SPECIAL STUDY No. 8

Science, Technology and Innovation

by Andrew H. Wilson

prepared for the

Economic Council of Canada

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PREFACE

The background reading and research work for this study were done, as time permitted, over a period of about three years. The earlier versions of the study were longer and somewhat broader in scope. The text of this final version was completed in January 1968.

The material which this paper contains has been selected to precede and to supplement other research work which is currently being undertaken by members of the Council's staff and which will be published in due course.

The author wishes to express his thanks for the many useful comments which he has received during the course of his work. In particular, he wishes to thank a former member of the Council's staff, Mr. James F. O'Sullivan, for the time he spent in reading and appraising the earlier versions of the study and to thank Mrs. Doris DesJardins for her valuable secretarial assistance.

REFERENCES, FOOTNOTES AND APPENDICES

The numbered references given in the text of this paper may be found in the list of sources shown in Appendix I.

The references with asterisks given on certain pages in the text refer to footnotes which appear at the bottom of these same pages.

Appendix II contains a list of books, papers and articles related to the subjects discussed in this paper. It is not a complete bibliography of these subjects but, together with the Appendix I sources, provides useful additional background and discussion material.

Appendix III outlines the General Incentive and Special Assistance programmes established by the Canadian government since 1959 to encourage research and development activities in Canadian industry.

INTRODUCTION

This position paper or prospectus has three principal aims. The first is to present a short historical review of the growth of science and technology and their related activities. The second is to discuss some aspects of the innovation process. The third is to look ahead and to identify factors related to science, technology and innovation which will be important in the future development of Canada and the Canadian economy.

With regard to the principal aims of this paper, some remarks from a speech made by Dr. J. J. Deutsch when he was Chairman of the Economic Council of Canada are particularly apposite:

> "Canada's economic hopes and aspirations have never been easy to achieve. Indeed, one of the primary reasons for the establishment of the nation nearly 100 years ago was to provide the means for forging a co-ordinated economic development on a continental scale.
>
> "Today new problems are emerging and new forces are at work. We are in the midst of a great scientific, technological and educational revolution which holds the promise of exciting new accomplishments and improvements in our standards of life. But at the same time, there is an urgent need to adjust to the implications which rising levels of skills and growing specialization and inter-dependence have for our economic life, both at home and in our trade with other countries. The changes of the second half of the twentieth century are both creating and destroying occupations and industries with rising speed and great unevenness.

> These are bringing significant new possibilities for progress in some industries and in some areas and declining opportunities for others.
>
> "More than ever before, we must be prepared to look ahead, to try to anticipate developments which are likely to take place, and to arrange our affairs so that we shall be able to take advantage of the opportunities which the future will offer."

The material presented in this paper is germane to the background work of the Economic Council of Canada and of the more recently established Science Council of Canada. A significant portion of this material, however, originated abroad. In the last few years the volume of published literature on the history, economics and sociology of science, technology and their related activities has grown steadily, but little of it was developed in Canada. A secondary aim of this paper, therefore, is to provide a basis upon which more detailed analytical work in these fields can be carried out in this country.

This paper has been designed for the general reader rather than for the specialist in economics or in scientific and technical affairs. The first three parts of the paper provide background information and discussion material relating particularly to science and technology. The fourth part is devoted to a discussion of the innovation process, and the final section of the paper looks to the future.

A wide range of factors will influence the degree to which Canadians will participate in the production of scientific and technical knowledge and in the application of new and existing knowledge in these and other fields in the years to come. Some of these factors will be geographical, some will be economic or social, and some political. Others will include the quality of the available manpower, the challenges and opportunities which are presented, the effectiveness with which individuals can communicate with one another, and the attitudes of the public, of governments and of businesses towards providing an environment in which scientific, technical and innovative activities can flourish and be effective.

This study does not provide detailed recipes or prescriptions for achieving accommodations between sets of social or economic goals and the corresponding levels of scientific, technical and innovative activity. This would be an impossible task. The interactions between science, technology and innovation are too complex for there to be any simple formulas for goal attainment. Instead, this paper discusses a number of ways in which the effectiveness of the various activities might be increased in Canada. These discussions are predicated on the acceptance of two broad premises. The first is that the social and economic growth and development of Canada, and the prosperity and well-being of Canadians generally, will become increasingly dependent upon rising levels of scientific and technical competence and entrepreneurial ability. The second is that Canadian institutions and individuals will become increasingly skilled in the management and administration of their scientific, technical and innovative activities and in the conception and prosecution of forward-looking and anticipatory studies in these fields. In the last analysis, however, future growth and well-being will be related to the degrees of encouragement and support given to the most talented and creative Canadians.

PART I

DEFINITIONS AND CONCEPTS

Any attempt to pin down the meanings of words like "science", "research", and "innovation" in a sentence or two must be made at the risk of oversimplification. But in the interests of understanding and consistency throughout this paper, something has to be said about each of them right at the beginning.

It is also necessary at this stage to mention the main limitations to the discussions which follow. This paper is concerned with the physical and the life sciences and their related technologies; that is, with disciplines such as physics, chemistry and biology and the various branches of engineering that are associated with these disciplines. This paper is also concerned with the relationship of the innovation process to scientific and technical activities. By imposing these limits, it is not intended to ignore or downgrade the "R & D approach" or the process of innovation in, for example, business management or marketing activities. It is obvious that the R & D attitude of mind and the desire to broaden the scope of innovations should be, by now, part and parcel of the way in which all the economic sectors conduct their business. The enemies of broader scope in this paper are space and time.

Science, Technology and Their Related Activities

Science and technology are bodies or inventories of knowledge and experience, but inventories which are accumulated in order that they may be applied, in time, to useful purposes.

Science, on the one hand, embraces the entire stock of our current knowledge of the physical and living elements in the world around us -- our knowledge of Nature. Technology, on the other hand, contains our current knowledge and experience about how to use scientific knowledge for practical purposes and about the way in which other things may be made to "work" even although the scientific basis of their performance is not fully understood. In other words, technology is "know-how" while science is "know-why".

Scientific knowledge tends to be accumulated on a systematic basis in response to new ideas and concepts and to curiosity about natural phenomena. The growth and development of technology, on the other hand, is probably less systematic and is more responsive to needs, problems and opportunities than to curiosity or even to novel ideas.

In addition to providing a deeper understanding of Nature, science also embraces a "method" or attitude through which this particular kind of knowledge is discovered. The sequence of steps used in this "method" may be described in the following way:

- the formulation of a new idea or concept about some aspect of Nature;
- the collection and analysis of existing information related to the idea or concept;
- the construction of a working hypothesis;
- the testing of this hypothesis by experiment;
- the acceptance or rejection of the hypothesis after testing.

If the hypothesis is rejected, the scientist must start again at the beginning with a reformulation of the idea or concept. If the hypothesis is accepted, it becomes part of science until it is, in turn, refuted or modified.

Modern scientific method is not a success-guaranteed procedure but it does enable the work of the theoretical scientist to complement the work of his experimental colleague. While it helps to produce order from disorder, it cannot wholly replace inspiration or chance or trial-and-error in the process of discovery. Nor can it be applied as easily to the history-based disciplines of science like archaeology or palaeontology in which the scope for experimentation is quite limited. The early Greek philosophers considered that their conclusions represented the ultimate truth about Nature. Modern scientists make no such claim.

Technology is principally concerned with things that "work". Although scientific method can be employed in the process of building up technical knowledge and experience, it is not always possible or necessary to follow through each and every step of the method. On the one hand, adequate background data may not exist and, on the other, the practical end is usually achieved without expenditure of the resources required to make the necessary additional discoveries. And for the generation of new technology, trial-and-error methods may frequently produce the required results more quickly and at less cost than a thorough and systematic investigation.

Until quite recently, the study of Nature and the development of tools and techniques have tended to advance independently of one another but, in the last two or three decades, their interdependence has been more fully recognized and exploited. New "hardware" has made possible significant new scientific discoveries, and vice versa. But the relationship between science and technology does not end with a new piece of hardware or with the confirmation of a new theory. The relationship between them as bodies of knowledge has been expressed in the following way:1/

> "... science and technology are so inextricably interwoven that one has often led to the other. In the case of the steam engine the technology came first and the science afterwards. Carnot developed the physical science of thermodynamics after the investigations of the implications of the steam engine. In the case of atomic energy, the science of quantum mechanics came first and the technology second. Planck's work and that of many other theorists and laboratory experimentalists came before the atomic bomb and the plant at Shippingport, Pennsylvania. But in both cases, whichever came first, there is a technology and there is a science."

The accumulation of scientific and technical knowledge and experience requires the exercise of imagination, creativity and ingenuity on the part of individual people and groups of people. The activities which add most to this knowledge and experience are, of course, research and development.*

It has become common practice to distinguish between "basic" or "fundamental" research and "applied"

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* From this point on, the word "research" means "scientific research". There are various other types of research, not all of which are scientific -- space research, operations research, market research, and so on. These will be spelled out when used.

research. While both types of research are aimed at achieving a fuller understanding of the physical and living elements in Nature, it is clear that the main differences between them are differences in motivation and environment. Basic research is done with no practical application in mind and in an environment free from the pressure to produce one. In the case of applied research, the opposite is true. Both basic and applied research add to the existing inventory of science. But what is considered to be "basic" work at one period in time may be classified as "applied" later on, and vice versa.

Applied research most frequently leads to the growth and development of technology. Indeed, in many instances of continuous laboratory activity, it is not always possible or important to determine when the applied research actually stopped and the development work began. Development work is principally concerned with using existing science and technology to generate the new technology associated with the production and use of goods and with the provision of services. In most countries, development is considered to include experimental and investigative work done on pilot plants, scale models and prototypes, but to exclude the more routine technical activities of production such as quality control and the testing of materials.*

Within an economic sector, a government department, or a particular company, research and development activities may be identified in a variety of ways. For example, the general term "industrial research" is

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* In any one country, several definitions of research and development activities may be used, each for a different purpose. In the case of a government-sponsored industrial R & D assistance programme, for example, the definition used will be designed to take into account the breadth, or otherwise, of the aims of the programme.

frequently used to differentiate between the R & D work done in industry and done elsewhere and to underscore industry's preoccupation with applied research and development. At the operating levels of an organization, terms such as "mission-oriented research", "advanced product research", "new process development" and "advanced engineering development" may be used to identify those parts of the R & D spectrum which best describe the organization's goals and the responsibilities of its various divisions or units.

The generating of new knowledge through experiment and investigation are the properties which serve to distinguish research and development from the other activities which are related to science and technology. The majority of these other activities are users of technical "know-how" in the production and use of goods and in the provision of services, although some -- like systems engineering, work study, engineering design and plant maintenance -- may also make important contributions to new technology. Also, in contrast with a decade or two ago when technology could be equated with the "hardware" of products and processes, there is now a growing body of technological "software" through which production and other processes can be systematically organized.* In this context, the methods whereby science and technology are disseminated or diffused from one activity to another and from one place to another become important. In the case of science, the availability of information is often relatively free from constraints. It becomes a question of knowing about, and consulting, the appropriate "open" literature or the appropriate expert. But for technology, the need to avoid the disclosure of commercially valuable information and the lack of incentives or opportunities to publish new

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* For example, PERT -- the Programme Evaluation and Review Technique.

material may reduce the amount of information transferred at any one time. Much new technology also goes unreported because there is a less well-developed tradition of publication, because its significance in fields other than its field of origin is not recognized, or because it may still be considered as "art" which is difficult to describe in technical terms.

Dr. Harvey Brooks, who is Dean of Engineering and Applied Physics at Harvard University, has described the technology transfer process in the following way:2/

> "Technology transfer is the process by which science and technology are diffused throughout human activity. Wherever systematic rational knowledge developed by one group or institution is embodied in a way of doing things by other institutions or groups, we have technology transfer. This can be either transfer from more basic scientific knowledge into technology, or adaptation of an existing technology to a new use. Technology transfer differs from ordinary scientific information transfer in the fact that to be really transferred it must be embodied in an actual operation of some kind.
>
> "I have . . . hinted at two different kinds of technology transfer, which might be called vertical and horizontal. Vertical transfer refers to the transfer of technology along the line from the more general to the more specific. In particular it includes the process by which new scientific knowledge is incorporated into technology, and by which a 'state of the art' becomes embodied in a system, and by which the confluence of

> several different, and apparently unrelated technologies, leads to new technology.
>
> "Horizontal transfer occurs through the adaptation of a technology from one application to another, possibly wholly unrelated to the first, e. g., adaptation of a military aircraft to civilian air transport . . . . "

Some technological transfers may combine both vertical and horizontal components. And most transfers -- whether vertical, horizontal, or both -- may be considered as having a connection with a third component or dimension that represents the interaction of technology with nontechnical factors such as social goals, economic goals, education policies, resource exploitation, etc.

There are also several important activities which do little or nothing by themselves to generate new science and technology or to use the available knowledge in these fields. Their purpose is to encourage individuals or institutions or economic sectors to perform these functions. Government-sponsored R & D assistance and incentive programmes are examples. So are technical information and translation services and university research grant programmes. Through teaching and instruction, students are given the opportunity to acquire a basic understanding of science and technology. And, through periodic retraining in particular areas of new science or new technology, experienced scientists, engineers and technicians upgrade their capacities to contribute to their current day-to-day activities.

Lastly, there are a number of activities, such as production management, sales engineering, market research, corporate planning and manpower forecasting, to which the methods and content of science and technology are being increasingly applied. Consequently, many of the performers of these activities need to have background training and continuing interest in certain areas of science and technology. But whether a particular activity is on the fringe or is actually part of the broad range of scientific and technical activities, it is -- in the last analysis -- just one of a kit of tools which can be used to provide whatever services science and technology are called upon to help perform.

Scientists, Engineers, Technologists and Technicians

Until the end of the nineteenth century the scientist who did research was the exception rather than the rule. If he did research at all, he would do it in a university or private laboratory, usually in an unhurried fashion, and with little or no technical help. He would maintain close contact with colleagues elsewhere who had similar interests. He would publish his results from time to time and belong to scientific societies at whose meetings his own work and the work of others would be discussed. The merit and importance of his work would be judged by his senior colleagues or by colleagues of equal eminence. The greater part of his time might be spent in teaching. The majority of the members of his university graduating class would not be doing research. The monetary rewards for his contribution to teaching and to research would not be large.

In a great many ways the situation of the research scientist today is quite different. There is now "team" research and multiple authorship, there are scientists who do nothing but research, and there are pressures to publish results. The whole field of scientific enquiry has broadened but the degree of specialization by individuals in the various subdisciplines or branches of knowledge has often narrowed considerably. Laboratories have been set up on an interdisciplinary basis to bring together different kinds of specialists for work on problems of common interest, such as the properties of materials, molecular biology, or specific diseases. The spectrum of employment functions of the members of each class graduating in a scientific discipline has broadened to include engineering, development, management, and other functions outside of teaching and research. The monetary rewards in all of these functions are higher. But the research scientist still prefers to do the work which interests him most or which excites his curiosity. And he still prefers that his colleagues judge the merit and importance of what he has done.

The term "applied scientist" is relatively new and its use has increased along with the degree of technical sophistication of modern industrial products, processes and services and along with the emphasis which has come to be placed on science -- as opposed to empirical experience -- as the basis for engineering education. The applied scientist who does research usually serves two sets of masters -- his professional colleagues and his employers -- and the degree to which he is able to serve one group or the other or both depends upon the environment in which he happens to be working. His desire to do applied instead of basic research is probably brought about by an amalgam of a number of personal and motivational factors such as his own attitude towards specialization, the attitudes of his professors towards basic and applied research, and the job opportunities available to him at any one time during his career. A recent U. S. National Academy of Sciences report has this to say:3/

> "A good applied scientist should first of all be a good scientist by standards similar to those applied to basic scientists. However, a primary difference between basic and applied scientists lies in their respective attitudes towards disciplinary specialization and personal recognition by professional peers. Good applied science usually, though not always, requires greater breadth and a more

> eclectic attitude towards knowledge. A recurring shortcoming of university training in applied science and engineering arises from disciplinary over-specialization. The applied scientist must often be satisfied with just enough understanding for his immediate purposes and cannot pursue every interesting lead to its logical conclusion. He must be interested in more than strictly intellectual solutions."

Nowadays, in addition to research work, the applied scientist is to be found in development, in advanced design and production-oriented work, in management, and in consulting activities. His initial academic training may have been in one of the sciences or in one of the branches of engineering. In practice, the training courses of the applied scientist and the professional engineer are becoming more closely related than they once were.

One hundred years or so ago there were only two kinds of professional engineers -- military engineers and civil engineers. The Industrial Revolution in Europe brought about changes in the scope of engineering itself and the single nonmilitary classification became insufficient to cover the newer fields of specialization. Speaking about the early Canadian engineers at the 1967 Congress of Canadian Engineers, a distinguished British engineer, Lord Hinton of Bankside, had this to say:4/

> "Those engineers were, generally, men who had learned the art of engineering in the hard school of practice. They had less theory than is now taught to professional engineers but, in an industry that was then less sophisticated, they were able to dominate the great works that they undertook. Those times produced great engineers and it is a loss to engineering that fewer men now face the great physical and mental

> challenge that moulded these earlier engineers into greatness. But engineering has become complex and few engineers today are dominant, autocratic dictators of great projects; they are more often members of a team made up of people trained in many disciplines."

There are now a great many branches within the profession of engineering and the number is growing as technology itself grows and develops. But in some respects the engineer has hardly changed. Engineers have always performed a variety of functions directly or indirectly related to their profession. The engineer has been a "man of many parts". In contrast with the scientist, he has been more concerned with "know-how" than "know-why" and more concerned with finding practical solutions to everyday problems. But the professional engineer of today is faced with an increasingly complex world -- scientifically, technically, politically, socially, and internationally. He is having to learn to apply new areas of technology and new techniques successfully to current problem areas. And, at the same time, he is having to adapt his skills to attack entirely new problem areas in teams that include professionals from disciplines other than the physical and life sciences and engineering.

