern electronics to health care, show how fruitful such activities can be. Present advances in materials, informatics and control systems offer important possibilities for technological advance in traditional fields. No doubt it is often too early to judge the potential scope of such activities. But they deserve consideration by government, given its role as an important customer in these areas and as the main creator of a favourable climate for technological innovation.

238. Broadly speaking, two policy approaches can be taken by government to the problem of specialisation. One is the policy of reinforcing successful patterns. The other is the policy of creating options for new patterns developed on the basis of scientific, technological and market trends and opportunities. The former approach has the advantage of strengthening technological and entrepreneurial capabilities in the institutional framework where they are most needed, namely in industry, but the disadvantage that they do not necessarily take into account either long term technological or market developments or "externalities" associated with technological innovation. The latter approach can take into account precisely these factors, but has the disadvantage that it may not be sufficiently close to the realities and uncertainties of technological and market development, and that it does not necessarily create a technological and entrepreneurial capability in industry.

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

defence and the provision of complex equipment for the performance of fundamental research. But they have also been undertaken in relation to primarily economic objectives.

D. 1. Arguments For and Against

242. Proponents of such programmes argue that, by mobilising big resources around specific objectives, they give an important impetus to improvements and changes in scientific and technological levels in a wide number of sectors, that they help bring radically new technologies more rapidly down cost and learning curves to the point where they become commercially competitive with existing technologies, that they help break down barriers between institutions and between disciplines, and that they create exciting research opportunities for scientists and engineers. As examples, they point to the development of radar, atomic energy, satellite communications and solid state electronics.

243. Whilst these may be the effects of large-scale programmes, many would disagree with the implication that large scale programmes of any kind are necessary for a strong national performance in technological innovation. It is widely recognised that programmes related to non-economic objectives divert resources from potential projects of similar scope directed to civilian ends (89). And in some countries it has been suggested that even those large programmes oriented towards economic objectives may be a misallocation of resources, and that the support of a number of smaller and less spectacular projects is likely to lead to a greater economic return (87). Finally, some economists have questioned the principle of large-scale government involvement in the financing of civilian technological developments, arguing that - although the costs of innovation may have increased in absolute terms and by comparison with the size of countries - they have not increased by comparison with the size of firms, and that government involvement can lead to the development of "pure technology" beyond either the capabilities of the industrial structure or the requirements of the market (152).

D. 2. Some Empirical Evidence

244. The fact remains that data in Annex A to this report suggest no significant relation between the degree of government involvement in R and D, and total, national performance in technological innovation, nor between the degree of government involvement and the quality of fundamental research. More specifically, the Netherlands and Switzerland - and to some extent Germany and Sweden - have had strong fundamental science and industrial technology without heavy involvement in large-scale, government-financed programmes.

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".

and market uncertainties have been reduced; and an absorptive strategy the definition of a programme for the effective assimilation and exploitation of knowledge developed elsewhere.

248. All these questions are complex, and their answers full of uncertainties. As in industrial firms, data collection, analysis and forecasting are essential inputs to effective decision making. But, as in industrial firms, the right policy will not result simply by pushing the data through a computer. Given the lack of quantifiable information on many important parameters, and the unforeseeable nature of many future developments, flexibility will always be required, as will the judgment and intuition of individuals in what are often and inevitably "entrepreneurial" decisions.

E. EDUCATION

249. The close links required between educational policy and policies for technological innovation - and science policy in general - have been described often enough, so that they do not need to be set out in detail here. In the past, one aspect of educational policy - namely, the training of ever more scientists and engineers - has received particular attention by science policy makers. This is understandable given that, as we have seen in Table 19, the supply of qualified scientists and engineers ultimately conditions the amount of R and D that a country can usefully undertake and exploit.

