R&D INNOVATION AND ECONOMIC GROWTH:

A REVIEW PAPER FROM A GOVERNMENT PERSPECTIVE

B. Bhaneja
D. MacDonald-McGee
M. Smith

Government Branch
Ministry of State for Science and Technology
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Summary

For a variety of inter-related reasons, economic growth in Canada and other OECD countries has been slower and less predictable during the 1970s. In attempting to remedy this situation, governments have turned to various policy approaches, including increased emphasis on R&D and technological innovation. This paper focusses on this concern and reviews recent literature on linkages between research and development (R&D) on one hand, and economic growth and related economic variables on the other. Particular attention is paid to the economic impact and influence of government-funded R&D.

The paper examines studies that have been carried out on the contribution of R&D and innovation to productivity growth at the levels of national economies, industries, and firms. The conclusion is reached that the correlation between R&D/innovation and productivity growth is better established at the level of the firm than at the level of the economy, and that the private and social rates of return on R&D investments in industry have been high, though often hard to quantify with precision. The paper also concludes that the impact of government-funded R&D, whether performed in industry or government, has proven difficult to estimate for various

methodological and conceptual reasons. In general, the literature appears to undervalue the contributions of such R&D.

The paper also examines the nature of innovation. Various studies are cited to show that linear models of innovation are unrealistic, and that the innovation process is quite complex. The sources and nature of the scientific and technical knowledge that contribute to innovation are many and varied, and innovation depends on a time-consuming and expensive diffusion of knowledge among governments, industry and the universities. R&D is only one stage in the innovation process, with its cost and relative importance varying with the characteristics of national economies and the nature of the industries involved. Governments can and do play a significant role in innovation through funding and performing R&D that contributes many of the necessary knowledge inputs, through various incentive mechanisms, and through the establishment and enforcement of regulations. With respect to regulation, the paper suggests a need for more systematic assessment of the risks involved in adoption of new technologies, so that resulting economic growth is achieved with adequate social and environmental protection.

The paper goes on to look at the relationship between R&D and a number of economic variables. With respect to inflation, for instance, the literature reviewed in this paper suggests that rising prices tend to discourage investment in R&D. At the same time, it is also thought that R&D and innovation have a stabilizing effect on prices through lower product and production costs.

The paper examines the opposing viewpoints that have emerged on the relationship between technological innovation and employment. On the one hand, it is argued that the adoption of radical technological innovation, where impact is felt across a wide variety of industries, can result in a considerable degree of job displacement. This effect, however, is seen as temporary by those who feel the more efficient and cost effective production brought about through these new technologies will result in enhanced economic growth, and will therefore compensate for any large scale displacement.

The literature also indicates that there is a strong linkage between domestic R&D/innovation and success in international trade. In particular, R&D intensive industries and firms in both Canada and the United States have enjoyed strong export performance. The paper also shows, however, that various structural adjustments are occurring in international patterns of trade and technological change which have significant implications for western countries. Canada has particular concerns in this context, because of its heavy reliance on exports of natural resources and its dependence on foreign investment as a source of industrial technologies.

Broadly speaking, the literature examined in this paper suggests that there is a need to shift from a short-term view of economic growth to a longer term perspective which recognizes the need for continuing innovative activity to exploit new market opportunities. This perspective should be based on analyses of anticipated structural shifts in the Canadian economy and the economies of our trading partners, so that resulting innovational thrusts will offer returns in the international market place.

In this context, it is obviously important to have a full understanding of the role of R&D and innovation in the Canadian economy. The available literature is heavily concentrated on American experiences, and the paper urges that more research is needed on the Canadian situation. Furthermore, given the relative importance of government-funded R&D in Canada concerted efforts are required to identify more clearly the economic benefits that are derived - and can be derived - from this R&D.

Finally, the paper concludes that we have reached the end of the first generation of government science policies in Canada, which culminated with the setting of the 1.5 per cent GERD/GNP target. It is suggested that the second generation of science policies should focus on four major objectives:

-- the closer integration of science and technology in the processes underlying the formulation of our macroeconomic policies -- through a better understanding of the innovation process;

-- the development and maintenance of comparative advantage in the resource sector, and in certain leading-edge technologies -- taking account of changing trade patterns and industrial structure;

-- the identification of ways and means of increasing the economic impact of government-funded R&D -- through a better understanding of the benefits of this effort and how they are most effectively derived;

-- an increase in the government's ability to alert society to, and protect it from, the negative impacts of technological change.