It is not possible to lay down hard and fast rules about the connotations of the terms "technologist" and "technician". Current usage involves a considerable area of overlap and local rules frequently determine whether a person in this area is called one or the other. At one end of the technologist-technician job scale is the university-trained graduate in applied science or engineering and at the other is a person with uncompleted high school education who performs a specialized job requiring a fair degree of manual skill. The job environment also affects the use of these classifications. In research laboratories, for example, it is often the practice to classify qualified tradesmen as technicians while in production plants they would be identified by the name of their trade.

Invention and Innovation

Scientific activities seek to discover, to demonstrate and to understand the laws of Nature. Technological activities, on the other hand, make use of scientific and technical knowledge and experience for a practical purpose. It is therefore technology, and not science, that has made possible the changes which have taken place in our environment.

The achievements of technology have been emerging more and more frequently from applied research and development laboratories, but they have also come from design and production engineering work, from interactions between sales, marketing and technical people, and from private workshops. The early versions of these achievements may be called inventions -- not in the limited sense of patentable inventions -- but in the sense that an idea related to a potential product, process or service has been explored and has been made and tried out in some initial form.

Few inventions are capable of being made for the market place or the processing plant in this initial form. In most cases, once the decision to exploit the invention has been taken, further development, evaluation and testing are required. At the same time, the capital, production, manpower and other resources have to be allocated and organized so that the product or service may be put on the market or the process may be used for quantity production at the most appropriate time. Once in use for an economic, military or other purpose, the new idea has completed the "process" of technological innovation. It is therefore innovation, and not invention, that has brought about the changes in our environment which have taken place from time to time.

Although the various stages in any one discovery-invention-innovation or invention-innovation sequence may be widely separated in time and in place, the process as a whole is likely to make use of the full range of scientific and technical activities in some way or other. While discovery and invention are principally the concern of scientists, engineers and technicians, innovation is principally the concern of entrepreneurs. Discovery and invention involve uncertainties. Innovation involves risks. An editorial in the British science journal, Nature, a year or so ago had this to say about the risks of innovation:[5]

> "The view that one should not do things for the first time has, of course, a great deal to commend it. Nothing ventured, nothing lost, is as good a proverb as the more familiar version taught to schoolchildren still innocent of disappointment. The difficulty is that caution, however prudent, is the enemy of innovation. A person, a company, or a nation wishing to do something for the first time must be prepared to take a gamble. Good management may limit some of the risks, while zeal, enterprise and hard work can improve the chances of success. Yet all technical innovation entails the possibility of failure and financial loss. Sometimes, ironically, technical success may not ensure financial success. Fortune is not always kind to innovators."

But whatever happens in the laboratory or in the market place, the invention has to come before the innovation can be made at all.

Science and Technology in the Service of Man

The problems of the allocation of human and material resources to the various scientific and technical activities, to the different disciplines of science and technology, and to specific projects have become increasingly complex. These are problems which both the public and private sectors of an economy are called upon to solve, and the work which has been done to examine the background facts and factors has so far shed only a little light on possible solutions. It therefore seems important to identify at this stage the "services" which science and technology can perform.

Historically, scholarship and education and the search for new knowledge for its own sake have been the principal catalysts in the growth of science and research. Technology, on the other hand, has responded to economic, military and social needs. In more recent years, political, foreign policy and military requirements have done a great deal to encourage research, development and advanced product design in certain countries and in certain industries.

In the list that follows, eight separate "services" have been identified:

- the discovery and demonstration of the laws of Nature;
- the advancement of scholarship and culture;
- the achievement of individual, national and international prestige;
- the advancement of education;
- the achievement of economic goals;

- the achievement of social goals;
- the solution of military technical problems;
- the achievement of domestic and foreign policy objectives.

This list has been put together in no particular order because, in practice, the eight services are interdependent. The achievement of economic goals, for example, will owe something to the ways in which the other seven services are, or are not, supported. Each of the services may be provided through the various scientific and technical activities and each may make use of the knowledge and experience available in the various disciplines of science and branches of engineering. However complex the problems, the allocation of resources to any activities at the national, company or department levels must begin with some basic format. It is suggested that this list might provide such a format in the case of scientific and technical activities.

PART II

A SHORT HISTORICAL REVIEW OF SCIENCE AND TECHNOLOGY

The following paragraphs appeared in the First Annual Review of the Economic Council of Canada.[6]

> "Inevitably, in a new country of vast area and small population it has been necessary to bring in from outside not only men and capital, but also the most up-to-date technology. Very often they have come together, especially in respect of capital and technical know-how, and have constituted a dynamic instrument for progress and the achievement of a comparatively high level of income. Moreover, by these processes Canada has become one of the advanced industrial nations of the world.
>
> "The readiness and the ability to use on a large scale the technology and skills developed in older and more advanced countries has been one of the special features of the Canadian economy as contrasted with many of the other new developing nations. However, Canada has increasingly come into the position where she can, in her own interests, make an important and a rapidly growing contribution to scientific and technical knowledge."

It is not enough to say that Canadians ought to contribute more to science and technology in the future. The methods by which this may be accomplished for the good of the economy or for education or any other valid purpose have to be spelled out. However, these methods will be dependent to a considerable extent upon the ways in which Canadian skills and Canadian institutions have already contributed to new knowledge and experience. The existing network of these institutions, for example, is extensive. It cannot be effectively dismantled and replaced overnight or even in a few short years. But it can be adapted, reorganized and built up in response to the needs and problems, the opportunities and ideas to which Canadians should be devoting a great deal of attention in the years ahead. In other words, to be able to say something about the future, it is necessary to take a closer look at the past.

In what follows, an attempt is made to trace the growth of science and technology in Canada and elsewhere, and briefly describe the development of a number of institutions associated with scientific and technical activities. These accounts are necessarily brief and, in most cases, descriptions of the related political and social circumstances have been omitted.

Some Notes on the History of Western Science and Technology

Man may have been using tools with some degree of skill for as long as half a million years. His first tools were pieces of stone and wood but later he came to use the spear, the axe, and bow and arrow and a variety of bone instruments. He used these tools and skills to satisfy the very basic needs of gathering food and protecting himself and his family from enemies.

The centuries between 4000 B. C. and the beginning of the Christian era saw a number of significant economic and social changes take place. Some men became farmers and stockbreeders and produced more food than they consumed. The resulting food surpluses made possible larger families and the establishment of villages and communities and, later, of cities and city states. Activities in the technical arts increased because men no longer required for agriculture and animal husbandry could now devote all their energies to them.

Early technical progress was slow. There is no way of knowing, for example, how often men had watched trees floating down a river before realizing that, if these trees were stripped of their branches and bark, cut into suitable lengths and hollowed out, they could be used for crossing navigable waters. But before these first boats could be made, chopping and cutting tools and the opportunity to make use of the boats had to exist.

Primitive "technology" developed on the foundations of need, opportunity, and the existence of techniques or tools which lent themselves, largely by trial and error, to adaptation or improvement. The initial steps in the accumulation of a body of "scientific" knowledge, on the other hand, were founded on Man's curiosity about the world around him and on his desire to know more about it. By the closing centuries of pre-Christian times, certain Greek philosophers were taking the view that Nature behaved according to a number of fixed laws, and had begun the intellectual exercise of discovering what these laws might be. This first, or Greek, period in the history of science extended from about 600 B. C. to A. D. 200 and was based first at Athens and later at Alexandria.

The "method" used by the Greek philosophers involved two basic assumptions: the first that Nature's secrets could be learned by applying deductive reasoning to a set of empirical observations, and the second that sound logic would adequately test the validity of any subsequent hypotheses. The Greeks used this method with considerable success and came to accept its conclusions as true laws of Nature. But after they had worked out all the implications of the premises, the forward progress of their work virtually stopped.

Most of the Greek philosophers apparently lacked an interest in experimentation. Consequently, they did relatively little to develop the tools and instruments which might have extended their studies. And, although much of their early work was written down, the men themselves tended to remain aloof from nonintellectual society.

The study of the laws of Nature had to wait for more than a thousand years before much further progress could be made in Europe. Technical knowledge, however, continued to expand throughout the whole of this period. The city states and kingdoms that rose and fell in the Mediterranean area and in Western Europe were constantly at war. Prosperity depended upon the ability of each state or kingdom to overcome its war-like neighbours and to protect its trade routes. Advances in military technology were therefore important to the progress of technology generally, but these advances were often made in response to changes in the art of war rather than in response to changes in the techniques of making armour, weapons and fortifications. Another major factor in technological advance in Europe during this period was the influence of the East, and particularly that of China. Eastern inventions were transferred to the West through the Byzantine and Islamic empires of the day and through the migration of technicians who taught their methods and skills to European pupils. By the fifteenth century, Europeans had become highly skilled in the use of wind and water power, in the use of rotary motion, in metalworking, weaving, building construction, ship construction, agricultural methods and in the chemical arts.

The renewed emphasis on the study of the laws of Nature in the hundred years from 1450 to 1550 was brought about by a number of factors. Among these were the rediscovery of the work of the earlier philosopher-scientists at Athens and Alexandria, the existence of the advanced empirical technology and skills that had been developed during the Middle Ages, and the spread of the techniques of printing and artistic illustration. The beginning of the second, or "modern" period of European science was also stimulated by the desire of many far-sighted and skilled men of that time to find a better basis for understanding the sum and substance of their practical experience and technical knowledge. But, most significantly, it had become obvious that the shortcomings of the method practised by the Greeks lay in their use of deductive logic and preoccupation with empirical observations. The post-Renaissance period also brought to a gradual end the kind of secrecy which had at first surrounded the work of the Athenian and Alexandrian schools.

At the close of the Middle Ages, points of contact between science and technology hardly existed. The business of explaining natural phenomena was left to the philosopher, while the craftsman, who cared little for theories, concerned himself with his trade and with the methods and processes which he used. Craft knowledge was handed down from master to apprentice. Philosophy was diffused through the written and spoken word. Although scientists of the Renaissance period -- such as Francis Bacon and Galileo and their immediate successors -- believed that science must ultimately guide technology and shape and change the course of civilization, technology remained the "sleeping partner" of science for a very long time to come.

Nevertheless, during the eighteenth century a number of the important technological developments which preceded the Industrial Revolution in Europe were based on new scientific work. James Watt's improvements to the steam engine, for example, were guided by the research on latent heat carried out by Professor Joseph Black. Until the end of this century, it was still possible for the exceptional man to acquire an understanding of most of the branches of scientific knowledge. But as the stock of knowledge grew, the "man of science" tended increasingly to become a specialist in some portion of the whole field. Those who attempted research also found that the inductive-experimental method required a great deal more labour and analysis than the part-time nonprofessional scientist could afford to devote to a special interest.

The late eighteenth and the first half of the nineteenth centuries saw technological advances which profoundly affected the whole pattern of economic development, first in Britain and later in Continental Europe and North America. The Industrial Revolution brought with it developments in the working of iron for use in building ships and railways. New methods of manufacturing textiles contributed, among other things, to the rise of Britain as a producer and exporter of manufactured goods. As in the centuries before the Industrial Revolution, the progress of technology depended largely on the ideas and skills of craftsmen, on the acumen of individual entrepreneurs, and on new economic and social pressures. But by the second half of the nineteenth century Britain's leading position in technology and production had been seriously challenged by Japan in textiles, by Germany in the new and growing electrical and chemical industries, and by the United States where the rapid and extensive exploitation of vast natural resources of that country had recently begun.

The twentieth century saw the trend towards increasing participation by states and governments in the progress of scientific and technical activities. But as a phenomenon, political sponsorship of such activities was not new. The leaders of the city states and kingdoms of Europe in the Middle Ages encouraged advances in the technology of war and weapons. Noblemen gave their patronage to individual philosophers and alchemists. In the fifteenth, sixteenth and seventeenth centuries European rulers lent support to exploration. In the eighteenth and nineteenth centuries, interest turned to agriculture and to the discovery and exploitation of natural resources.

During the First World War, the British Government set up an Advisory Council for Scientific and Industrial Research and through the work of this Council attention was directed for the first time to the need for training graduate students in scientific research and for providing adequate research support in universities and colleges. The First World War also saw the major participating countries mobilize and organize their scientific and technological manpower and resources.

Between the two World Wars, both public and private scientific and technical activities were affected by the unsettled economic and political conditions in Europe and North America. Public and private support for research improved modestly in comparison with the pre-1914 years and groups of distinguished scientists were formed on both sides of the Atlantic. The migration of European scientists to the United States which began in the 1930's had a significant effect on the scientific and technical capability of that country a decade later. However, before the Second World War it was still possible to say that Europe set the pace of scientific discovery, while the United States did much of the pioneering in the development and application of technology.

The Second World War brought about the mobilization and organization of the scientific and technical resources of the combatant countries on a scale unmatched before. By this time there was, of course, a great deal more knowledge available for use for warlike purposes. But there was also a better understanding on the part of the governments concerned of the possibilities of using this knowledge and of generating more.

From this War emerged the concept of the expensive, government-backed, large-scale, team-based "Big Science" project which contrasted markedly with the inexpensive "Little Science" projects of individuals or of small groups which had previously been the rule.* The "Big Science" concept survived the War partly because of the existence of two leading science-based countries with very different political philosophies and partly because further research into certain fields of science required extensive and expensive new equipment. "Big Science" has not, of course, been exclusively practised in the United States and Russia. The United Kingdom, France, China and Canada -- to mention a few countries -- have also undertaken expensive, large-scale, specialized projects in the post-war period. But cost and specialization have been factors in the establishment of a number of relatively large international research co-operation projects and programmes in recent years.

In the last twenty years, the significance of the discovery and application of scientific and technical knowledge for economic development, for education, and for the well-being of countries, regions and communities has been more widely and fully appreciated.

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* Although it is seldom spelled out, "Big Science" must include "Big Technology". In practice, projects like the U. S. and U. S. S. R. space programmes involve a mixture of science and technology and, in any analysis of expenditures, it is likely that more has been spent on new technology than on new science.

It is not quite so clear that "Little Science" must include "Little Technology" because projects of these kinds are usually less complex. However, in the context of this paper, "Little Science" should not be construed as necessarily excluding "Little Technology".

The so-called "science-based" industries and companies have become pace-setters in national and industrial growth. The application of technology to the processes of production has increased the output of the people employed. Higher living standards have brought demands for new and better goods and services. In most industrialized countries, expenditures on research and development for nondefence purposes have been rising steadily.

At both the government and intergovernmental levels, the formulation and development of policies for the allocation of resources to scientific and technical activities in general and to research and development in particular have been very live issues. Councils and committees have been formed to advise governments. Organizations such as the United Nations and the Organization for Economic Co-operation and Development (OECD) have taken a great interest in policy matters of this kind and have encouraged and sponsored high-level discussions. The United Nations and OECD have also sponsored background studies designed to provide better material on which policies for science and technology can be based.

Nowadays, as never before, efforts are being made to learn more about the organization and management of science, technology, and their related activities. It is already evident that studies are being made at the various levels at which scientific and technical activities are sponsored or undertaken. But it is also evident that subjective factors may weigh heavily on the outcome of final decisions for some time to come. In a sense, however, the present-day wish to discover more about the mechanisms underlying the choice of the most appropriate techniques of organization and management is analogous to the desire, at the time of the Renaissance, for a better basis for understanding the sum and substance of practical experience and technical knowledge.

Technology and the Development of Canada

Long before the first Europeans ever reached Canada, the Eskimos and Indians had developed tools and skills for gathering food, for self-protection and for transportation. The Algonquin Indians, for example, used dug-out and birch-bark canoes, snowshoes, axes, and built weirs and dams for trapping fish, beaver and other animals. Some Eastern tribes had also made significant advances in plant breeding. The Coast Indians of British Columbia had sea-going canoes and elaborate fishing lines and nets. The Eskimos had developed the kayak, the toggle-headed harpoon and the igloo.

Until there were reasonable chances for the survival of Europeans in the physical environments of Canada, and until there was some assurance that people and goods could be taken across the hazards and distances, there was little incentive to open up this country beyond the sea coasts for exploration and trade. When the first explorers did go into the interior they quickly adopted the existing indigenous "technologies". But, with time, their needs, opportunities and problems changed. In transportation, for example, the people who set up the continental trade routes built new types of canoes -- the canot du maître and the canot du nord -- and developed the York boat.

The fur and forest resources of this country and the development of agriculture and mineral resources sustained the Canadian economy until almost the end of the nineteenth century. By that time, a system of canals had been built in Central Canada, the Great Lakes-St. Lawrence route had been completed, and a railroad linked the Atlantic and Pacific coasts. The railroad systems brought with them the foundries, engineering plants and maintenance operations associated with rolling stock and other equipment and in this way Canada became involved for the first time in a heavy engineering industry. Railroad construction also led to the chance discovery of the rich copper-nickel and silver ore bodies in Northern Ontario. It provided access to the coal deposits of the Rockies. Far East markets came within reach of products from Eastern Canada. And the Prairies were opened up for settlement.

But the technological development that has been one of the most significant in Canadian economic history so far was the harnessing of large-scale hydro-electric power for the first time at Niagara Falls at the turn of the century. From the Niagara plant and from the other hydro-electric and fossil fuel plants which have been built in the last seventy years, has come the power to sustain the growth of both primary and secondary manufacturing industries in this country and to help improve working and living conditions.

The First World War provided the opportunity for more rapid development of industrial capacity in Canada. For example, base metal output rose sharply and in step with new developments in ore-handling and metallurgy. The wartime demand for shells and other products led to a significant increase in steel production. An aircraft industry began in Canada in 1917 and produced several thousand aircraft before the end of hostilities. Shipyard output increased. Oil refineries increased their capacities significantly and the catalytic cracking of crude oils was introduced for the first time. A process for making acetone commercially was developed by a group of Canadian chemists. The manufacture of pharmaceuticals and fine chemicals began to reach substantial volumes when importation from Europe and the United States was sharply reduced. And reductions in the volumes of other imported manufactured goods stimulated the establishment of a wide range of new plants in Canada and the development of new Canadian skills.