E. 1. Some Qualitative Problems

250. However, it is possible that the quantitative supply problem will be resolved in many Member countries in the 1970's. Educational policy problems related to technological innovation are likely to become qualitative rather than quantitative. One qualitative policy problem - namely, how to link university research and training more effectively to the innovative needs of society - has already been discussed in the conclusions of Part III of this report. Another policy problem may grow out of the fact that an increasing supply of scientists and engineers may eventually mean that relatively fewer of them will go into R and D, or that they will go into R and D for a shorter period. What sort of training is appropriate for scientists and engineers not going into R and D? What sort of retraining is appropriate for those moving on from R and D to other functions? Finally, the increasing scope of scientific and technological advance - growing out of greater R and D efforts in the Member countries and the economic requirements for growth and competition - raises the problem of retraining scientists and engineers throughout their working lives.

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.

Table 21. NATIONAL INNOVATIVE PERFORMANCE AND THE EDUCATIONAL CHARACTERISTICS OF CHIEF EXECUTIVES OF INDUSTRIAL FIRMS

COUNTRY	RANKING ACCORDING TO NATIONAL PERFORMANCE IN TECHNOLOGICAL INNOVATION	RANKINGS ACCORDING TO EDUCATIONAL CHARACTERISTICS OF CHIEF EXECUTIVES OF INDUSTRIAL FIRMS			
		PERCENTAGE WITH UNIVERSITY EDUCATION	OF THOSE WITH UNIVERSITY EDUCATION		
			PERCENTAGE IN SCIENCE AND ENGINEERING	PERCENTAGE IN BUSINESS AND ECONOMICS	PERCENTAGE IN LAW AND SOCIAL SCIENCES
	I	II	III	IV	V
Belgium	6	2	1	6	2
France	4	1	2	3	6
Germany	1	3	3	4	3
Italy	5	3	6	2	4
Netherlands	3	5	4	5	1
United Kingdom	1	6	5	1	5

SOURCE: Column I : See Annex A.
Columns II-V: D. Hall, H. de Bettignies and G. Amado-Fischgrund: The European Business Elite, in European Business, October 1969.

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.

order to create a climate favourable to technological innovation. Some of the areas of government policy that influence this climate will now be discussed.

F.1. Competition

258. The importance for technological innovation of competition can be simply stated. Innovation involves often unquantifiable risk and often uncomfortable change. Without competition and the potential threat that a competitor will innovate first, firms and other institutions may well prefer to avoid the risk and the discomfort of innovating. The validity of this hypothesis is demonstrated in one of the conclusions of a survey of ten successful innovations in the General Electric Company:

"Competition of the market place is a prime factor motivating the sponsor in all American industrial research. Each one of the ten cases discussed in this report had its basic roots in the fundamental objective of the sponsoring company to achieve profitably growth and maintain profitable business leadership ...

"Therefore, in the cases such as the tunnel diode, the vacuum circuit breaker, and the Lucalux lamp the motivation to innovate ... resulted not from an actual announcement by a competitor but rather from a continual apprehension that the competitor is surely seeking better products, too. The examples of actual research programmes triggered by a competitor's announcement are surprisingly rare in the company's history (examples of "catch-up" development activities are somewhat less uncommon). None of the cases herein were initiated by a competitor's surprise announcement: rather, they all stemmed from a general - but extremely powerful - belief that only by innovating as fast as possible can long term business leadership and growth be maintened." (128)

259. Thus government policy towards competition has a considerable influence on the conditions for successful technological innovation. In practice, however, there may sometimes be conflict between government policies to maintain competition, and industrial firms' policies with regard to innovation. A recent report to the U.S. Government listed the areas where this might occur, and particularly stressed restrictive agreements amongst firms involving the use or non-use of technological property (2). However, the report was unable to offer any general guidance to policy determination in such cases. Instead, it recommended the collection and analysis of empirical data, as a guide to government policies towards innovation and competition.

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

an "equitable" and assured rotation of orders to a number of suppliers, and of creating a monopoly supplier (89).

263. It is also important that government departments, with a view to increasing the productivity or quality of their operations, be able to assess their future needs and - on the basis of the technological state of the art - to specify performance requirements which suppliers must try to meet. Past experience suggests that this has been done more successfully for defence and energy requirements than for areas such as public works, public transportation and construction. A number of possible reasons can be advanced to explain this state of affairs: differences in the level of resources allocated to various policy objectives, in the level of technical competence in government and amongst users, in the pressure of strategic or economic competition, in the degree of fragmentation of responsibilities, or in the degree of accuracy with which future needs can at present be assessed. A more effective coupling of technology to a wider range of government requirements may require a closer examination of these factors.

264. Furthermore, recent experience in urban and high speed ground transportation, and in education, suggests that, given the lack of clear definition in many areas of public responsibility of the real needs to which technology could respond, and given the lack of incentive to take the inevitable risks associated with trying new technologies, government may have an important role to play in supporting "experimental" or "demonstration" projects so that - through a process of trial and error - public needs can be more clearly identified, technological solutions developed and proved, and individuals and institutions convinced of the contribution that new technology can make to the meeting of public needs (136, 137).

F. 5. Mobility and Person-to-Person Contacts

265. The mobility of scientists and engineers and personal contacts amongst them appears to be the most important mechanism for the transfer of technological knowledge. The degree to which scientists and engineers move amongst institutions and talk to one another is, of course, influenced by deep-seated historical and social factors, as well as by more mundane matters such as the availability of housing and other amenities, the transferability of pension rights, and rules regarding secrecy. Yet science policy makers in government can have an important influence on the mobility of scientists and engineers in universities and, more particularly, in government laboratories. Given the requirement for mobility, should a research worker be encouraged, contractually or otherwise, to see his life's career as staying in research

in the 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

made towards integration over the past 25 years has been one of the main stimuli to technological innovation in the OECD area; it has led to greater R and D and innovative efforts in industry, to closer links between the universities and industry, to greater governmental concern with national innovative efforts, and to a greater international spread within the OECD area of the benefits from new technology.

269. Part II, Section D of this report suggests that integration has, on the whole, successfully enabled industrial firms with the requisite technological and managerial capabilities to respond to demands for innovation across national frontiers. However, the overcoming of barriers between nations has had its price, the reduction of tariffs, of barriers to international mobility and right of establishment, and the greater harmonisation of patent and company law, codes, regulations and standards are all likely to increase both the incentives for, and rewards from, technological innovation. Part II, Section D also suggests that the largest barriers are those to the entry of foreign government markets. The effect of these barriers on innovative performance depends on the size and technological sophistication of the national government markets: the greater the size of this market, the greater the opportunities for maintaining competition, for benefiting from scale, and for keeping open multiple options in conditions of uncertainty.

270. Although Part II, Section D of this report suggests that the size of government markets does not have a determining influence on total national innovative performance, its effects on sectors related, for example, to aircraft; energy and communications can be considerable. And it is relevant to speculate as to what will be the effects of certain present practices when scientific and technological efforts in such areas as marine exploitation, educational technology, new transportation methods and health management - where governments will be important customers - reach the stage of large-scale, worldwide, commercial exploitation.

F. 8. Mitigating the Harmful Effects of Technological Change

271. Technological innovation and its diffusion cannot be made entirely free from risk and uncomfortable change. But, as the public debate over the past two years has shown, it is important that the risks and changes be socially acceptable. The task of government is essentially to ensure that this is done. Member governments already accept that they have a responsibility for dealing with changes in skill requirements and in regional and industrial patterns of employment, brought about by technological change. More recently, member governments have become more actively concerned with the latter's harmful effects on physical amenity.

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.

policy measures designed to stimulate innovation through action on the deficient parts of the innovative process. But we do not live in an ideal world. Our knowledge of the innovative process, and of the influence of government policy measures upon it, is still insufficient. This is why Annex B lists some problem areas where further empirically based research is required, both for better understanding of technological innovation and as a sounder basis for policy. There is a particular lack of such knowledge in Member countries other than the U.S.A.