The years between the World Wars were years of economic and political uncertainty. Canada was affected no less than other countries. There were, however, periods of rapid expansion in the pulp and paper industry, in the automobile industry, and in the production of non-metallic minerals and chemicals. The aeroplane -- usually equipped with floats or skis in place of landing wheels -- assumed an important role in explorations associated with the discovery and development of remote natural resources. And during this period a major Canadian contribution to medical science and the treatment of disease was made. Dr. (later Sir) Frederick G. Banting and his colleagues at the University of Toronto discovered insulin and developed methods for its extraction and purification. Commercial production was subsequently undertaken by the Connaught Laboratories.*

The Second World War did more than the First to develop and diversify the Canadian economy. The range of products of manufacturing industries broadened, and the growth of those based on technology accelerated. Much of this expansion was related to the War effort. Among the new products made were synthetic ammonia, synthetic rubber, nylon, high octane fuels, magnesium and uranium. Canadians also took part with French and British scientists in research work in nuclear science and, by so doing, were favourably placed to continue this work when the War ended.

During the past two decades, the word "technology" has become a watchword of particular significance in

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* The Connaught Medical Research Laboratories were established by the University of Toronto in 1914 to prepare and produce antitoxins and to undertake research in hygiene and preventive medicine. Revenues from the sale of insulin over the years have been used to support the research work of the Laboratories.

Canada, as it has in so many other countries. This period has seen the most rapid increase and broadening of the world's stock of technical and other knowledge. It has also seen extensive changes in the kinds of goods consumers want to buy, in the possibilities for more rapid interpersonal communication, in the potential for the substitution of synthetic for natural products, and in the development of electronic computer systems. This country has benefited enormously from new knowledge and experience which originated abroad, but Canadian scientists and engineers have also made important contributions of their own.

With rising manufacturing output in post-war Canada has come still greater diversity of products. While Canadian companies have continued to devote efforts to the advancement and application of technology in the older primary industries, new industries based on petroleum and natural gas have been rapidly developed. The rise in the output of basic iron and steel has helped to strengthen output in the metal fabricating, industrial machinery, transportation equipment and electrical equipment sectors. In secondary manufacturing, Canadian products now include communications equipment, radiation therapy equipment, and STOL aircraft. The Alouette satellites, which were designed, developed and built in Canada, have been major contributions to the new field of space technology. And, in the construction field, the joint Canada-United States St. Lawrence Seaway project has changed the dynamics of the Great Lakes Region.

For three hundred years and more, the various regions which are now Canada were sources of raw materials and foodstuffs, first for France and Britain, and later for Britain and the United States. They were dependent upon the economic and political climates in and between these countries for the profitable markets and additional capital and technical resources necessary for further development. But since the beginning of the twentieth century, many things have changed.

The Growth and Development of Scientific and Technical Institutions in Canada

The story of the growth and development of these institutions goes back to the decades before Confederation and runs parallel to the growth and development of the Canadian economy. Of the earliest institutions, only those in the universities could be considered as formally organized -- and preoccupied with teaching. Government interest in scientific and technical activities was at first confined to agriculture, to the administration of Acts and Regulations, and to the discovery and exploitation of natural resources. Until comparatively recently, industrial interest in science and technology was limited largely to the adaptation of the work of others and to problem-solving on the basis of need.

The institutions which are mentioned in this section are mainly research and development institutions. They have been grouped under four headings -- Federal Government, Provincial Governments, Universities, and Industry. No attempt has been made to include descriptions of each and every institution now operating in this country and only in certain cases has the growth of a particular institution been followed through from its founding to the present day.

Federal Government Institutions

The Geological Survey of Canada is one of the oldest institutions of its kind in the world. It began its work in 1842 shortly after the union of Upper and Lower Canada. The early members of the Survey were not only explorers and geologists, they were also concerned with locating mineral, forest and water resources and with work in the biological and other related sciences. After Confederation, the work of the Survey expanded to cover all the provinces and the northern territories of Canada. For more than three decades from the time of its founding, the Survey had independent status as a government department without that title. In 1877, however, an Act was passed by which the Director became responsible to the Minister of the Interior. By another Act in 1890 the Survey was formally recognized as a department of this Ministry. In 1901 the Minister of the Interior removed from the Geological Survey the responsibility for the collection of mineral statistics and other information about the mining industry and formed a new organization which became the Mines Branch in 1907. In 1911 the National Museum was founded and became, for many years, the Survey's headquarters.

The present Department of Agriculture had its origin in the Bureau of Agriculture set up in 1852 by the United Province of Canada. With Confederation, the responsibilities of this Department also expanded. During its early years, the Department was principally concerned with the health of animals but by 1884 it had become clear that the industry of agriculture was going to play an important role in the growth and prosperity of the country. It was equally apparent that agricultural conditions must be studied and adjusted to remedy the defects of the primitive agricultural methods then in use. The causes of the trouble were mainly ignorance of good farming methods which led to soil impoverishment and poor crop returns. A Select Committee of the House of Commons reported in 1886 and, based on the recommendations of this Committee, the Dominion Experimental Farms System was inaugurated later that year. By 1890 the Department had three agricultural branches -- Animal Quarantine, the Experimental Farms, and a general branch administered by the Commissioner of Agriculture and Dairying. Out of this latter branch grew the agricultural research institutes, stations and laboratories which are in operation today.

The origins of the present Fisheries Research Board also go back to 1852 when the United Province appointed Pierre Fortin as magistrate in command of an expedition for the protection of the fisheries in the Gulf of St. Lawrence. Fortin undertook a number of studies which provided the basic data for much of the later work. However, it was not until 1899 that the Canadian Government made a grant towards the work of the first marine biological station. In 1907 this station was located on a permanent basis at St. Andrews, New Brunswick, as the Atlantic Biological Station and in 1908 a corresponding Pacific Station was set up at Nanaimo, British Columbia. In 1912 the Biological Board of Canada was created.

Federal activity in forestry research began in a small way with the establishment in 1909 of a Commission of Conservation. The object of the Commission was to bring about the conservation and improved utilization of the forest resources of this country. An inventory of the forests in Nova Scotia was undertaken in 1909-10 and a similar inventory was made in British Columbia between 1914 and 1916. This Commission was terminated in 1921. The Department of the Interior, however, had established a forestry branch in 1899 and in 1917 set up a division for research in silviculture. Also in 1917, a 100-square-mile area of the Petawawa Military Reserve in Ontario was set aside for a Forest Experimental Station and work began there during the following year.

Although individual Canadians made contributions to military science and technology during the First World War, there was no organized national effort by Canada. In 1916, however, the British Colonial Secretary suggested to each of the Dominions that they examine their scientific resources. On June 1 of that year, a committee of six Canadian Cabinet Ministers was formed. As a result of its work, the Honorary Advisory Committee for Scientific and Industrial Research was created in November 1916. This Committee later became known as the National Research Council. At first an advisory body, the National Research Council began by making a survey of Canada's scientific resources. This survey showed how meagre these resources then were. Industrial research was practically non-existent and the national supply of capable scientific investigators was inadequate. Undergraduate work absorbed the energies of university professors, leaving little time for research. There were no scholarships for graduate work in Canada and most Canadian postgraduate students went to foreign universities. Many did not come back. The Council therefore set up immediately a system of postgraduate scholarships and a system of grants to professors to stimulate research in science and engineering in Canadian universities. Also in 1917, the Council began to co-ordinate research programmes of a national character through the mechanism of Associate Committees of experts from governments, universities and industry -- a system which has since been adopted by other government agencies active in scientific or technological activities. The Council, however, gradually became convinced that it could not fulfil its obligations to industry without a laboratory of its own. In 1925 small-scale laboratory work was started. This work increased in 1932 when the Council's Sussex Drive Laboratories in Ottawa were opened.

Between the two World Wars, some of the other federal departments expanded or reorganized their scientific and technical activities. For example, forest products laboratories were established in Ottawa and Vancouver in the 1920's. In December 1936 the Department of Mines and Resources came into being, bringing with it a regrouping of the Geological Survey, the Mines Branch and the National Museum. In 1937 the Fisheries Board was established. But during the Depression years of the 1930's very little over-all expansion in government activities took place. The decades of the 1920's and 1930's, however, brought together groups of experienced scientists and engineers in the main fields of science and technology. These groups proved to be of great value during the manyfold expansion of R & D activities in Canada during the Second World War. In contrast to the First World War, Canada could and did make a national contribution to the wartime R & D programmes of the Allies.

By 1940 the National Research Council was engaged in almost every field of war research and its peacetime activities had been drastically curtailed. The Council co-ordinated all Canadian military R & D during the war years. New laboratories were opened up from coast to coast. The Council's own scientific staff and its Associate Committee structure were expanded. The Canadian Armed Forces also became involved in research and development.

In Montreal, late in 1942, a nuclear research team began work. Set up as a separate unit under the President of the National Research Council, this team included British, French and Canadian scientists. The team's main task became the design of a heavy water, natural uranium reactor (NRX) which would not only generate nuclear energy, but which might also provide components for an atomic weapon if required. In August 1944 the Chalk River (Ontario) site of the government's nuclear research laboratories was finally approved. Although the construction of the NRX reactor was not completed until 1947, a small test reactor went "critical" on September 5, 1945, making it the first reactor in the world outside the United States to do so.

Federal government scientific activities continued to expand after the Second World War. Although it administered the atomic energy project for some years more, the National Research Council relinquished its preoccupation in defence research almost immediately. In December 1945 a Director General of Defence Research was appointed and on April 1, 1947, the Defence Research Board was established with its Chairman holding a rank equivalent to the chiefs of the three Services and with a seat on their Committee. Although the Services were to continue their own R & D programmes, the establishment of the new Board to serve all three Services and the ranking of its Chairman were institutional innovations which few governments had attempted to make.

The National Research Council, itself, has expanded since the War. Several new divisions have been formed and the Atlantic and Prairie Regional Laboratories have been opened. Five other developments of some significance for the Canadian economy have also taken place:

-- The Department of Reconstruction and Supply in 1945 began a Technical Information Service (TIS) to provide information and advice for industry. NRC took over this Service in 1947. In the period 1952-54 the first arrangements were made with Provincial Research Councils to operate TIS field services in conjunction with their other activities. In 1962 the TIS began developing an industrial engineering service and in 1964 set up a special section whose job is to keep small companies, in particular, informed about the latest technical advances.

-- In 1948 NRC set up Canadian Patents and Developments Limited, a wholly owned subsidiary, to handle patent and licensing matters arising from work done in the Council's own laboratories. These services were later extended to cover other federal departments and certain universities and Provincial Research Councils.

-- Canada's National Science Library had its beginnings forty years ago when a library was established to serve the newly organized NRC laboratories. Over the years, the Library's collections increased and its services were extended to serve other laboratories throughout Canada. In 1956 it was decided that the NRC Library would formally assume the responsibilities of a National Library for science and technology, while continuing to make use when required of other specialized federal libraries in Ottawa to supplement and complement its own collections.

-- On April 1, 1952, the NRC atomic energy project became a separate Crown Corporation as Atomic Energy of Canada Limited. In addition to the Chalk River Nuclear Laboratories, AECL now has laboratories in Toronto and at Whiteshell, Manitoba, and commercial products plants in Ottawa.

-- In November 1960 the Medical Research Council was established as an autonomous unit within the administrative framework of the NRC. The primary aim of the Medical Research Council is the development of medical research facilities and the support of medical research workers in the universities in Canada.*

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* The Council is not the only supporter of medical research in Canada. The Department of National Health and Welfare and the Defence Research Board, which have medical laboratories of their own, and the Department of Veterans Affairs have provided grants since the late 1940's.

Provincial Government Institutions

Provincial activities in fields of science and technology date from the turn of the present century. Ontario and Quebec, for example, appointed their first Provincial Geologists around that time. Research in the various Departments of Lands and Forests, on the other hand, has been a later development. As in the case of the federal government, the early provincial activities in science and technology were concerned with legislation and regulation, with agriculture, and with the development of natural resources.

Provincial governments have, in the past, relied extensively for R & D assistance on the federal laboratories and research stations within their boundaries and on the universities. Only Ontario, Quebec and British Columbia have comparatively large research programmes within certain provincial government departments, although in some other provinces the regulatory authorities have undertaken significant scientific and technical studies from time to time. The principal external technical activity of many of the provincial departments has remained the provision of technical information and assistance.

Seven out of ten provinces have established Research Councils or Foundations.* The first two of these Councils -- in Alberta and Ontario -- were set up prior to 1939 and the most recent, in Manitoba, just over four years ago. The Councils in Nova Scotia, New Brunswick, Alberta and Saskatchewan function as "research arms" of their respective governments and undertake or co-ordinate selected projects on behalf of departments and agencies. They also undertake or co-ordinate contract work at the request of provincial industry. The British

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* Quebec, Newfoundland and Prince Edward Island, so far, have not.

Columbia Research Council was established principally to provide research services for business and industry, but basic support for the Council's work has been provided by the provincial government. The Ontario Research Foundation was set up as a nonprofit commercial organization and, although it derives income from the provincial government for research and other work, it receives more than half of its income from contract research work for industry. The Ontario Research Foundation, like the B. C. Council, also undertakes contract work for sponsors outside the province. The Manitoba Council is the only one which is part of a provincial department.*

The scientific and technical interests of each Council are related to the natural resources of its province and to the composition and structure of provincial industries. They therefore vary from Council to Council. Laboratory facilities are well established in Alberta, British Columbia, Ontario and Saskatchewan. New Brunswick at present has a small laboratory and is building a larger one with funds provided by the Atlantic Development Board. This Board has also awarded funds to the Nova Scotia Research Foundation for the construction of its laboratory. The Research Councils are active in field services and in technical information work in support of manufacturing industry.

The concept of the "research community" or "research park" has been developed extensively in the United States, but so far the only one that has been formally organized in Canada is the Ontario Research Community at Sheridan Park, near Toronto. This community was established and developed under the aegis of the Ontario Government and the Ontario Research Foundation and now includes the R & D laboratories of seven industrial

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* The Manitoba Department of Industry and Commerce.

companies as well as new laboratories for the Ontario Research Foundation and Atomic Energy of Canada Limited. The Foundation's laboratories form the core of the community. In addition to public and private facilities, the community is being planned to include computing, conference and library facilities for use by all member organizations. Sheridan Park has become, in embryo, Canada's first Science City.*

University Institutions

The first record of public instruction in science in Canada dates back to the early eighteenth century. The first medical school was opened in Montreal in 1824. But until well into the nineteenth century, most of Canada's scientists, engineers, doctors and teachers of scientific disciplines were educated abroad. And until the 1920's, the preoccupation of institutions of higher education was with undergraduate instruction. In Canada, as elsewhere, the growth of instruction and research in the major scientific disciplines preceded the growth of instruction and research in applied science and technology.

Research in Canadian universities is almost exclusively a twentieth century phenomenon. At the beginning, professorial research lacked money, apparatus and time, and was done more for personal satisfaction than for any other reason. However, university research

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* A number of informal research communities have also grown up in Canada in recent years. The two largest and best known are perhaps those in the Pointe Claire-Senneville area at the west end of Montreal Island and at Sarnia, Ontario. Smaller communities have also been growing up, for example, on the outskirts of Edmonton and on the campus of the University of British Columbia.

in physics in Canada got off to a notable start at the beginning of this century with the work of Rutherford and Soddy at McGill. In medicine, there was of course the later discovery of insulin in the Department of Physiology at the University of Toronto which earned the 1923 Nobel Prize in Medicine for two of the co-discoverers.

Prior to 1900, degrees awarded in Canada at the M. A. and M. Sc. levels were often granted for additional studies beyond the Bachelor level and not for research theses. Around 1900, the first Master's degrees were granted for work involving research. The first Canadian Ph. D. degree in science was awarded in 1901. The work of the National Research Council and of other government agencies and the opening of new universities across Canada between 1900 and 1939 did help to increase the number of research workers in the universities in this country.

In the last twenty years, university research and teaching in Canada have expanded rapidly -- although perhaps not rapidly enough to keep pace with the growing population and with the demand for places. Support from the senior levels of government has been increased, with the federal government's contribution being principally at the graduate level and the contributions of the provinces at the undergraduate level. Applied science faculties have been developing faster than before. The number of specialized institutes within the universities has also increased and ranges across the whole spectrum of science and technology from oceanography through microbiology and aerospace studies to materials science. Although not yet so evident at the undergraduate level, graduate level courses in the universities have demonstrated that the traditional divisions within and between the science and engineering disciplines have been changing. New areas of specialization and new "cross-disciplines" have been growing up. Since the War, new subdisciplines of physics, such as cryogenics, plasma physics, and biophysics have been taught in Canada.

University professors have acted as consultants to industrial companies in the past. Since the Second World War, the scale of this activity has increased and, in some cases, groups of staff members have formed themselves into consulting organizations. In response to the rapid growth of the inventories of science and technology, manufacturing companies have been turning increasingly to these organizations and to the university departments themselves for ad hoc advice, for further training and retraining of their scientists and engineers, and for contract research. During 1967 the federal Department of Industry initiated a programme of grants to establish and administer Industrial Research Institutes in certain universities in Canada. This programme is intended to help promote closer relationships between universities and local industries.

Industrial Institutions

The advanced technical activities in Canadian industry before 1920 were to be found mainly in companies in the base metals, chemical, and pulp and paper industries. A number of important inventions and innovations were made, but the main technical activity of the scientists and engineers was the improvement of existing processes and products and the application of processes and products developed abroad to the needs and opportunities of the markets for Canadian manufacturing output.

During the inter-war period, however, there were a number of important developments. For example, companies in the food industries began setting up control laboratories and gradually getting into research and development work. This period saw the steady growth of Canadian research in the pharmaceutical industry. It saw the beginnings of independent industrial consulting and testing laboratories to serve mainly the chemical, food and base metals industries. Progress in the base metals, chemical, and pulp and paper industries continued.

The Pulp and Paper Research Institute of Canada -- the first Canadian industrial research association -- was founded during the 1920's. Unlike certain European countries, associations of this kind have played only a small part in the growth of industrial R & D in this country. Apart from the PPRIC, only a few small and regional associations have so far been set up.