276. However, one generalisation can perhaps be made. Many aspects of national scientific and technological systems change only slowly. This may appear paradoxical, given the general talk of rapid change in the modern world, and the rapid rate of increase in national resources devoted to R and D in the 1960's. But it takes a long time to change national patterns of performance of R and D, to train research workers, to build up effective R and D teams, to translate scientific discoveries into innovations, to establish effective feedback between industrial technology and university science, and to change attitudes. These characteristics mean that policies for technological innovation may often involve problems which are not stark and obvious - thereby provoking an immediate response - but problems which, if not recognised and dealt with in good time, can lead to irremediable situations. They also mean that policy measures must often be applied for a long time before their effects are felt, and results achieved. Thus, policies for technological innovation must be both farsighted and persistent.

277. The available information also shows that the main agents for the creation and application of scientific and technological knowledge are the universities and industry. This reflects the basic political philosophy of OECD membership, but also the requirements for successful technological innoation. Uncertainty, change, the need for competition, flexible structures, rapid decision making, and being close to technological and market developments, all imply that technological innovation is more likely to flourish in a decentralised and pluralistic environment. Thus, government's role in the innovative process, although important, is not determinant. Furthermore, given the increasing openness and scientific, technological and economic interdependence amongst OECD membership, the pace and direction of individual nations' science and technology - as well as governments' policies for science and innovation - must increasingly reflect and take into account developments beyond national boundaries.

278. When developing policies for technological innovation, some member governments - either explicitly or implicitly - have taken as their model the innovative system of the U.S.A. This has been understandable and perhaps even inevitable, given the success, the size and

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)

In other words, the imperatives of technology and its economics may eventually lead to changes in political concepts.

281. Finally, it is worth raising a number of questions related to other aspects of science policy with which the OECD Committee for Science Policy is concerned. First, the example of industry shows that successful innovation requires not only scientific and technological capabilities, but also competition, mobility, flexibility in organisation and evaluation, entrepreneurship, and the existence of a market which reflects needs. What implications - if any - does this have for the present concern of many member governments to make science and technology contribute more effectively to society's social needs?

282. Second, we have seen that, as long as economic growth and international competitiveness continue to be important national policy objectives, the economic pressures for technological innovation and diffusion will continue to be strong. We have also seen that the act of innovation often implies considerable risk. At the same time, governments are increasingly concerned with controlling the harmful side-effects of technological change. What types of regulatory or control mechanisms can do this without stifling the characteristics essential for technological innovation and long term economic growth? What technological solutions will enable the attainment of both the quantitative and the qualitative objectives of economic growth?

283. Third, is the process of scientific discovery, technological innovation and diffusion sufficiently well understood, or is it working sufficiently well, for governments to assume that science and technology will automatically assure the basis for economic growth in future?

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.