Since 1955, however, the scale on which research and development activities have been undertaken by companies themselves has increased. In the last five years, many new industrial laboratories have been opened. Several hundred companies now have their own facilities. The development of the Sheridan Park and other research communities was mentioned above. The diversity of Canadian industry has, of course, increased since the War and among the main R & D performers at present are the aircraft, electrical and electronics industries. On a geographical basis, however, the majority of the industrial laboratories in Canada are located in Ontario and Quebec.

It is now clear that a favourable business climate and changing attitudes towards R & D activities in industry were factors which contributed to the relatively rapid growth and development of industrial laboratories and R & D activities in Canada after 1960. The four special assistance programmes and the general incentive programmes established by the federal government to encourage industrial R & D activities also made contributions.* Recent experience has also shown that co-operation and understanding between industry, on the

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* Appendix III contains a brief outline of these programmes.

one hand, and governments and universities on the other, have been improving, but that much remains to be done.

International Aspects of Science and Technology

The communication of theories, experimental results and discoveries through exchanges of correspondence, publications and visits among scientists has been part of the essence of science and has contributed to its growth and progress and to the spread of new knowledge to the domain outside the laboratory. Until the end of the eighteenth century, the community of scientists in Europe was small and those who had broad common interests tended to know each other personally. From the nineteenth century on, foreign travel by scientists has become increasingly frequent. This trend was fostered by continuous growth in the number of international scientific conferences and meetings -- the earliest of which were held in Belgium, France and Germany between 1848 and 1862 -- and by the establishment of international scientific societies.

But obstacles to effective communication between scientists also began to appear in the nineteenth century. Among these have been the growing specialization and the increasing numbers of active professional scientists. Political restraints on the activities and travels of scientists have also been in evidence. There have been problems of language and problems with "jargon". Some conferences have been too big or their subject coverage too broad. And nowadays, with science advancing rapidly, the announcement of a significant new discovery is seldom held back for presentation and discussion until the time of the most appropriate international conference or meeting.

The first extensive project in international scientific co-operation on a multilateral basis was in the field of astronomy and took place in Europe in the middle of the nineteenth century. It involved specialists in only one branch of science and required no government support. The first government-supported international project that was built around a common programme of research involving scientists from several disciplines was the International Polar Year of 1882-83. Eleven national expeditions and observatories in 35 countries took part. A second International Polar Year was organized fifty years later. Both may be considered forerunners of the International Geophysical Year (1957-58) and of the International Years of the Quiet Sun (1964-65). Some sixty nations participated in IGY and important data were gathered about the oceans and the earth's magnetic field. IGY was also the year in which the first Russian-built earth satellite was launched.

An important role in the organization and co-ordination of IGY was played by the International Council of Scientific Unions (ICSU). This organization was formed in 1931, following the dissolution of an earlier and similar organization. Its purpose is to facilitate and co-ordinate the activities of the various constituent unions in particular fields of science and to act as a co-ordinating centre for the national organizations adhering to it. The ICSU is financed by member countries and constitutent Unions and by subsidies and donations, principally from UNESCO. Among the other activities of ICSU and its constituent Unions are the organization of international meetings and the setting up of committees to co-ordinate scientific research on an international basis.

Experience among the Allies during the Second World War did a great deal to foster the idea of international co-operation in research and development projects. A recent OECD report had this to say:[7]

> "Furthermore, the war having demonstrated the fundamental role that science can play in the progress and defence of societies,

> political objectives were from then on seen to be directly linked to scientific aims. At once benefitting from the achievements of science and technology and called upon to bear an ever-increasing share of the cost, governments found in scientific co-operation a means of achieving some of their national and international objectives more quickly and more effectively. Theretofore a means of action, interchange, and communication reserved in the main to the scientific community, international co-operation in science now became also of political, economic, social, cultural and military concern to governments."

Since the end of the Second World War, the number of intergovernmental and nongovernmental international scientific organizations has increased considerably. Although an exact count is difficult to make, there now are over fifty intergovernmental and between two and three hundred nongovernment organizations. Some have precise tasks and laboratories of their own. Others are mainly concerned with sponsoring research or fostering co-operation in certain fields or have scientific activities forming only a part of their over-all programmes. Some are world-wide in scope, while others have been established on a regional basis. Within the United Nations, for example, the specialized agencies concerned with fostering scientific co-operation on a world-wide basis include UNESCO, the Food and Agricultural Organization, the World Health Organization, the World Meteorological Organization and the International Atomic Energy Agency. Among the regional organizations that have scientific and technical activities included in their responsibilities are the Organization for Economic Co-operation and Development (OECD) and the European Coal and Steel Community.

In the industrial sector, international co-operation is just as active but naturally takes a variety of forms depending upon the particular industry, upon the competitive situation between companies in each industry, upon the structure and resources of each international corporate unit, and so on. A recent Economic Council of Canada report had this to say about industrial R & D activities in the international context:[8/]

> "No technically based Canadian company can cover completely all fields of R & D which are relevant to its products and manufacturing processes. It must, therefore, have access through reports, journals and personal contacts to R & D performed in Government, university and other laboratories in Canada and abroad to supplement its own 'in-house' activities. Those companies in Canada which are affiliated with foreign corporations are placed in a position in which they have a degree of access to the stock of new scientific and technical information developed within their affiliated companies and can from time to time obtain information which, for various reasons, could not be produced in Canada at all. In this connection, it should also be noted that the policy of many international corporations is to distribute R & D work among their affiliated companies on the basis of the relative abilities of these companies to make the most effective contribution to certain areas of work, or to make the best use of the anticipated results.
>
> "...this 'trade' is not in one direction. In recent years, a growing number of Canadian companies, in the context of increased internationalization of business firms, have been acquiring R & D capabilities which have enabled them to supply their affiliates abroad with new information to complement the work of these affiliates for specialized markets."

Science, Technology and Innovation

Besides research and development, the activity related to science and technology that has perhaps received the most attention in international forums is the collection, dissemination and translation of information. Organizations for this purpose have been formed as separate units or as departments of international bodies with the intention of improving communications among members. At present, several hundred separate international organizations are active in the information field and some of them have been in existence since the nineteenth century.

International activities in the fields of science and technology are by no means problem-free. Communication problems have already been mentioned. Another problem area is co-ordination between the various interested agencies and individuals in any one country. Another is the lack of co-ordination and the tendency for unnecessary duplication of effort between the international organizations themselves. And, for small countries, participation at the international level may lead to difficult financial and other problems. Each country has to determine, on the basis of continuous and anticipatory reviews, how best it can participate in -- and contribute to -- international scientific and technical activities. *

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* With regard to the international organizations and projects specifically mentioned in this section, Canada participated in the International Polar Years, in IGY and IQSY, and participates on a continuing basis in the work of the United Nations agencies and OECD. Two Canadian scientists (Dr. E. W. R. Steacie and Dr. J. M. Harrison) have served as President of the International Council of Scientific Unions. And it was a Canadian (Mr. Dana Wilgress) who prepared the background report on scientific research co-operation which formed the basis of much of the work of the Directorate of Scientific Affairs of OECD.

Policy Advisory Structures for Scientific and Technical Activities

Councils and committees have now been established in most of the industrial countries of the world to advise on the formulation of national policies and postures to govern the conduct of scientific and technical activities. Organizations like OECD and UNESCO have taken an active interest in the exchange of information about how policies have been, and are being, developed. Policy-making for scientific and technical activities within, and for, the constituent companies of international business enterprises is one of the functions of the central management bodies of these enterprises.

For the purposes of this paper, the history and development of the government science policy advisory bodies in Canada and the United Kingdom and in the Executive Branch of the U. S. Government will be discussed briefly.

Canada

In 1916 the federal government established the National Research Council and, in the same statute, the Committee of the Privy Council on Scientific and Industrial Research. Under the Research Council Act and later under the Atomic Energy Control Act, this Committee of Ministers was given responsibility for the supervision and co-ordination of government research and for developing broad policies for government R & D expenditures. As originally conceived, it was to be the duty of the National Research Council to advise the Privy Council Committee on matters relating to science and technology and affecting the expansion of Canadian industries and the utilization of Canadian natural resources. But in the years which followed, the Council developed a system of national laboratories and programmes of financial support for the universities and for industry and became less directly concerned with the discussion of policy questions. In 1949, an Advisory Panel for Scientific Policy was set up by the federal government. This Panel of senior department and agency officials was made responsible for advising the Privy Council Committee on the formulation and conduct of government scientific policies.

In December 1960 the National Productivity Council was established. The main object of the Council was to promote and expedite continuing improvement in productive efficiency in Canadian economic activities and, in particular, to foster and promote the extension of industrial research programmes and the dissemination of technical information as means to these ends. An Applied Research Committee of the Council was formed. In 1963 the Productivity Council was dissolved and replaced by the Economic Council of Canada. In order to fulfil its responsibility for the study of those factors which contribute to the development of scientific and technical competence of Canadian industry, the Economic Council formed an Advisory Committee on Industrial Research and Technology.

Following the report and recommendations of the Royal Commission on Government Organization early in 1963 and a subsequent report prepared for him by Dr. C. J. Mackenzie, the Prime Minister announced in the House of Commons, on April 30, 1964, that the Government proposed to set up immediately a Science Secretariat as part of the Privy Council Office and to study further the recommendation that a national committee be set up to advise the Government on questions of science policy.

The Science Secretariat began work on July 1, 1964, and on May 12, 1966, the Bill establishing the Science Council of Canada was given Royal Assent. This Council has twenty-five members and four associate members drawn from the universities, industry and the departments and agencies of the federal government. The Science Secretariat assists the Science Council with its work in addition to performing other duties as part of the Privy Council Office.

In his address to the inaugural meeting of the Science Council, the Prime Minister said:

> "Today Governments in all countries, with any claim to being called advanced, recognize the importance of close and competent expert advice on public policy with respect to science and technology. By policy, I do not mean the management of laboratories or the direction of research projects. By science policy, as it concerns this Council, I mean decisions that determine the balance of our national scientific effort; the role of that effort in relation to our country's aspirations; its adequacy as to research on the one hand and applied use on the other."

The United Kingdom

The first steps in the process of setting up government machinery for science policy were taken in the United Kingdom during the First World War when, in 1915, the Department of Scientific and Industrial Research (DSIR) was created by an Act of Parliament and placed under the control of the Committee of the Privy Council for Industrial Research. The Lord President of the Council, a Cabinet Minister who was normally free from the pressure of administrative duties, was made Chairman of the Committee. A small part-time Advisory Committee composed of eminent men from the universities and industry was also created within the Department. In effect, the Lord President became responsible for the expenditure of government funds for scientific and industrial research, but judgment on the scientific and technical value of individual projects was the responsibility of the Advisory Council.

During the Second World War, the government set up a Scientific Advisory Committee to the War Cabinet to co-ordinate both civil and defence research. After the War, this Committee was replaced by a Defence Research Policy Committee and by an Advisory Council on Science Policy (ACSP) whose duty it became "to advise the Lord President of the Council in the exercise of his responsibility for the formulation and execution of Government Scientific Policy". In 1959 the Lord President's responsibilities passed to the Minister of Science.

In March 1962 a Committee of Enquiry into the Organization of Civil Science was set up by the British Government. This Committee, which became known as the Trend Committee, reported in October 1963. It recommended a number of extensive changes in the structure and organization of civil science, some of which the government was in the process of implementing during 1964.

Following the General Election in October of that year, however, the new government began a more extensive reorganization of its scientific and technical activities. At the national advisory level, the Advisory Council on Scientific Policy was dissolved and replaced by two Councils -- one for Science and the other for Technology.

The new Council for Science Policy has been given narrower terms of reference than its predecessor. Its principal duty is to advise the Secretary of State for Education and Science in the exercise of his responsibilities. This includes advice on such matters as the government's civil science programme as a whole and the research programmes of the various Research Councils for which the Secretary is responsible. The terms of reference of the new Advisory Council on Technology are to advise the Minister on the application of advanced technology in British industry. A separate Committee on Manpower Resources for Science and Technology has also been established to assist both the Secretary of State and the Minister of Technology.

The most recent step in the British Science policy structure was taken to provide over-all co-ordination of the deployment of the country's scientific resources. In October 1966 it was announced that a Central Advisory Committee would be appointed under the chairmanship of the government's Chief Scientific Adviser. The main object of this Committee is "to promote the growth of our scientific and technological resources at a rate which is sensible in relation to our needs and resources, but also to ensure that they are deployed to the best national advantage". The Committee is to advise the Cabinet rather than individual ministers.

The United States

Prior to 1957 and the launching of the first Russian satellite, the only formal scientific advisory body within the Executive Branch of the U. S. Government was a Committee which was part of the Office of Defence Mobilization and which advised the President through the Director of the Office. The Committee was principally concerned with scientific and technical aspects of defence mobilization and national security. In 1957 this Committee formed the nucleus of the President's Science Advisory Committee (PSAC). At the same time, a Presidential Science Adviser -- the Special Assistant for Science and Technology -- was appointed. The Science Adviser and his staff were assigned the primary task of taking stock of the scientific and technical resources of the United States and of advising on ways to increase and mobilize these resources. The Science Adviser was also named Chairman of the PSAC.

The PSAC reports to the President directly. Its members are appointed for four-year terms and are drawn from among the country's most distinguished scientists and engineers in industry, the universities and other nongovernment institutions. The Committee meets on an average of two days a month and is concerned with major issues related to science and technology in the country as a whole. It undertakes studies on its own initiative and at the request of the President.

In 1959 the Federal Council for Science and Technology (FCST) was created with the Science Adviser again as Chairman. This Council is composed of top-level policy representatives from the federal agencies concerned with science and technology and its function is to co-ordinate the total federal effort in these fields.

The White House policy organization was completed with the establishment of the Office of Science and Technology (OST) in 1962. The President's Science Adviser was named Director. In effect, this Office formalized the functions of the Adviser's staff and gave statutory permanence for continuing Presidential staff support to the Adviser, to the PSAC, and to the Federal Council. It also answered the demand of Congress for a single authority which it could call on to answer questions on the Administration's plans in the fields of science and technology. The OST is responsible for advising and assisting the President with the over-all co-ordination of federal functions in science and technology and with such matters as the development of major policies, plans and programmes for the federal agencies, with scientific and technical questions involving national security, and with the assessment of scientific and technical programmes and their impact on national policies.

PART III

THE AVAILABLE STATISTICS

No national or international agency has so far been able to collect, analyze and compare input and output measurements for the full range of scientific and technical activities and no agency has developed methods for effectively measuring the costs and benefits of innovative activities on a national scale.

The statistics collected up to the present time have been concerned principally with the input of resources to national, sector and industry research and development activities. Measurements of the output from these activities have also been attempted, but fully satisfactory methods have not yet been devised. As far as individual projects are concerned, both input-output and innovation cost-benefit estimates are sometimes made, but these figures are not usually published.

The first continuing efforts to obtain data on a comprehensive basis began in the United States in the early 1950's following the establishment of a series of survey programmes by the National Science Foundation. Since that time, the majority of the industrially advanced countries -- including Canada -- have started their own R & D survey programmes. International organizations have also been playing a useful part in the encouragement and co-ordination of statistical work. The OECD's "Frascati Manual" -- published first in 1963 -- has been a pace-setter in the attempt to bring an element of uniformity into international statistical comparisons. This Manual formed the basis of the work done in connection with the Organization's first International Statistical Year project which covered R & D expenditure, manpower and other statistics in OECD member countries for 1963 or 1964.

One problem which pervades this statistical work is the problem of defining the "end products" and arranging for the collection and analysis of matching data. These end products may range from the needs of national policy-making to the allocation of resources to development work in a small science-based company. Usually, it is first necessary to carry out the matching process on an experimental basis. In some cases, the end products cannot be properly identified until this work has been completed. In the R & D field, these experiments are still in progress and are likely to continue for some time to come.

The main purpose of this part of the paper is to discuss some of the imperfections in the available statistics and, in this way, to draw attention to problems that policy-makers and managements must face in allocating resources to scientific and technical activities. The secondary purpose is to comment briefly on a few of the problems relating to the so-called "brain drain", the "technology gap", and the "technological balance of payments".

The statistics presented below have been chosen to illustrate the various points under discussion. The assessment of the implications of these figures for Canada or for Canadian policies for scientific and technical activities must be left to others. *

Research and Development Input Statistics

The two principal measures of the input to R & D activities at all levels are the financial and manpower resources actually allocated to these activities.

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* See, for example, the First Annual Report of the Science Council of Canada (Queen's Printer, Ottawa, June 1967).

The arrangements for collecting R & D expenditure and employment statistics have varied from country to country in the past. In Canada, for example, surveys of federal government and industrial sector expenditures have been made by the Dominion Bureau of Statistics every two years since the mid-1950's, but attention has only recently been turned to the university, nonprofit and provincial government sectors. In the United States, there have so far been four "bench-mark" years -- 1953-54, 1957-58, 1964 and 1966 -- in which there have been surveys of all sectors. National expenditure data for non-bench-mark years have usually been based on surveys in the government and industrial sectors and on estimates for the university and nonprofit sectors.

While surveys give full coverage of R & D activities in government departments and in most of the nonprofit institutions, surveys in industry usually cover only those companies known or thought to be active in research and development. Industrial surveys organized in this way usually include all major business enterprises performing R & D, and it is unlikely that the aggregate expenditure statistics would be altered significantly if all the remaining eligible companies received and responded to survey questionnaires. But one important point must be made in connection with surveys of business enterprises. Some of them perform a great deal of development work in the same engineering department or division in which the design and other technical work associated with production is also undertaken. The expenditures on development work alone are not always easily separable from those for the division's activities as a whole. In these circumstances, a company may respond to the R & D questionnaire with a nil return unless it has some incentive to do otherwise.