Table A. 1. SIX INDICATORS OF TEN INDUSTRIALLY ADVANCED COUNTRIES' PERFORMANCE IN TECHNOLOGICAL INNOVATION

INDICATORS / COUNTRY		I. LOCATION OF 110 SIGNIFICANT INNOVATIONS SINCE WORLD WAR TWO			II. MONETARY RECEIPTS FOR PATENTS, LICENCES AND KNOW-HOW, 1963-64			III. 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		
	NUMBER OF PERSONS EMPLOYED IN MANUFACTURING INDUSTRIES ('000)	ABSOLUTE No.	WITH USA BASE INDEX 100	INDEX RANKED	IN m.	WITH USA BASE INDEX 100	INDEX RANKED				% SHARE OF 10 COUNTRIES' MANUF. EXPORTS	ABSOLUTE No. IN '000	WITH USA BASE INDEX 100	INDEX RANKED	% SHARE OF 10 COUNTRIES' EXPORTS IN R.I. IND.	WITH USA BASE INDEX 100	INDEX RANKED	% SHARE OF 10 COUNTRIES' EXPORTS IN R.I. IND.	WITH USA BASE INDEX 100	INDEX RANKED
	X	A	A/X	B	A	A/X	B				Y	A	A/Y	B	A	A/Y	B	A	A/Y	B
Belgium	1,645	1	20.6	5	7.9	34.2	5				5.8	1.8	12.4	10	3.5	45.4	10	3.0	37.6	10
Canada	2,428	0	0	10	6.2	18.3	8				5.5	1.9	13.9	9	3.4	46.3	9	2.9	38.3	9
France	7,940	2	8.5	8	46.3	41.9	4				9.8	9.3	38.1	6	7.7	59.0	7	6.5	48.2	8
Germany	12,385	14	38.3	4	49.4	28.7	7				18.1	29.9	64.7	2	22.1	92.0	2	21.1	84.7	2
Italy	7,776	3	13.2	7	9.9	9.1	9				7.5	4.6	24.6	7	5.9	59.1	6	5.7	55.2	6
Japan	17,129	4	7.9	9	5.9	2.4	10				8.1	3.5	17.4	8	5.3	49.2	8	5.9	52.9	7
Netherlands	1,847	1	18.3	6	26.0	101.2	1				5.9	6.4	43.6	5	5.3	67.3	4	5.9	72.7	5
Sweden	1,535	4	88.4	2	7.1	33.3	6				3.5	3.8	43.7	4	2.8	60.0	5	4.0	83.1	3
U.K.	11,798	18	51.8	3	76.1	46.4	3				13.2	15.2	45.2	3	14.2	80.7	3	13.9	76.5	4
USA	25,063	74	100.0	1	386.7	100.0	2				22.6	56.3	100.0	1	30.1	100.0	1	31.1	100.0	1

NOTE: - For indicators I and II, Column B was derived after dividing Column A by working population in manufacturing (Column X) to correct for country size; the figures were then transformed into an index, with USA as the base 100 in each case, and ranked (Columns B).
- For indicators IV, V and VI, Columns B were derived after dividing Column A by percentage share of the ten countries' manufacturing exports (Column Y); the figures were again put in the form of an index with USA = 100, and ranked (Columns B).
- Data for indicator III can be found in "Gaps in Technology: Analytical Report - Comparisons Between Member Countries", Book III, Table 11.

SOURCES: Column A from Book III of "Gaps in Technology: Analytical Report".
Column X from OECD Observer Supplement for 1967 Statistics.
Column Y from Book III of "Gaps in Technology: Analytical Report".

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	COLUMN 2
	SUM OF SIX COLUMN B INDICATOR RANKS	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. NATIONAL PERFORMANCE AND OTHER NATIONAL PARAMETERS IN TECHNOLOGICAL INNOVATION FOR 10 COUNTRIES: RANKINGS AND RANK CORRELATIONS