There are a number of other general problems. For example, the division of a professor's time between research, research supervision, teaching and other duties is one factor that complicates the collection of university research statistics. A problem that pervades all sector studies is the problem of eliminating discrepancies in intersector transfers of funds. The definitions of terms such as "basic" and "applied research", "development", "capital" and "current" expenditures may vary between sectors in one country and over time in the same sector. Interpretations of these definitions can also vary from establishment to establishment and from person to person. There is also the continuing problem of defining product classifications for business enterprises in a period of fast-changing product lines and highly diversified companies. These and other factors and problems require that updating procedures be used on all time-series data after each major survey of the sectors.

The research and development expenditure figures that are normally compiled from questionnaires relate to the following: gross national expenditure; funding and performance by major sectors; capital and current operating expenditures; expenditures at home and abroad, in particular government departments, and according to the industrial classification system; defence R & D; basic research, applied research and development; numbers and sizes of responding business enterprises; government incentive and cost-sharing programme expenditures; and so on. From the available time series, growth rates and rates of change in growth rates can be calculated. The figures may be related, as required, to the corresponding figures for Gross National Product, population and labour force, sales, or value added. Most of these figures and calculations have been used at one time or another for international, intersector, interindustry and other comparisons. But whenever statistical comparisons are made between national or sector or other levels of expenditure, care is required in their interpretation.

For example, the first volume of the report on the OECD International Statistical Year included the following data:9/

	Canada 1963	Sweden 1964	Belgium 1963	Netherlands 1964
Gross National Expenditure ($ Million U.S.)	425	257	137	330
Expenditure Per Capita of Population ($ U.S.)	22.5	33.5	14.7	27.2
% GNP (at market prices) The "Research Ratio"	1.1	1.5	1.0	1.9

In terms of the common currency (U. S. dollars) and at the going exchange rates, the aggregate Canadian R & D expenditures for 1963 were three times the corresponding expenditures of Belgium, while the research ratios for the two countries were almost identical. Canada's per capita figure was also half again as high as the figure for Belgium. Canadian aggregate expenditures for 1963 were also significantly higher than those for Sweden and the Netherlands, although the per capita figures and research ratios for these two countries exceeded the corresponding figures for Canada by fair margins.

One other set of figures should be also mentioned in this particular context. In 1963-64, the United States is reported to have incurred gross national expenditures on R & D at an annual rate of just over $21 billion, which gave a research ratio of 3. 4 and a per capita expenditure figure of about $110. *

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* Reference 9/, page 14, Table 2.

Four main points emerge from these comparisons. First, in terms of the potential output of new science and technology in one country as compared with another, it would appear that the United States was ahead of the other countries because its input in money terms was so very much higher than the inputs of the other countries. On the same basis, Canadian output was potentially higher than that of Sweden, the Netherlands and Belgium. Second, if R & D "production" costs differ significantly between the United States and the other countries, then "R & D exchange rates" should also be calculated and applied to the relevant expenditure data. * Third, per capita expenditure figures do not reflect such factors as the industrial structure or the age structure and educational levels of the population of the various countries. Finally, the research ratios of "similar" countries may at least provide some indication of how the resources available in each of them were allocated in the years in question and, indeed, may also provide some useful indications of how the allocations to R & D and to other activities have been changing in each country over a period of time.

When comparing levels of research and development activity within the industrial sector, it has become common practice to speak of the "research intensity" or "R & D intensitv" of particular industries. ** When

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* Christopher Freeman and his colleagues developed a "research exchange rate" and used it in their paper for OECD listed in Appendix I, Reference 10/. However, such calculations are still very much in the experimental stage and their use is not problem-free.

** A company or an industry may also be distinguished as "research-intensive" or "development-intensive", the former designation referring to companies or industries which tend to do most of their own basic and applied research and the latter to those companies or industries in which product and process development tend to predominate.

designating intensity on the basis of expenditure measurements, the R & D figures are often expressed as percentages of the figures for sales or profits or value added for the same business or calendar year. But this technique does not take into account, for example, the inevitable time lag between the performance of the work and the appearance of any resulting innovations. It does not take into account the fact that some projects are not successful or the fact that business enterprises undertake R & D both "offensively" and "defensively" and, in certain instances, in order to earn income from the sale of their accumulated "know-how". In the "science-based" industries, in particular, the R & D financed by governments for some military, political or other purposes may vary considerably from country to country and from time to time. And in industries in which large international corporations participate, it is the practice of a number of them to allocate the available funds and projects among their affiliated companies on the basis of their particular areas of scientific or technical competence and their abilities to complete the innovation process with little further assistance.

Problems also arise in the comparison of the growth rates of national, sector and other R & D expenditures. Growth rates in current dollar terms can be calculated from the results of the various surveys and questionnaires, but it is very difficult to measure the difference between these apparent rates and the "real" rates of growth. There are a number of reasons for this, apart altogether from any general increase in costs. For example, the techniques of experiment and investigation have become generally more complex and sophisticated -- as have the problems themselves -- and the equipment has become correspondingly more expensive. On the other hand, research salaries have increased in the last decade and some of this new equipment has been installed primarily to reduce the amount of time the individual researcher or his technicians spend doing "chores". Again, prices and salaries have not increased uniformly in all countries, nor are all countries equally engaged in the same fields of scientific research or technological development.

The interpretation of the implications of the apparent growth rates is affected by a number of other difficulties. For example, while growth for growth's sake or for the sake of "fashion" can be wasteful, it is not always possible to know in advance how best to manage an R & D project whose outcome is uncertain. And there are growth constraints or encouragements which are determined more by profit levels, traditions, taxation and duties, incentive and assistance programmes, and the supply of skilled manpower than by the existence of a good idea or a pressing problem or of an opportunity to exploit the results of a promising project.

There are, in practice, two problems that pervade the assessment of comparative R & D expenditure levels and growth rates and of research ratios and intensities if these levels, ratios, and so on, are considered in isolation from the associated political, historical and economic factors. In the first place, the assessments can say little, if anything, about the appropriateness of the levels and ratios and, in the second place, they can say nothing at all about the quality of the work which was actually done.

The research and development employment data that are obtained from R & D surveys are normally supplemented by information from census material and from the special surveys-in-depth covering all types of scientific and technical manpower which most industrialized countries undertake from time to time.

In Canada, R & D employment data have been included in all the recent biennial R & D expenditure survey reports. On a more general basis, however, the collection and analysis of statistics on scientific and technical manpower began in this country during the Second

World War. At the federal level, the principal agencies active in this field in recent years have included the former Departments of Labour, and Citizenship and Immigration, the new Department of Manpower, the Dominion Bureau of Statistics and the National Research Council. Decennial censuses have also provided information and, in addition, nongovernment bodies such as the Association of Universities and Colleges in Canada, the Canadian Association of Physicists, the Canadian Council of Professional Engineers and the Agricultural Institute of Canada have done, or are doing, work on manpower questions in their particular fields of interest.

While a census may be more complete in terms of coverage, the special manpower surveys can usually include much more detailed information because the individual scientists and engineers are required to respond to the questionnaires. The main problem with these surveys is that they have to be designed to obtain -- at one and the same time -- detailed information and the highest possible voluntary response rate.

To be useful, manpower surveys must include a broad range of questions covering formal education and training, fields of skill and specialization, and work functions and experience. It is not enough, for example, to know that a graduate scientist of 10 years' standing took his first degree in physics and did graduate work in nuclear physics because there are fields of science in which formal instruction was not given 10 years ago. Work functions may also present difficulties because some scientists and engineers divide their time between two or more functions. To overcome this problem and to make comparisons more useful, some of the most recent manpower surveys have made use of the "full-time equivalent" technique of measurement instead of counting heads on a "prime employment" or "main employment" basis.

With regard to R & D employment statistics, it is common practice to make international, interindustry and other comparisons between aggregate levels of employment, growth rates, and so on, and to calculate ratios which relate R & D personnel to the corresponding population, labour force and industry employment statistics. It is also fairly common to find comparisons made on an interindustry or intersector basis involving the ratios of professional to technical and other supporting R & D staff. * In addition to the problem of "full-time equivalence", the usefulness of comparisons like these is limited by the consistency with which the various classifications and definitions are formulated and interpreted.

The most important limitations in any assessment of the significance of R & D employment data by itself or in relation to the modes of employment or other classifications of manpower are that the figures may reveal relatively little about the real "capability content" of the personnel concerned or about the effectiveness of their utilization.

Research and Development Output Statistics

The output of research and development activities is, basically, new knowledge and experience. ** Some R & D activities are supported as ends in themselves -- at least initially -- but most activities have practical objectives of one kind or another. The ability of any one person or company to measure the "worth" of a particular piece of research or package of information is limited by the ability of that person or company to foresee the long-term "value" to all potential users in terms of a common

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* The term "QSE", meaning "qualified scientists and engineers", is commonly used in international comparisons to designate the professional segment.

** Much of this new knowledge and experience may, of course, be incorporated already in identifiable "hardware" or "software".

currency or some other acceptable standard of measurement. While long-term "worth" measurements of this kind have not been undertaken, there are a number of ways in which shorter-range appraisals of R & D activities can be made in noncurrency terms.

For example, one method of appraising and comparing the science-related output of two countries or of two particular disciplines is to count the number of papers which have been published over a specific period of time. One difficulty with this technique is that it cannot distinguish important from unimportant contributions and, unless some form of type classification is employed, the single lengthy review paper will count the same as each of the 10 or 20 or more constituent papers on which the review paper has been based. But since new science is usually written up and published with fewer constraints than new technology, this paper-counting method may provide a very rough -- if incomplete -- guide to the status and growth of research output in a particular country or a particular field.

One method of appraising the technology-related output of a country is to examine the statistics of the patents issued to its own nationals over a period of time. These figures may then be compared with the patents issued to other nationals in their own country or in the country in question. Once again, the quality of the respective outputs cannot be measured and, as far as the country goes, only a fraction of all the patentable inventions ever issue formally as patents. There is also the problem of the time lag between application and issue, the problem of differences in the rigour of examination prior to issue, and the fact that formal R & D activities are not the only activities from which patents may result. Patent-counting for appraising the "worth" of new technology is probably a great deal less satisfactory than paper-counting is for appraising the "worth" of new science.

The "Technological Balance of Payments"

In their recent paper, Christopher Freeman and his colleagues commented as follows on this relatively new concept of measuring and comparing international flows of information and the "productivity and effectiveness" of R & D activities:10/

> "The 'technological balance of payments' of a country compares its payments to other countries for technical know-how, licences, and patents, with its receipts for these items. It would be reasonable to expect that an underdeveloped country would have negligible receipts but significant outlays, depending upon the scale and speed of its development plans, and would thus have a substantial and long-term 'deficit' in its 'technological balance of payments' until it reached industrial and scientific maturity. A developed country on the other hand would normally have substantial receipts as well as payments as a result of its own successful research and development work. A persistent 'favourable balance' would be an indication of considerable success in developing new processes and products, arousing demand for licences and know-how from abroad. The firms which have developed new products or processes may prefer to export or to start production by subsidiaries abroad rather than grant licences or sell know-how. But in the second case some 'technological payments' will normally flow to the parent firms even though this flow may sometimes be distorted by international taxation factors ... Nevertheless, although only a partial

> and incomplete measure, the 'technological balance of payments' could be a useful indicator. There is, of course, no stigma attached to an 'unfavourable balance'. It may well represent by far the most efficient and economical method of acquiring know-how."

There is, so far, no generally agreed definition of the "technological balance of payments" concept and only an evolving methodology for the collection and analysis of the statistics. The difficulties are formidable. For example, exchanges of "know-how" between formally affiliated companies or between governments may take place under a number of different arrangements, some of which involve no identifiable cash flows at all. Even the exchanges between two or more independent companies may involve only a nominal cash flow or none at all depending upon the terms of the cross-licensing, or "know-how" agreements. And over and above these cases, there is the pervasive problem of deciding how much any piece or package of information is "worth" in different currencies or in different business or political situations. In spite of these difficulties, an increasing number of countries have begun to collect "technological balance of payment" statistics.*

Canada has always had a "deficit" in its "technological balance of payments" -- and may always have one. With time, Canadian receipts may become more substantial. But it will always be difficult to arrive at a figure for the Canadian "balance" because of the special relationships which exist between some Canadian and foreign business enterprises and because cross-licensing and exchanges of "know-how" should become more common as the capacity of Canadian companies to generate new and marketable scientific and technical information increases in the future.

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* Data of this kind were gathered for the OECD international Statistical Year (1963-64) project.

The "Brain Drain"

The most general statement that can be made about international migration statistics is that they are not readily available. With regard to data for Canada, for example, Professor Louis Parai commented as follows in his study of the immigration and emigration of professional and skilled manpower for the Economic Council:11/

> "Any analysis of the effects of migration on Canada's manpower resources is handicapped by the fact that there is no complete record of the movements of people into and out of the country. Although the number of immigrants is recorded by Canadian authorities, they do not record emigration from Canada and there is no complete count of the number of emigrants who subsequently return to Canada or of the immigrants to Canada who leave the country at a later date. However, some emigration data are available from the immigration statistics of other countries, and an estimate of net migration can be derived from census data. Thus, a reasonably reliable picture of population movements can be pieced together."

The so-called "brain drain" is something more than just a migration of people. It has to do with the movement of large numbers of young, highly trained, creative and talented people out of one country and into several others. In recent years, the "brain drain" has been of particular concern with regard to the movements of scientists, engineers, medical doctors and other technically trained people. As a phenomenon, it has received extensive study in the United Kingdom, for example, and efforts have been made both there and elsewhere to improve the quality of the estimates of migration flows so that the statistics for the groups of people most involved in a "brain drain" may be amenable to more detailed analyses.

Some of the data problems are formidable. For example, Professor Parai's report could say nothing about the "capability content" of the skill and experience which immigrants brought to Canada or which emigrants took away with them. He could say nothing about the reasons for, or the permanence of, the migrations into and out of Canada. These are important points because there is some evidence that Canada is a staging post in migrations to the United States and because a country which gains in number but loses in quality may well suffer a net loss in competence in the longer term. And, in the case of Canada, which has close industrial links with the United States, it is important that permanent and non-permanent emigration should be distinguished because of the new and useful skill and experience acquired by individuals during temporary periods of absence from this country.

There are other difficulties. One is that, for the purposes of international migration statistics, immigration or emigration "head counts" usually depend on the description that the migrant himself gives of his profession or trade. Another is that no consolidated data are available to show whether immigrants actually followed in the second country the profession or trade that they declared at the time of entry. And a third is that no consolidated data exist to show the number of students who later stayed to work in the country in which they received or completed their education.

It is important to recognize, however, that a "brain drain" may be interregional within one country as well as international and that the same data problems arise. It is also important to remember that there are other factors that have to be taken into account in analyses and judgments with regard to this phenomenon -- factors that relate to history, education systems, traditions, and politics more than they do to head-counting.

The "Technology Gap"

The so-called "technology gap" is another new phenomenon which has received a great deal of attention in recent years, particularly in political circles. Its existence has been postulated on the basis of the apparent technical superiority of the United States over the rest of the world -- over Western Europe, over Canada, and so on. Investigations into the "gap" between the United States and Western Europe are in progress. One major project in this area has been undertaken by OECD.

The United States has enjoyed scientific and technical leadership in many fields for some time. In new fields of technology, the United States has often been first to innovate although not necessarily the first to discover or invent. The allocation of resources to research and development in the United States has been very significantly greater than in Western Europe and its recent "research ratios" have been consistently high. The principal "brain drain" from Europe has been towards the United States. These and other arguments have been advanced in support of the "technology gap" hypothesis.

What may lie behind the political and emotional aspects of any "gap" hypothesis may be related more to the enormous economic potential of U. S. technical "know-how", risk-taking capacity, resource availability, management ability, and so on, than to what the hard statistics which do exist happen to show. But it is pertinent to note that "gaps" exist between the different regions of the United States itself for the same kinds of reasons. On the other hand, it should be remembered that the United States has no internal tariff barriers, that it has a single working language, and a single system of law relating to patents.

Whatever the eventual outcome of the current studies, a number of points can be made at this stage. The first is that no "gap" can be based solely on disparaties in the levels of research and development because R & D are only two of a wide range of scientific and technical activities which can make direct or indirect contributions to economic needs and aspirations. The second is that science and technology are only two kinds of knowledge available for the conduct of business. The third is that, while the country or the industry spending more on R & D may have a better prospect for economic gains, the real test comes in the market. And lastly, some of the people and agencies who can significantly influence the outcome of the test of the market place often have nothing at all to do with R & D or with production or marketing but have a great deal to do with credit and foreign exchange facilities, transportation arrangements, and a variety of legal and regulatory matters. It is therefore impossible to measure the size of any "technological gap".

PART IV

INVENTION AND INNOVATION

There is general agreement among economists that science and technology and research and development have made contributions to economic growth and development and to improvements in the productivity of capital and labour. However, the problem of quantifying these contributions satisfactorily has proved to be difficult. In this part of the paper, it is not proposed to discuss R & D, invention and innovation in the context of economic growth or to comment on the problems of measurement. * Its main purpose is to comment on some of the mechanisms relating to those inventions and innovations which have their foundations in science and technology.

A good deal has been written about successful inventions and innovations, but little about the unsuccessful ones. The one general comment that may be made is that inventions and innovations, like fingerprints, are all different. Jewkes, Sawers and Stillerman examined a relatively large number of successful inventions in a recent book. They made this point about the histories of these particular inventions: 12/

> "Each was an intricate skein which refused to shake out into simple lines and which tended to become more complicated the more thoroughly it was examined. Some of the histories, indeed, appear more sharp cut than others ... But, at every

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* At the time of writing, it is planned to include a chapter introducing this subject in the Fifth Annual Review which will be published by the Economic Council of Canada later in 1968.

> point, the contributions of even the most outstanding workers are clearly bound up with the speculations, reasoning, guesses and mistakes of others."

While statistics covering R & D activities and patented inventions are now obtainable in some detail, data relating to specific inventions and innovations or to the discovery-invention-innovation process as a whole are not.* However, the ad hoc Panel on Invention and Innovation set up by the Secretary of Commerce of the United States included in its January 1967 report some "rule of thumb" figures for the distribution of costs in certain successful innovations. These figures -- which follow -- were based on the personal knowledge and experience of the Panel members:13/

Activity	Percentage of Total Cost
Research - Advanced Development - Basic Invention	5 - 10%
Engineering and Designing the Product	10 - 20%
Tooling - Manufacturing Engineering	40 - 60%
Manufacturing Start-up Expenses	5 - 15%
Marketing Start-up Expenses	10 - 15%

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* In this part of the paper, the term "innovation process" has been used as the short version of "the discovery-invention-innovation process as a whole".

The most important point emerging from these figures is that R & D costs are usually very much smaller than the costs of the other activities that make up the remaining parts of the innovation process.

Research, Development and Invention

The history of the linking of R & D activities and invention was discussed by an American commentator, Donald A. Schon, in a recent book. In particular, he had this to say in the Introduction:14/

> "The concept of organized scientific research is derived from the German universities of the nineteenth century. Organized invention seems to have come into being with Edison, around the turn of the century. And fifty years ago the notion that established corporations should hire scientists and engineers and undertake systematic enquiry into their own products, materials and processes, with the aim of improving existing products and processes and developing new ones -- the idea of industrial research -- was a strange one."

Later in the same book, Schon identified three stages in the history and growth of the "research cycles" of industrial corporations:*

> "In the first, or craft, stage, technology is regarded as the private property of a few individuals. It is empirical and intuitive. It comes only through life-long experience. The sign that a man has it is his membership of the guild or its equivalent ....

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* Reference 14/, pp. 50-51.

> "In the second stage, scientific analysis of production begins to replace craft. Engineering begins to replace mechanical ingenuity. Chemistry begins to replace kitchen formulations. The new scientific grasp of production pays off in increased productivity, reduced cost and better quality control. Technical service to sales begins. . . .
>
> "In the third stage, technology comes into its own. The company has extended and consolidated its scientific grasp of production and quality control. It begins to undertake research into the materials and processes related to its field without being sure where that research will lead. Work is done toward the development of new products and processes to replace those in existence. Research and development is no longer a service to production or to sales . . . The company becomes accustomed to investing a certain percentage of its sales in research which is accepted as a major corporate function."

Countries and companies investing in research and development activities are doing so in the hope of gaining future economic, social or other benefits from any resulting inventions. But invention is seldom a straightforward business. The scientist or engineer does not sit down to "invent". In the R & D laboratory, his real work is discovery and demonstration of new knowledge, the solution of particular problems, the investigation of certain promising possibilities, and so on. In design and production activities, the engineer's role is to solve design and production problems. Any identifiable invention is therefore likely to be a by-product of these activities, and it may have been the result of a chain of events which had no clear beginning or ending. Plans and objectives, for example, can change and during the lifetime of a project, frustrations or incentives can appear for technical reasons or for reasons having little or nothing to do with the progress of science and technology.

There have been elements of randomness and accident in the history of many inventions but, on balance, it would appear that the majority of inventions have been based on some aspect of the science or technology of the time. They have usually come about in a step-by-step -- or evolutionary -- fashion rather than in a sudden, spectacular, and revolutionary way. Increasingly, however, it appears that even "revolutionary" inventions can also be traced back to particular scientific discoveries or demonstrations. But in the background to inventions of all kinds -- however simple and obvious they may now seem -- has usually been a great deal of hard and painstaking work to overcome difficult technical problems.

The techniques and methods of invention tend to vary from field to field. In certain areas of chemistry, for example, it may be more appropriate to speak of "discoveries" than of "inventions" because the synthesis and testing of hundreds of compounds in the hope of finding one with all the desired properties is an empirical, trial-and-error procedure which may have a high or very high degree of uncertainty of outcome and a heavy cost in time and money. Two of the most important factors in work of this kind are knowing where to look for the possible new compound that is required, and knowing when to give up the search. In more mechanical fields, on the other hand, the methods of invention are a good deal less empirical because the end-product or the mechanism or the system has to be conceived as a whole at the start of the work, and because there is usually a greater amount of relevant background knowledge in existence. In the more mechanical fields, the engineer or scientist with the greater imagination and "flair" may be the more successful inventor. But history shows that significant progress in any field of science and technology has not always been made by those most familiar with the available knowledge in that field.

In any one country, only a small fraction of the industrial or manufacturing companies are known to support formally organized research or development activities or to support R & D in outside institutions. In Canada in 1961, for example, approximately 500 firms reported having made R & D expenditures.[15] For the same year, the total number of manufacturing companies in the country as a whole is reported to have been upwards of 32, 000.[16] The many thousands of companies without laboratories -- most of them small companies -- were not necessarily "inventionless". They may simply have organized their inventive activities differently. However, a significant trend has been emerging in recent years. The invention capabilities of an industry or a company are tending to be concentrated more and more in laboratories and in divisions or departments performing combined development, design and production engineering work. There are many reasons for this, such as the increasing cost of experimental work, the speed and complexity of recent technical advances, competitive situations that require "instant" solutions to particular problems, and the health, safety and other regulations which require thorough testing and evaluation of certain classes of products prior to marketing.

It has sometimes been suggested that the scientific research performed in universities ought to be directed more often towards the solution of current and future social and economic problems and into projects that will give industry more information that it can usefully apply. It has also been suggested that patent literature contains many new and interesting ideas which "work" but which require a great deal more background investigation of the kind the universities might be free to undertake in order to understand how they work. In other words, university research should be more effectively "directed" and have a higher "invention coefficient". But in practice, few university projects nowadays are not "directed" in some way for the reason that the university professor must apply to one or more agencies for financial support for his projects. Those responsible for making the policies under which such applications are screened and granted have considerable influence on the kind of work done in these institutions. In practice, also, a growing proportion of the research work of a university involves the training of students in the procedures and methods of research. And, in practice, the project preferences of university professors do not always conflict with research into industry-oriented problems or into problems of explaining observed phenomena. Information applicable to this area has not yet been appraised. However, if there is to be one R & D sector in which the project choice of the individual should be relatively free, then the universities -- with their parallel responsibilities for teaching and research -- would appear to be it.

Unlike university laboratories, the major preoccupation of government laboratories should be with projects that have some potential application in the economy, in society, or in the world as a whole. As in industrial laboratories, government R & D activities are normally designed to solve particular problems, to increase productivity and reduce costs, to combat obsolescence, and to investigate the feasibility of proposed new projects. Government laboratories also have unique responsibilities for work in the social and military fields, for providing research support and services for the private sector which are beyond the means or scope of that sector to undertake, and for providing facilities and measures to encourage greater technical competence in industry as a whole. In these circumstances, however, governments' own laboratories may or may not produce their fair share of inventions.

In summary, while research, development and inventive activities may now be more closely linked than ever before, there is no way in which R & D activities by themselves can assure success in invention.

Development, Enterprise and Innovation

As noted at the beginning of this paper, few inventions are ready to be exploited in the market place in their initial forms. A great deal of development, design and other engineering work usually remains to be done before the commercial versions can be put on the market or placed in service. For example, the technical problems involved in producing a new material on a large scale may be quite different from those of laboratory-scale or pilot plant production, or the degree of purity of the material demanded by customers may be quite different from the purity anticipated as satisfactory by the producer, or the method of handling the material in bulk may require the development of special containers or vehicles. The majority of a company's R & D expenditures are usually made for development work done in the post-invention stage of the innovation process. Experience also shows that only a relatively small percentage of the available inventions ever reach the end of this process. Those that do survive will have passed successfully through a series of feasibility and other studies to determine their potential from the technical, economic and market points of view. This work will have helped to narrow down the remaining technical uncertainties and to identify more closely the size and nature of the commercial costs and risks involved. As a potential new product, process or service moves from the invention to the post-invention stage of the innovation process, the purely technical appraisals and judgments of the scientists and engineers concerned tend to be supplemented by market considerations in which the appraisals and judgments are often made by people whose functions are essentially nontechnical.

It is not always possible to predict in advance the market reaction to entirely new and novel products and services. In spite of advancing market survey and product-trial techniques, the public's reaction to new versions of older products may be much more readily anticipated. For this reason, innovations -- like inventions -- tend to be evolutionary rather than revolutionary. At the level of the individual company, innovations may owe a great deal more to imitation than to "in-house" invention, but substantial pre-production development efforts may still be required. And a company that provides superior "software", follow-up, or maintenance services may be in a strong business position regardless of whether its product innovations are novel or have been based on imitation. Innovation in production processes is more likely to be cost-dependent than market-dependent unless the product itself undergoes a significant change at the same time.

In addition to invention and imitation as sources of innovation, there is a third possible source -- innovation by "invasion" or "inducement". Innovation by invasion would occur, for example, when one industry produced a marketable substitute for the product of a second industry and, by so doing, forced the second industry to begin manufacturing the substitute as well as its regular product. With regard to inducement, suppliers of advanced components and equipment may, through sales of their products, induce their customers to innovate. In the reverse direction, however, customers may demand different or higher quality products from their suppliers. Another form of innovation by inducement is through the widespread use of realistic but mandatory standards and codes for technical performance, safety, and so on.

Companies can, and do, seek opportunities to improve their innovation potential by using what might be called the "bootstrap" technique. One variant of this technique involves subcontracting work from larger and more technically advanced companies which also provide the necessary "know-how" to enable the work to be completed.

One very important function of an R & D laboratory in industry, at least, is to act as a "listening post" and to undertake the continuous appraisal of the current publications and the patent positions and products of competitors, so that its own programme of work can be effectively designed and its own bargaining posture in licence and "know-how" negotiations strengthened. But however well the "listening post" functions, the opportunities for eventual innovation will vary from company to company and from time to time.

Technology-based innovation is as much a function of the public sector of the economy as it is of the private sector. Governments have their own research and development projects to plan, and their own operations and programmes to make effective. Appraisals and judgments relating to social and other public innovations are the responsibility of elected and appointed officials whose decisions have to take into account such factors as the possible public and political reactions to new expenditure proposals, existing and potential agreements with foreign governments for co-operation in research and for the exchange of information, the possibilities for "spin-off" from the government's own research, and so on. But whether the aim of the technology-based innovation is to improve amenities in the public sector or to foster growth in the private sector, or whether it is the adaptation of an old idea rather than the invention of a brand new one, there will be some risks involved and there will be problems of timing. In both the public and private sectors, watchfulness, imagination, and enterprise are therefore prime prerequisites for innovation.

The innovation process as a whole needs the talents and resourcefulness of at least five different kinds of people. These are: the scientists, engineers and other technical people who look after the R & D, the design and engineering aspects of a project; the project manager who becomes identified with the project and who carries it forward through the laboratory, through feasibility and market studies, and through the other stages right down to the assembly line; the marketing and sales specialists who find the customers; the entrepreneur who recognizes the need or the opportunity for innovation, who decides to bring the necessary resources together, and who accepts the risk of failure; and the venture capitalist -- who may be an individual, an organization or a government -- but who, after appraising the risks and resources involved, is willing to back the project financially (and managerially as well, if necessary). Occasionally the engineer, the project manager, the salesman and the entrepreneur are one and the same person. Very rarely is this person also the venture capitalist.

The Inventor

Inventing, like research and development, is a dynamic activity but it is often a much more personal activity than R & D.

In their book, Jewkes and his colleagues discussed the case histories of some 60 of the most prominent technical inventions of the past hundred years or so. They concluded that they could classify more than half the cases as "individual" inventions because much of the pioneering work had been carried out by men who were either working on their own with limited resources and without the backing of a research institution or who were working in universities and in other institutions where they were free to follow their own ideas. *

However, there are nowadays some areas of invention which are effectively closed to the majority of independent inventors. There are areas of growing scientific and technical complexity or of inherent empiricism

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* Reference 12/, p. 82.

in which intuition, "flair", and ingenuity have to be supplemented with knowledge, experience, equipment, and financial resources. In these circumstances, it is not surprising that "inventing" is becoming more of a company-based team effort.

Nevertheless, a number of comments regarding inventors and inventing should be made. For example, it is not unknown now -- and it never was -- for the relatively untrained independent inventor to work in collaboration with research and other technical people in industry. Nor is it unknown for the formally qualified inventor to prefer independence because he feels unsuited for work in an organized environment. In practice, however, and whatever his training, the inventor who is on the "inside" of a company usually knows more about the technical problems the company is facing, and about the resources and objectives of the company itself, than do the independent inventors on the outside.

The problem of helping the independent inventor -- whatever his qualifications and experience may be -- to make a continuing contribution to the economy and to society is a very real one. Such men have undoubtedly stimulated technological change and economic development in the past. But the areas in which they may be able to make contributions in the future could be further restricted because the necessary levels of formal training and experience and financial support are likely to be rising more rapidly than they have done up until now.

The Small Company

The "small" company may be defined in various ways. For the purposes of this discussion, the small company is one which has fewer than 100 employees, whose products are science- or technology-based, and which is probably less than 10 years old. *

The important point about small companies is that in many of them there is the potential for growth into much larger companies. But whatever the potential, there is little room in small companies for making expensive mistakes. Growth and development depends primarily on the abilities, courage, energy and enterprise of a few people and on the way in which the limited resources available are utilized. Some of the best known of the new, large and successful technology-based companies which are now setting the pace of innovation and growth around the world have grown from relatively small beginnings only a decade or so ago.

Small companies nowadays may be "born" in a variety of ways. One of these ways has been described recently by Dr. Harvey Brooks:**

> "(the) 'spin-off' of small science-based firms from Government laboratories and larger industry occurs when technology reaches a stage at which the risks of further innovation can be borne by a smaller organizational unit than the parent organization. The process of spin-off is often

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* It is usually the practice to include a sales or capitalization figure in the definition. Some small technology-based companies, however, may have high sales revenues per employee and would therefore be excluded.

This particular discussion centres on technology-based secondary manufacturing companies. Many of the points raised may be applied equally to small productive units in the primary and service industries.

** Reference 2/, p. 33.

> assisted by the fact that the new entrepreneur may be partially supported by the parent research organization. A spin-off organization serving a specialized sector of the market is often more effective in the later and more applied stages of innovation than is a large organization with much greater technical resources."

The "profile" of a young, small, technology-based company might include the following elements: the principals are scientists and engineers; each principal looks after a number of jobs; R & D responsibilities are shared according to background experience, but the activity is not always formalized; the products are specialized and have a high technical content; the production methods are likely to be skill-intensive rather than capital-intensive; there are not many customers; the shortage of money for the exploitation of good ideas and innovation possibilities seems to be chronic; the larger competing companies often make the hiring of skilled labour difficult, if not impossible; sophisticated research and test equipment cannot always be purchased when needed and improvisation is frequent; management skills in cost accounting, inventory control, and so on, are often lacking; the company was a very high-risk investment initially, but the potential returns also seemed very high; the start-up costs were a great deal higher than they would have been 15 years ago; the principals all have a financial stake in the business but, after the first three years, some of the original ones left the company and others were taken in to replace them.

Many small companies start up in order to exploit ideas and potential innovations that one or more of the principals of the company worked on during their previous employment. In fast-moving branches of technology, however, the number of years of product life and the number of models or model changes which are possible may be quite limited. Those companies that wish to remain viable must therefore begin soon after they are established to plan some form of strategy that will lead to new product lines when the old ones disappear. This strategy will usually include some research and a greater amount of feasibility study and development work.

In a paper published about four years ago in the United States, Arnold C. Cooper examined the hypothesis that research and development work performed in a "small" company could often be more effective in terms of the results obtained per dollar spent than R & D work performed in a large company. 17/ Although Cooper did not define his "small" company, he did find some support for the hypothesis in the material he gathered for his study. The evidence he gave suggested that the average capabilities of staff members in small technically oriented companies, in particular, tended to be higher than in similar, but larger, companies. It appeared that there was considerably more concern about project costs in the small company. Company goals were more widely appreciated. The staff, being physically closer than in a larger company, were in better communication with one another and were more sensitive to business prospects since each one of them might have a stake in the business. Small companies, of course, also had offsetting disadvantages. Among these were smaller resources, narrower technical experience, and the lack of people with the knowledge and ability to perform very specialized technical skills. However, even if product development in a small company was performed efficiently, this did not ensure competitive success in the same way that it did not ensure success in the larger company.

The most challenging problem which small companies face is not the lack of potentially exploitable ideas but the problem of getting adequate infusions of venture capital when they will do the most good. Generally speaking, the holders of venture capital have little technical appreciation of the companies' products but have some feeling for the risks involved. The dynamic small-company entrepreneurs, on the other hand, usually have little or no capital, a modicum of management experience, and an inadequate understanding of all the production and market factors involved. Much depends on the kind of independent appraisals that are given the venture-capital holders before they weigh the prospects and invest in the small companies. Appraisals, therefore, have to be competently done. And if the money is invested, management assistance may also be required. Otherwise, many potentially valuable contributions to innovation which technically expert small companies can make will be lost to the market place.

Some Factors Associated with Innovation in Larger Companies

Regardless of their past contributions, and regardless of how productive of ideas or energetic and enterprising they may be, no country can rely solely on its independent inventors or its small companies to come up with all of the potentially significant inventions of the future. Larger companies and formally organized R & D institutions in both the public and private sectors have roles to play in over-all national development.

Watchfulness, imagination and enterprise are not the prerogatives of one industry or of one size of business enterprise. Within the limits imposed by management skills, the larger companies usually have more resources with which to sustain innovation opportunities. Robert A. Charpie, a senior executive in U. S. industry, spoke about staying power in a recent paper. He said:[18/]

> "History shows us time and again that it is necessary to have substantial staying power in order to see even the best ideas through to complete success ... Thus, although a small company may be more likely to be committed to a revolutionary

> idea leading to dramatic economic impact, the chance of successful technological innovation is much greater in a large company if and when such a company can become totally committed to such an idea."

In the larger, more mature and experienced companies, the entrepreneur and not so much the venture capitalist is the key figure. Another American, Sumner Myers, put the position this way:19/

> "Entrepreneurial skill is the crucial factor in the innovation process. It takes a special kind of ability to look at a proposal and see its market -- where it is, how big it is, and, most importantly, how accessible it is. Many innovations have met every test but the last. The market exists, but the firm cannot reach it. Unfortunately, it is too easy to underestimate both (1) what it will cost to take an idea and translate it into successful business -- and (2) how much time it will take. The combined effect can be disastrous."