INDICATORS \ COUNTRIES	BELGIUM	CANADA	FRANCE	GERMANY	ITALY	JAPAN	NETHER-LANDS	SWEDEN	U.K.	USA	SWITZ-ERLAND	CORRELATION COEFFICIENT R=	SIGNIFICANT AT 1% ** 5% *
A. Composite Ranked Index	8	9	6	2.5	7	10	4	5	2.5	1	-	-	-
B. Composite Ranked Index + Switzerland	9	10	7	3.5	8	11	5	6	3.5	1	2	-	-
C. Size of Market GNP	8	7	4	2	6	5	8	8	3	1	11	0.18	n.s.
D. R and D Financed by Business	6	8	7	5	10	9	4	2	3	1		0.79	1%**
E. Total per capita Expenditure on R and D	8	7	4	6	10	9	4	3	2	1	-	0.77	1%**
F. Expenditure on R and D Performed by Business	7	8	6	4	10	9	5	3	2	1	-	0.87	1%**
G. Government Financed R and D Expenditure	8	5	3	7	10	8	6	4	2	1	-	0.59	n.s.
H. Number of Firms with Sales of $m500+	10	7	6	4	8.5	8.5	5	3	2	1	-	0.87	1%**
I. Number of Firms with Sales of $m250+	8	4	5.5	5.5	10	9	7	3	2	1	-	0.65	5%*
J. Total QSE in R and D	8.5	6.5	6.5	8.5	10	3	5	2	4	1	-	0.29	n.s.
K. Total QSE in R and D in Industry	7	7	5	7	10	4	6	2	3	1	-	0.45	n.s.
L. Total QSE and Technicians in Business	7	9	8	5	10	6	3	4	2	1	-	0.75	5%*
M. Income per capita	7	3	4.5	4.5	9	10	8	2	6	1	-	0.45	n.s.
N. Nobel Prizes in Chemistry, Physics, Medicine and Physiology, 1943-67	10.5	10.5	6.5	5	8	9	6.5	4	3	2	1	0.92	1%**
O. Scientific Abstracts	11	6	5	7.5	10	9	1	7.5	3	2	4	0.67	5%*
P. Graduates as a Percentage of Total Labour Force	9	4	5.5	3	7	2	8	10	5.5	1	-	0.12	n.s.
Q. Graduates of Pure Science as a Percentage of Total Labour Force	7	4	6	5	3	10	8.5	8.5	2	1	-	0.49	n.s.
R. Graduates (Engineers and Technicians) as a Percentage of Labour Force	8	3	5.5	1	9	4	10	7	5.5	2	-	0.28	n.s.
S. Graduates (Scientists, Engineers and Technicians) as % of Labour Force	10	4.5	8	2	6.5	6.5	3	9	4.5	1	-	0.61	n.s.
T. Composite Index minus Germany	7	8	5	-	6	9	3	4	2	1	-	-	-
U. Average Number of Years' Schooling of Labour Force	6	2	4.5	-	9	8	7	4.5	3	1	-	0.46	n.s.

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.

However, the following limitations to these results must always be kept in mind.

First, the total sample (i. e. ten) is too small, and the levels of correlation highly sensitive to slight changes in the rankings. The statistical meaning of the results should not, therefore, be over-interpreted. Nonetheless, they do help in interpreting the experience of a number of Member countries.

Second, high correlations do not demonstrate causality. They simply show that, on the basis of the information available, certain national characteristics exist at the same time as strong national innovative performance.

Third, it is not possible to obtain data on all the national characteristics advanced as being associated with strong innovative performance. For example, no data exist which compare the ten countries' mobility of research workers, the quality of education and of management, or the propensity to take risks.

Fourth, not all the data are available for precisely the same time period. However, the nature of the characteristics measured is such that they do not fluctuate widely over time. With the exception of Japan, it is unlikely that the rankings have altered significantly over the past ten years. Thus the lack of a common time period is unlikely to invalidate the results.

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

Academy of Sciences has recommended the encouragement of studies of the history and sociology of science and technology, in order to further understanding of the principles behind the great variety of successful patterns of applied research and its application (52). Furthermore, in making policy recommendations concerning technological innovation to the U. S. Department of Commerce, a recent report noted that the U. S. "... spends tens of billions of dollars every year on innovation ... Yet we know very little about the processes of technological change and growth ... Until adequate data and better insights are developed, we will have to continue to rely on inappropriate information, educated guesses and, unwittingly at times, on lore. It is inexcusable that decisions, both in and out of government, as to the probable impact of proposed policy changes on technological innovation, have to be made on the basis of such information." (2).