The encouragement of innovation within a particular business enterprise will come from pressures, opportunities, needs, problems, and so on, both inside and outside the company itself. The initiative to undertake particular innovations within the company may come from the most senior people or it may come from any one of the various levels below them. But for innovation, in general, to be accepted as an integral part of company policy, it has to have the full and firm commitment of the most senior people because it is these people who set the tasks and objectives for the company as a whole.

Since innovation means change, and since change is always resisted to some degree, it is remarkably easy for a company which has become established and profitable to become less enterprising than it once was and to coast along on the momentum gained from its past activities and achievements. Larger companies can be reluctant to innovate for a variety of reasons. For example: companies with extensive investments in physical plant may not wish to replace this plant until it has ended its useful life; they may be poorly equipped in terms of business knowledge to enter new markets with their existing products or to enter existing markets with new products; they may actively discourage the exploitation of ideas or inventions originating elsewhere -- the so-called "NIH" or "NOT-INVENTED-HERE" factor; their internal and external technical communications and information transfer systems may be inadequate or ineffective; they may have insufficient or insufficiently adaptable resources to seek new business at the particular time at which the potential profit margin makes this new business attractive; or, after investigating the potential market for "evolutionary" new products, they may conclude that the products of the next stage of the evolution will meet with considerable sales resistance.

The pressures that tend to work for and against innovation in larger, established companies may have something to do with the way in which they are organized. For example, a company may be unduly fragmented, with the result that people and ideas are seldom interchanged between its plants or divisions. Some companies may wish to preserve their traditional products and their traditional plant locations because of the particular positions they have come to hold in the local, regional or national social systems. Company goals and objectives may be ineffectively formulated or inadequately understood. Resistance to innovation by a particular level of management may be widespread and dynamic. Or, technology and production may be controlled from elsewhere without adequate appreciation of local opportunities for the manufacture and sale of new or improved products by more efficient methods.

Innovation initiatives in the larger companies are influenced by the attitudes and actions of governments. This does not mean that governments will necessarily know the answers to the innovation problems of particular companies, because it is unlikely that even the most highly qualified government officials will have more than a general knowledge of the technical, commercial and other factors that affect the operating decisions made in each of many thousands of companies. It does not mean that government programmes designed to stimulate research and development activities will necessarily stimulate subsequent innovation either directly or indirectly, or that programmes that suit the general needs of the larger companies will necessarily suit the needs of smaller ones.

The actions and attitudes of government can, however, enable innovation to take place in the larger -- as well as in the smaller -- companies. The range of measures over which governments have control, and which affect this enabling process, include tax laws, patents and industrial designs, codes and standards, direct assistance and incentive programmes, tariffs, combines and mergers, education, training and retraining, and the governments' own purchasing policies. The precise effect that each of these and other government measures has had on innovation in the past cannot be measured. Even if it could, the relevance of their detailed provisions to the past and to the present does not guarantee continuing relevance in the future in a world which is capable of rapid political, economic and social change. For this reason, measures relating to the innovation process need to be kept under almost constant review.

As with scientific discovery and with invention, there is no success-guaranteed method of innovation, even in larger companies.

Information Dissemination and Technology Transfer

In the principal activities under discussion in this paper, the communication of ideas and information in spoken or written forms between people is of particular importance. Fortunately, communications and technology transfer problems are now under active study in many quarters.*

In view of the greatly increased volume of research and development activities of recent years, it is not surprising that the main emphasis is apparently being placed on the communication and transfer of new ideas and new information. But, in practice, relatively "old" information and ideas may be of just as much value to the innovator. In a way, old ideas and new information can sometimes be interdependent. Sumner Myers put it this way:**

> "New technical information . . . lowers barriers to the implementation of old ideas. Ordinarily, few projects that are economically and technically unrealistic are started. Ideas for innovations that are not yet feasible may be shelved.

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* For example, in Canada the Science Secretariat initiated a study in March 1967 which will examine the present scientific and technical information services in this country and assess the future requirements of the industry, university and government sectors.

** Reference 19/, p. 8.

> Technology must be used in packages;
> if all related pieces are not available,
> the incomplete package may be dormant
> for a decade or longer until some key
> piece of technology completes the package."

The main purpose of information transfer should be to improve the rates of generation and application of scientific and technical knowledge. But attention has also to be paid to the mechanisms of transfer because information costs of one kind or another are incurred.

Dr. Harvey Brooks identified a number of technology transfer mechanisms.* Among these were: the movement of people between the different scientific and technical activities; the spin-off of new missions or enterprises from existing organizations; scientific and technical publications; patents and trade in "know-how"; programmes of education and training; the interactions of customers and suppliers; consulting services; sales and marketing; technical conferences and meetings; and accidental personal contacts.

The potential value of information transfers in the forms of "feedback" or of "cross-fertilization" between fields or branches of science and technology have been of considerable importance historically. Donald A. Schon has noted:**

> "Throughout the history of technology, devices, like the wheel, lever, screw and balance, found their way from one field of technology to another, transforming themselves and introducing novelty as they moved. This pattern of invention by technological displacement

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* Reference 2/, p. 59.

** Reference 14/, p. 17.

> is by no means eccentric. It is characteristic both of recent industrial technology and of the whole history of technology.
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> "This does not mean, of course, that it is entirely a matter of chance from which disciplines or technologies answers come, but that we cannot expect answers only from technologies traditionally associated with a problem. To do so would be to eliminate an important source of novelty."

To transform technical knowledge into specific inventions and innovations requires organized effort on some appropriate scale. In the technology-based industries, the extent and complexity of this effort usually demands that fairly elaborate arrangements be made for both vertical and horizontal modes of transfer. In the more "traditional" industries, the arrangements are usually a good deal less elaborate and the dominant transfer mode is likely to be the horizontal, company to company, mode.

Generally speaking, the larger the company or the more technologically based its products, the greater will be the incentive for the company itself to arrange to look after its own information and technology transfer needs once its objectives, problems, and so on, have been identified. In the small company -- and even in the small technology-based company -- the situation may be much less satisfactory and much less amenable to improvement for a number of reasons. For example, in Canada alone there are over 30, 000 manufacturing establishments which have fewer than 100 employees and which should have information needs of one kind or another. The problems of communicating with so many companies, of identifying their needs and interests, of broadening their technical literacy and capacity, and of providing training in the use of public search and research facilities are formidable. One danger that pervades all information systems is that the designers may pay too much attention to the problems of disseminating larger and larger volumes of information and not enough to considering how these volumes might be reduced by effective prior appraisal.

Applicable technology is not necessarily the most sophisticated or the newest technology. Simple ideas of some antiquity may be more effective than the latest research-based information. In addition to the problems of transfer and dissemination, therefore, there are the problems associated with information appraisal and "distillation". But it is unlikely that this appraisal or distillation can be effectively accomplished without the help of human perspicacity. Indeed, if only a few words were to be used to sum up the key elements in the dissemination and transfer of information, these words would be publications, patents, and people.

PART V

THE FUTURE

Recent literature from sources throughout the world clearly shows that every country with hopes and aspirations for the improvement of its living standards, for the achievement of continuing full employment and for other economic, social and educational goals of a high order, has realized that the extensive inventories of scientific and technological knowledge and experience which now exist are there to be used in the process of reaching these goals. These countries have also realized that the inventories are growing and changing continuously and that any country wishing to keep abreast of this growth and change must also participate to some degree in sophisticated scientific and technical activities.

In modern times, the United States has been a consistent and leading exponent of the vigorous application of science and technology to manufacturing processes and to products and services destined for the market place, but only in the last twenty years or so has the United States come to dominate in the generation of new scientific knowledge as well. However, the United States does not now lead the world in every discipline or branch of science and technology -- and it never has. While no single country except perhaps the U. S. S. R. can effectively challenge U. S. leadership across the broad spectrum of the scientific and technical disciplines and branches, this leadership can be challenged in certain areas by single countries or by countries working together under some kind of co-operative agreement.

In the past, Canada has benefited enormously from international exchanges of new and advanced scientific and technical information, whether they have taken place on an open or on a restricted basis. Without them, our industries, universities or government departments would not have been able to reach the current levels of research and development activity and technical expertise. And this "trade" has not been in one direction. Canadian work has been made available to governments, companies and individuals abroad. In the future, however, the volume of information crossing international boundaries is likely to increase and Canada cannot ignore this trend by attempting to devise methods for substituting national for international sources of knowledge.

In the future, change will become increasingly a way of life and the question of whether the rapidity of economic, social and other changes will become overwhelming and get out of control is a very real one. For Canada and Canadians to shape the process of technological innovation in this kind of environment will involve more uncertainties, risks and difficult choices in the allocation of public and private resources to the full range of scientific and technical activities than have been experienced up until now. These activities will have prior and consequent implications, for example, for education and training, for information transfer procedures, and for government-sponsored assistance programmes. New kinds of studies will be needed to find out how much useful information can be obtained about the appropriateness of proposed allocations and about the quality as well as the quantity of current Canadian activities. And broader, multidiscipline studies which attempt to anticipate as well as to plan will be required to sharpen human judgments about the impact of innovation on society as a whole.

This part of the paper does not provide detailed recipes or prescriptions for overcoming any of these problems in detail or for matching any particular set of economic or social goals and aspirations with the corresponding levels of scientific and technical activity. One of the most difficult problems in finding the required solutions or in matching the goals with the activities is determining how much of what has happened in the past is relevant to what may happen in the future.

In what follows, a number of broad issues are speculated upon quite briefly. Little else can be done until more background information relating to the past has been compiled and until more is known about the kinds of aspirations, goals, needs, and problems that science and technology must help achieve or provide or solve in this country in the years ahead.

In this context, however, two points should be remembered. The first is that from personal incomes and from the profits earned by business enterprises will be derived the majority of the financial support for future scientific and technical activities of every kind in the private and public sectors in this country. The second is that applied research and development activities, in particular, are only useful in economic and social terms when their output -- knowledge and experience -- has been incorporated in processes, products and services for sale in the market place or for distribution throughout society.

Some Problems of the Future

In the past 30 years, science and technology have become increasingly interdependent. As bodies of knowledge, they have become more extensive and complex for the scientist and the engineer and less easily understood by the interested layman. While "rules of thumb" are still being used in the solution of some problems, the reasons why things "work" are being investigated more often and in greater depth. And while accident and accumulated working experience are still helping to build up technology, the new fields are tending to result more and more from the discoveries and demonstration of science. The distinction between "applied science" and technology is narrowing continuously and may disappear completely in the years to come.

But, given the random or accidental nature of some of the most significant discoveries and inventions of the past, it would still appear desirable -- if not always feasible -- for a country such as Canada to have scientists and engineers working in the disciplines of science and branches of technology that have, actually or potentially, the most relevance for the development of the country as a whole. It would also appear desirable that the scientists and engineers who will be able to appreciate the revolutionary nature of discoveries and inventions made here and elsewhere in the future should be members of institutions in both the private and the public sectors. These suggestions are not, of course, without problems. For example, there are the problems of deciding upon which of the disciplines and branches of science and technology ought to be included and of deciding when to increase or decrease the experimental, investigative, or "listening post" activities in each of them. There are the problems of reaching a consensus on the economic, social and political significance of particular discoveries or inventions and of determining the levels of the resources to be committed to the further exploitation of those that show the most promise. And beyond this kind of judgment and consensus are the problems of coordinating the efforts of the various agencies, institutions, laboratories, and educational establishments.

Not long ago, the kind of education and training that the undergraduate student of science or technology received in Canada or elsewhere in post-secondary institutions was usually adequate -- if effectively applied -- for the kind of world in which most of these students would spend their working lives. But in the future, the knowledge which the undergraduate acquires in school may tend to become outdated in a shorter time, and periodic effective re-education or retraining will become more of a requirement than it is now. In the longer term, however, the effects of the rates of growth of certain areas of knowledge and specialization on the enrolment of undergraduates in science and technology may be indistinguishable from the effects of social, political and other pressures. But it is conceivable that these rates of growth and specialization, when combined with the need for continuing education and training, may encourage undergraduates to enrol in courses in subjects that are growing and changing less rapidly. In these circumstances, it is possible that research work in the disciplines and branches of science and technology might remain relatively attractive but that less "exciting" work on the application of knowledge in these fields might not attract scientists and engineers of sufficiently high calibre or in adequate numbers.

From the point of view of the efficiency and effectiveness of social and economic activities, at least, it is clear that the problems involved in utilizing all the various kinds and grades of scientific and technical ability in any country are going to be formidable. For example, the available -- and the best of the available -- personnel in each kind and grade should somehow be shared by regions, sectors, disciplines, activities, work functions and inclinations in accordance with needs, problems, potential contributions and other criteria. They should be encouraged to become more -- or less -- geographically mobile as these needs, problems, and so on, require. There should be more new personnel in some fields and fewer in others, or they should account for a higher -- or lower -- percentage of the total labour force than at any time in the past. Problems like these have never really been solved, and may not be amenable to solution in the future. But if the general level of scientific and technical competence in this country is to be raised at all, policies and programmes will have to be designed to avoid frustrating the tremendously creative talent and initiative which some of the people have.

Governments may be expected to play a leading part in designing these policies and programmes and in providing services that will help to guide the allocation of resources into scientific and technical activities generally. One of the most important ways in which these activities can be made more efficient and effective is through better continuing co-operation, communication and understanding between government agencies, companies, industries and the various education systems. Although co-operation, communication and understanding may have become more effective in Canada in recent years, it seems clear that there are going to be many opportunities for government and other initiatives to improve them still further in the years to come. There are now, for example, larger numbers of junior teaching and research staffs in the expanding universities in Canada whose experience of industry has been limited and who may have relatively little understanding of the contributions they might now make to the solution of some of the scientific and technical problems faced by individual companies or industries.

Research and development expenditures have been rising steadily and regularly in the industrialized countries of the world for the past decade. However, some slowing down in the rates of growth of federal government R & D expenditures in the United States, at least, has recently become apparent and there may even be a slight decrease in the corresponding aggregate levels between 1967 and 1968.* The question of the continuously rising levels of R & D expenditure in that country was discussed by the President's Science Adviser in an address given last year. In particular, Dr. Hornig said:20/

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* See, for example: "R & D Expenditures", by Dr. Victor J. Danilov, Industrial Research, January 1968; and "Money for Research", by D. S. Greenberg, Science, October 13, 1967.

> "The simple fact is that science and technology, research and development, have changed from being frosting on the cake of defense expenditures, health expenditures, and so on, to being a significant national expenditure which must compete with other claimants on national resources. The question is not whether we should have basic research, whether we should have research and development, or even whether it should continue to grow -- but rather in what ways and for what purposes it should be expanded. The answer to this question will have to be supplied not by me but by all of us.
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> "What has happened seems plain enough to me. Not so long ago, science was 'pure' and could be conducted by people who talked largely to each other; now the country has become convinced of its significance and has provided the resources which have enabled it to grow into an important national activity. By any standards, we provide a higher proportion of our very high national income to science than does any other society in the world. But now, instead of languishing in the wings, science is on front stage center; it is in the spotlight and the quality of its performance is reviewed by public critics in the popular press."

While engineers and scientists may now have a new and unaccustomed duty to make known the hopes, opportunities and challenges of their work, they also have a duty to explain their past work in ways intelligible to non-expert but interested members of the general public. By the same token, however, these same non-expert but interested people must become increasingly familiar with the background to the problems involved in the generation and application of science and technology. On the other hand, the non-experts should become involved as little as possible in what are essentially scientific or technical judgments.

Although the less-developed countries of the world are undoubtedly aware that the generation and application of science and technology have potential social and economic values, these countries usually lack the resources to implement the domestic policies that may seem to be appropriate. In this international context, Canada is fortunate in having steadily growing reserves of most of its natural resources and of its skilled manpower. It also has, in embryo, an institutional structure for scientific and technical activities which should be capable of adaptation to the circumstances of the 1970's. In addition, it has a growing degree of skill in the management of its resources and its enterprises. All these factors have important parts to play in the development of the country as a whole. But a listing of all the potential scientific and technical challenges and possibilities for large-scale innovations in Canada for the next decade or longer has not yet been compiled.*

While there will be many challenges for science and technology and many opportunities for innovation in Canada and elsewhere in the future, circumstances may also arise to discourage the further evolution of technology-based innovations before their full technological potential has been exploited. This sort of thing has happened in the past in response to public and market reactions. In other words, techno-social and techno-economic limits or "cut-off" points have emerged and are likely to continue to emerge. In industry, sensitivity to public and market reactions is normal. But

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* The Centennial Congress of Canadian Engineers, which was held in Montreal in May of 1967, raised many of the issues and implications pertaining to these challenges during the next ten years.

governments have not always been as sensitive to the effective limits to particular technological developments as they have been to the apparent opportunities to carry technological development further. *

In spite of the existence of advisory councils and committees, it is still too early to say that any one country has developed a "science policy". And even if one country had developed such a policy, its provisions would not necessarily be applicable to other countries, although the method or process by which the policy provisions were reached would be of considerable interest. In this particular context, some views expressed two years ago in the United States by Michael Michaelis are of interest:21/

> "On the one hand, it is confidently said -- and with good reason -- that we now have, or know how to acquire, the technical capability to do very nearly everything we want.
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> "On the other hand, we hear equally often the assertion that we will soon not be able to afford everything we want. A recent study by the National Planning Association estimates that the dollar costs of satisfying all our national goals in 1975 are going to exceed by about 15 per cent the gross national product then anticipated.
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> "This would suggest that the rising tide of human aspirations, here and elsewhere, is outstripping available resources, even

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* This point is discussed in an editorial, "The Cut-Off", in the January 6, 1968, issue of The Economist (London, England), pp. 8-9.