Finally, the relevance of further studies to science policy makers has been made very clear by the Chairman of the Committee on Science and Public Policy of the U. S. National Academy of Sciences:

"Many of the current demands for better scientific planning are probably as naive as the early demands for economic planning. We are like an untrained person suddenly set down in the cockpit of a jet aircraft, with hundreds of dials and levers in front of us, and little clue as to what lever to pull to steer the machine, though knowing if we push one too strongly the giant aircraft, which tends to fly by itself on an even keel, may go out of control, or respond in the exact opposite way from which we intended. As in the case of economic planning we have to develop a much more sophisticated understanding of how the existing system works before we can control it. Just as economics could not really be applied successfully to policy until it learned to distinguish between 'ought' and 'is', so must science policy rid itself of a certain reformist and missionary spirit before it can become a tool to successfully influence national and international actions." (144)

III. THE NEED FOR STUDIES IN A WIDER NUMBER OF COUNTRIES

Countries other than the USA can and do benefit from the results of studies on technological innovation undertaken in the USA. But they would also benefit greatly from indigenous studies which would enable more intimate contacts amongst those undertaking studies, practitioners in industry, the universities and government, and those in teaching and which would also take account of environmental conditions which may be very different from those existing in the USA. That empirical studies on technological innovation should be undertaken in all countries able 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 Current Projects on the Economic and Social Implications of Science and Technology. 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.

The numbers in brackets refer to the relevant paragraphs in the text of the report.

A. Historical Perspective

1. Science, Technological Innovation and Industrial Competition: historical developments in various industrial sectors (20); historical developments in various countries (95, 278).

B. The General Characteristics of Technological Innovation

2. The Diffusion of Technology: the factors affecting rates, levels and the effective use of new technology (5, 7).

3. Technology Transfer Between Industries: mechanisms of transfer and factors influencing their effectiveness (24, 26-32).

4. The Economic and Skill Characteristics of Research Intensive Industries (25).

5. Sources of Information and Initial Stimuli for R and D Programmes and Innovative Ventures: technological opportunity versus production or market need (28); information internal and external to the firm (97, 228, 257).

6. R and D Expenditure Patterns by Size of Firm: the reasons why (35-37, 50-51).

7. Contribution of Large and Small Firms to Technological Innovation: by country and by industry characteristics (38-59).

8. The Formation of New Science-Based Firms: regional and national differences, and the reasons why (60-73, 267).

9. The Mobility of Scientists and Engineers: the role of different types of mobility in the innovation process; the collection of data on mobility rates (88, 89).

10. The Time Scales in Technological Innovation: initial discovery, invention, innovation and diffusion - existing patterns and factors underlying them.

11. Thresholds for Successful Innovation: levels, trends and factors affecting them (74-82).

C. The Management of Research and Innovation

12. The Cost Structure of Technological Innovation: R and D costs by comparison with other costs (17); size distribution (74-82).

esses; 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).

22. Coupling Fundamental Research to Technological Innovation: evaluation and forecasting versus plurastic, person-to-person contacts (202-208).

23. Future Educational Requirements for Successful Innovation: qualified scientists and engineers (250); the managers of innovation (251-252).

24. The Deployment of National R and D Resources in Relation to Technological Innovation: industrial R and D (215-216, 222-226); R and D in government laboratories (220-221, 265-266); factors affecting the speed and effectiveness of the redeployment of national R and D resources (217, 219, 276).

25. Patterns of National Scientific and Technological Specialisation: factors affecting patterns; the influence of government; criteria for choice and action (226-240).

26. Effects on Technological Innovation of Large Scale Programmes: at the firm, industry, national and international levels (241-246); factors entering into decisions (247-248).

27. Coupling Science and Technology to Social Needs: factors affecting successful coupling; areas for government action (237, 261-264, 281).

28. The Climate for Technological Innovation: competition, taxation; regulations, codes and standards: government procurement (258-264).

29. Mobility and Person-to-Person Contacts: areas for government action (265-266).

30. Government Policy Towards the Formation of New, Science-Based Firms (60-73, 267).

31. International Technological Co-operation: past experience and future directions (279-280).

32. Nature and Effects of Barriers to International Market Penetration of New Technology (94, 268-270).

Annex C

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