> though at the same time the cornucopia of science and technology seems to offer boundless new opportunities. There are those who consequently see the need to make priority choices, lest aspirations and resources get frustratingly out of balance.
>
> "There are others, myself among them, who question whether our resources are indeed as limited as they appear to be. I would assert that the great untapped bounty of science and technology can create considerable additional resources, as well as find ways of better utilizing existing ones -- but only provided that institutions of our society can quickly so adapt themselves as to treat major social and technological innovations as a vital necessity. . . . "

Planning and Anticipation

An important factor in the post-war success of the large science- and technology-based corporations in the United States has been the emphasis that many of them have placed on detailed medium- and long-term planning. One of the important elements in much of this planning has been the increasing use made of technological forecasting techniques. These techniques have enabled the corporations concerned to take continuous note of foreseeable technological developments. The corresponding European-based business enterprises, so far as is known, have been less active in this kind of activity.

Technological forecasting studies have been going on for over twenty years, but it is only since 1960 that this kind of forecasting has become a recognized management activity. It is still an art based largely on human judgment rather than a science based on an inventory of systematically acquired knowledge and experience. Work in this field can help to provide important clues to the identification of possible steps in an "evolutionary" invention or innovation and to the identification of new objectives for applied research and development activities. It can also help to identify and expand the technological options which will be open to a particular society in the future. Although it is only a rough first approximation to future technology and can say nothing -- by itself -- about the possible public or market reactions to particular innovations, the aim of the forecasters is to arrive at something better than intelligent guesswork based on intuition or on a survey of the latest scientific and technical literature. Basically, it provides a framework and a series of techniques for those who have to sit down with a clear head to planning, forward-looking, or anticipatory studies. But effective technological forecasting cannot be done in isolation. The results have to be developed in conjunction with, and to supplement, the kinds of results that stem from forward-looking activities in economics, sociology, politics, and so on.

Military planning and anticipatory studies in the United States have, in the post-war period, been undertaken on a considerable scale and a number of research organizations have been set up to undertake work of this kind as a major or exclusive activity.* These organizations, together with institutions and consulting firms working in nonmilitary areas, have helped to develop another set of important "software" techniques through which options and alternative futures can be studied. The techniques which now make use of the "systems concept" grew out of the operations research work of

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* For example, the RAND Corporation, Santa Monica, California.

the Second World War, but the post-war developments also owe a great deal to advances in computer technology. *

The systems concept has been used extensively in military and aerospace research, in the improvements of management functions, in the organization of innovation and -- more recently -- to help with the solution of large socio-economic problems. The concept is not a panacea for administrative weakness or for ensuring that the latest revolutionary innovation will be commercially successful. A textbook published a few years ago described it in general terms in the following way:22/

> "The systems concept is primarily a way of thinking about the job of managing. It provides a framework for visualizing internal and external environmental factors as an integrated whole. It allows recognition of the proper place and function of subsystems. The systems within which business must operate are necessarily complex. However, management via systems concepts fosters a way of thinking which, on the one hand, helps to dissolve some of the complexity and, on the other hand, helps the manager recognize the nature of the complex problems and thereby operate within the perceived environment. It is important to recognize the integrated nature of specific systems.
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> "... But it is also important to recognize that business systems are a part of larger

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* By the same token, computer technology owes a great deal to the advances in the application of the systems concept.

> systems -- possibly industry-wide, or including several, maybe many, companies and/or industries, or even society as a whole."

The formal recognition of the multidiscipline approach to planning and anticipatory studies by teams of scientists, engineers, economists, sociologists, market specialists, and so on, is yet another development of the post-war period. This approach may be considered as generating three broad kinds of activity. The first corresponds to "basic research" and is performed full-time and mainly in the universities. The second corresponds to "applied research" and is again performed full-time but mainly in the profit-making and nonprofit institutions and business enterprises. The third, or "hybrid", approach is a part-time committee-based activity sponsored mainly by learned institutions or societies.

The "basic research" approach has sometimes been called the "science of science" or the "sociology of science". It attempts to study systematically the various ways in which the natural sciences and technology "work" and how they interact and react with the economic, political and other environments. The aim of studies in this field is to draw attention to implications for future policies for scientific and technical activities in general and research and development in particular. A number of active groups have already been established, principally in universities in Europe and the United States. *

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* For example, the Unit for the Study of Science Policy at the University of Sussex, England; the Research Policy Program of the University of Lund, Sweden; the Studiengruppe für Systemsforschung at Heidelberg, Germany; and the Institute for the Study of Science in Human Affairs at Columbia University, New York. No equivalent unit or group has so far been set up in Canada.

Each group has brought together people whose training and experience has been in the natural and social sciences and, not infrequently, in both. In time, those groups that have both teaching and research responsibilities become sources of research and administrative personnel for policy-advisory and policy-making agencies.

The "applied research" approach has, of course, practical end-products in mind and the activities take place under environmental pressures to produce them. The institutions in which the work is done have acquired generic names such as "think tanks" and "look-out" groups. The term "think tank", as commonly used, often has a very broad connotation which includes organizations with scientific research activities and few, if any, planning or anticipatory activities. In the more limited sense in which the term is used in this paper, "think tanks" and "look-out" groups describe those groups or separate institutions that employ diversely qualified staffs of experts with qualities of creativity and judgment of a high order on work that is almost exclusively concerned with planning and anticipation on a multidiscipline and systems-oriented basis. Some existing groups had their beginnings in the United States in the post-war period in connection with the anticipation of military problems. A few have now become integral parts of business enterprises.* Most of them depend for a high proportion of their projects on contract work from public and private sources.

One example of the "hybrid" type of organization is the Commission for the Year 2000, sponsored by the American Academy of Arts and Sciences, which began work a few years ago. The distinguished members of the Commission have been drawn from many of the fields

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* For example, U.S. General Electric's TEMPO Center for Advanced Studies, Santa Barbara, California.

of the social and natural sciences and from law, government, and so on. They have met from time to time and have prepared a number of papers on aspects of the future.* The Commission's work is continuing.

Technological forecasting, sociological studies of science, and anticipatory activities in these and other related fields have some definite limitations. For example, none of them can say anything at all about the unforeseen scientific discoveries of the future and little, if anything, about possible market or public reactions to revolutionary innovations. And none can take into account the equally unpredictable political factors which may prove later to be vital to the achievement, or otherwise, of planned goals and objectives. However, the exercises of planning and anticipation provide a rough, but necessary, "early warning system" for some of the opportunities or the pitfalls which may lie ahead.

In Conclusion

The discussions in this paper have not been in great depth, but they have been designed to draw attention to important issues which have implications for policies and programmes in the public and private sectors in this country in the years immediately ahead.

Historically, the application of science and technology and the generation of new knowledge in these fields have usually been undertaken with some useful purpose or "service" in mind. There have been many outstanding discoveries and inventions that have had random or accidental beginnings, and many which have resulted from personal curiosity rather than from institutional interest. On balance, however, the majority of new scientific and technical knowledge has evolved from

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* See, for example, the Journal of the Academy -- Daedalus -- issue for summer of 1967.

older knowledge and experience. And, with regard to innovations, evolution has also tended to predominate. Discovery and invention, and the associated uncertainties, have usually been the concern of scientists and engineers. Innovations, and the associated risks, have been the concern of entrepreneurs.

Much of the discussion in this paper has been centred on research and development activities because more data exist for them than for the other scientific and technical activities, and because research and development, unlike the production-oriented activities, are relatively new. But R & D activities usually account for a relatively small share of the resources allocated to the exploitation of particular discoveries and inventions. And no one has so far been able to discover the most appropriate aggregate allocations of resources that countries, sectors, or even industries should make to R & D or how these allocations should grow and change from time to time. Questions of this kind have usually been answered on an agency or laboratory basis by considering historical, budgetary, manpower capability and other factors as they related to a particular problem or project. More recently, however, the problems of setting broader and larger-range objectives for R & D activities and of encouraging more effective interactions between technical and nontechnical people and between technical and policy people have been receiving extra attention.

It has become clear that new institutions designed to undertake scientific and technical activities take time to become viable and productive and that existing institutions cannot be changed overnight even although the the traditional factors that normally oppose change can be successfully accommodated. It has also become clear that broad policies and programmes for scientific and technical activities have to be designed to be flexible in order to function successfully in an environment of constant, and sometimes rapid, change. At the same time, it has become clear that planning and anticipatory studies by "look-out" groups -- as well as by "listening posts" -- have a place in the structure of the public as well as the private sector. But studies of the implications and options of alternative futures must not exclude the reconciliation of policy planning with flexibility or of firm anticipation with the possibilities for rapid environmental change.

At the present stage in our knowledge, the principal factors that should influence the allocation of human and material resources to the full range of scientific and technical activities can be broadly identified. These factors, by themselves, have obvious limitations with regard to quality and appropriateness but they imply recognition of the fact that the human and material resources involved have alternative uses in the achievement of alternative objectives. These factors are also applicable to all levels of policy. On what might be called the "demand" side of the equation are the following:

-- human needs, hopes and aspirations;

-- economic, social and other goals which science and technology can help to achieve; and

-- ideas, problems, and opportunities which should be investigated, explored or exploited.

To a degree, these "demand" factors are interrelated. They have to be matched up with the principal factors of what might be called the "supply" side of the equation -- which are also interrelated -- and include:

-- the various ways in which science and technology can be of service to Man;

-- the broad and varied range of scientific and technical activities;

-- the knowledge and experience contained in the various disciplines of science and branches of technology; and

-- the kinds and levels of ability of the available people and the capabilities of the available material resources.

In the last analysis, the success with which scientific, technical and innovative activities are carried through will depend upon some very human beings demonstrating qualities of leadership, foresight, initiative and imagination of a very high order and having the courage to face uncertainties and to take risks.

The following remarks made by Dr. J. J. Deutsch in a speech in Vancouver in September 1966 perhaps provide an appropriate summary with which to end this paper:

> "In the complex world of the future, the possession of knowledge and skill will dominate every human endeavour. It is no longer possible to build success simply on human physical energy and on raw resources, no matter how enormous. Attainment of our ambitious economic and social goals will depend on how well we are prepared both intellectually and emotionally to solve the large political, social and economic problems of our times, how well we cope with the problem of improving the quality of life in our ever more crowded cities; how well we can compete in an increasingly interdependent world; how well we master the revolutionary new technologies while maintaining a proper regard for individual human values and human fulfilment; and how well we

understand and recognize the interests and legitimate aspirations of a culturally and regionally diverse people; how well we can contribute to maintaining the peace and to help the poor of the world. For this we need, above all in this complex country of ours, a highly educated and a highly informed population. We are entering into an age when man's accelerating knowledge of nature and of social processes will enable us, more and more, to invent the future, either for immense good or immense evil. All of us have a great duty to do what we can to make sure that there is in the rising generation both sufficient understanding and sufficient responsibility to make the right choices."

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APPENDIX III

CANADIAN GOVERNMENT PROGRAMMES

Outlines of the General Incentive and Special Assistance Programmes Established to Encourage R & D Activities in Canadian Industry

(i) Tax-Based General Incentive Programme

Since 1944, companies operating in Canada have been allowed to deduct a portion of their expenditures on "scientific research" activities from their taxable incomes. The rules governing the eligible portion were changed from time to time and by 1962 had reached 100 per cent of all current and capital expenditures. However, in order to encourage Canadian companies to increase their expenditures on these activities further, the Government incorporated certain new incentive provisions into the tax structure in that year. Under these provisions, the deduction from taxable income of a further 50 per cent of expenditures made in Canada which exceeded those of the 1961 "base period" was permitted, provided the expenditures qualified under the definition of "scientific research" used for tax purposes and under the other relevant provisions of the Income Tax Act. This tax-based programme was effective for the taxation years 1962 through 1966.

As well as encouraging increased expenditures on R & D performed by -- and for -- industry in Canada, this programme was intended to emphasize the importance of industrial R & D activities for the maintenance and development of production potentials and competitive capability in an environment of constantly changing domestic and economic conditions. It was also intended to strengthen the R & D capabilities of some Canadian companies in relation to the research activities of their affiliates abroad. The tax-based incentive was introduced to supplement the special assistance and other programmes which the Government was also using at that time for the same broad purpose. The five-year period was chosen because it was felt then the initial provisions would require amendment after a few years of experience. This period was, however, judged to be long enough to enable companies to undertake comprehensive R & D projects.

(ii) Grant-Based General Incentive Programme

Since taxation year 1967, a grant-based programme has been in operation. * It was introduced under the Industrial Research and Development Incentives Act and has become known as the "IRDIA" programme. All taxable Canadian corporations which qualify may receive grants under this programme. The grants themselves are not subject to income tax, although they may be applied by the individual corporations as a credit against tax payable. The IRDIA programme has not, however, altered the original 100 per cent tax-deductible allowance for scientific research expenditures.

The main purpose of the IRDIA programme is again to encourage Canadian industry to undertake or sponsor new scientific research and development projects and to expand existing ones. But the expenditures must also be likely to lead to, or facilitate, the extension of the business of the corporations. Applicants for grants should be free to exploit the results of the R & D activities in Canada and in export markets. These benefits are being made available to corporations regardless of their profit positions.

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* During taxation year 1966, companies could elect to receive benefits under either the tax-based or grant-based programmes.

The grants are to be equal to 25 per cent of the eligible capital expenditures made by the applicants for R & D activities performed in Canada in the fiscal year in question plus 25 per cent of the increase in the eligible current operating expenditures over the average of these expenditures during the "base period". For the purposes of the IRDIA programme, the base period is to include the five immediately preceding years and will, in effect, be a "moving average" which is likely to change from year to year. Applicants may request prior opinions regarding the eligibility of particular potential expenditures under the definitions and other regulations associated with the programme. IRDIA is administered and financed by the Department of Industry.

(iii) The Defence Development Assistance Programme

This was the first of the four special assistance programmes now in operation. It was established in 1959 to complement the U. S. -Canada Production Sharing Agreement which had been initiated during the previous year. The aim of the programme is to sustain and improve the development capabilities of Canadian companies active in the military product field. Companies are expected to contribute about half of the cost of each approved project. For companies which do not meet this level of support and for companies earning extensive profits from the sale of equipment resulting from an assisted project, the programme contains a "pay-back" provision. The programme is financed and administered by the Department of Industry in association with the Department of Defence Production.

(iv) The Defence Industrial Research Programme

This special assistance programme was initiated in 1961 and is administered and financed through the Defence Research Board. It has come to be known as the "DIR" programme.

DIR is intended to improve the ability of Canadian companies to compete for research, development, and ultimately production contracts in the United States and NATO defence markets by helping the companies to maintain or increase their R & D facilities and personnel. However, the initiative for submitting projects for support under the programme rests with industry. Each project is assessed on the basis of its technical merit, defence interest and potential, the competence of the company's research personnel and the growth potential which it will have for the company. Originally, contracts were negotiated with each company but the procedures were considered unnecessarily complicated and slow and the contracts were replaced by grants in 1963. The company pays half the costs of each approved project. In 1965, the Defence Research Board and the United States Air Force Systems Command signed an agreement whereby applied research projects meeting the Command's requirements and the objectives of DIR could be jointly supported in Canada.

For the purpose of the DIR programme, projects lasting from two to five years are preferred. The company retains any resulting patent rights but agrees to waive royalty payments for future government quantity purchases of a product which may result from the research work. The company also agrees to make every effort to exploit the results of the work in Canada. The DIR programme enables the Defence Research Board to assist Canadian companies through the dissemination of new technical information related to approved projects. The Board also appoints technical advisers to monitor the progress of each project.

(v) The Industrial Research Assistance Programme

This programme -- known as "IRA" -- is the civil sector equivalent of the DIR programme. It was initiated early in 1962 and has been administered and financed by the National Research Council.

The IRA programme was designed to encourage longer-term applied research activities in Canadian industry, particularly in companies in which these activities were at a low level or non-existent. The programme's secondary aim has been to improve communications between government and industrial laboratories.

Again, the initiative for submitting projects for support rests with the companies and preference is given to projects which will last from two to five years and from which new Canadian products or production processes could result. Companies are free to deal with commercial security questions as they see fit, and they are free to acquire any patent rights which may result from their work. NRC like DRB, appoints official technical advisers for each project. The IRA programme requires, however, that companies add to their existing scientific and technical staffs in order to qualify for support. NRC's share of the costs of each project has normally been earmarked to pay for the salaries and wages of these staff members. During 1967, approval was given to permit the participation of university professors in IRA projects in circumstances in which their advice or direct assistance in the industrial laboratory would accelerate the development of competence within the companies concerned.

(vi) The Programme for the Advancement of Industrial Technology

The Department of Industry's "PAIT" programme is the most recently established of the Government's special assistance programme. It received the necessary approval late in 1965.

The PAIT programme was designed to stimulate industrial growth in Canada through the upgrading of industrial technology and the expansion of innovative activity. Support is concentrated principally on the development of products and processes through the individual projects submitted to the Department by companies for approval. Each project is subjected to both technical and commercial feasibility tests and to criteria designed to ensure that the company concerned has the resources to complete the exploitation of the results of the work.

In order to ensure rapid and effective exploitation, title to patents, designs, technical data, and so on is usually vested in the company, but companies are normally required to give an undertaking that they will exploit successful projects in Canada within a reasonable period of time. Assistance given under this programme enables the Department of Industry to provide funds to cover half the cost of each project. However, the company is obliged to repay with interest the Department's share of those technically successful projects which are later "put into commercial use".*

Consideration is also given by the Department to submissions from groups of companies proposing to undertake co-operative projects and from companies proposing to subcontract portions of their development work to universities, research institutes, consultants or other companies where this appears to be desirable. All projects submitted for PAIT programme support, however, must involve a "substantial technical effort".

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* A company's own contribution under any one of the four special assistance programmes may be submitted as a deduction for income tax purposes and for benefits under the current general incentive programme.

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PUBLICATIONS DU CONSEIL ÉCONOMIQUE DU CANADA

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Second Annual Review: Towards Sustained and Balanced Economic Growth (EC21-1/1965, $2.75)	Council—Conseil	Deuxième exposé annuel: Vers une croissance économique équilibrée et soutenue (EC21-1/1965F, $2.75)
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