1. BACKGROUND

1.1 Introduction

During the 1970s, there has been general concern in Canada and other OECD countries about declining economic growth. By and large, growth has been slower and less steady during this period than it was during the previous two decades. A number of factors, interrelated as to cause and effect, have been suggested for this: energy pricing, trade uncertainties, unemployment, wage rates, inflation, interest rates, and the changing composition of demand.

In this uncertain economic environment, a great deal of attention has been focussed on ways and means through which governments can intervene to remedy the situation. Governments have thus promoted energy conservation and the development of alternative energy resources, created new types of job opportunities, supported the development of new industries, assessed the impact of regulation, and employed conventional fiscal and monetary tools.

In these approaches to economic adjustments, increasing attention is being focussed on the contribution of scientific research and technological innovation to economic growth, and in particular on the importance of government-funded R&D in this regard. This paper examines these issues, with particular emphasis on the latter.

1.2 Definitions

Economic growth is the increase in a country's capacity to produce goods and services, combined with the increase in actual production of these goods and services. The rate of economic growth is generally assumed to be the weighted sum of the rates of productivity growth in the various industrial sectors, plus the rate of growth of employment, and is conventionnally measured by the rate of increase in the Gross National Product (GNP)

In addition to productivity and employment growth, a number of other macroeconomic indicators provide measures of the strength and vitality of the total economy. These include the inflation rate and international trade.

Technological innovation refers to the introduction of new goods and services, or new ways of producing goods and services. In its broadest sense, innovation comprises a series of activities extending from basic research, to the design, testing, introduction and commercialization of new or improved products or processes. Innovation is not synonymous with research and development (R&D); rather, R&D is one step in the innovation process. R&D leads to knowledge which, when combined with other economic inputs, and subjected to decision-making processes on the economic viability of the intended product or process, results in an innovation.

1.3 Purpose

The purpose of this paper is to examine the literature on the relationship of R&D to indicators of economic growth and to other economic variables. The intention of the analysis is to clarify the relationship of the federal government's R&D policies and activities to the goal of economic growth, and to determine what further studies should be carried out on these issues.

To this end, the paper analyses the linkages between R&D, innovation and economic growth. Specifically, the following sections discuss the relationships between R&D (particularly government-funded R&D) and such economic indicators as productivity growth, inflation, employment and international trade.

1.4 Two Perspectives: Conjunctural and Structural

In examining the role of R&D and innovation, it is important to recognize that these are two quite different perspectives on how the economy actually functions. A recent OECD publication has categorized those broad perspectives as the conjunctural and the structural points of view (1).

The proponents of the conjunctural approach place much weight on the importance of market mechanisms, and thus tend to see the economy in a shorter-term light. The economy's natural state is one of equilibrium. Any "disequilibrium" is temporary, and its solution - a return to full employment and price stability - can be hastened through the implementation of the conventional fiscal and monetary tools of economic policy. This approach denies that long-term, fundamental changes (including technological changes) are taking place within national economies and in the world economy, or minimizes the significance of the changes taking place. Accordingly, current problems of economic slowdown, unemployment and inflation are seen to result from an exceptional combination of exogenous shocks and fortuitous circumstances, but not from any basic changes in the way the economy works.

From the structural point of view, however, the economy has changed. Long-term movements have not merely represented cyclical disturbances to a system normally at equilibrium, but have actually brought about profound changes in economic and social structures. From this perspective, conventional fiscal and monetary tools are seen as increasingly less effective, and alternative policy approaches are required to bring about favourable economic changes. A healthy economy will naturally tend to be in an unbalanced or dynamic state, according to this approach, and prosperity can best be maintained when its powers of innovative creativity outweigh tendencies towards stagnation.

2. R&D, TECHNOLOGICAL INNOVATION & PRODUCTIVITY GROWTH

An examination of the literature indicates that it is difficult to establish a straightforward causal relationship between R&D, technological innovation and economic growth. Nevertheless, most evidence consistently points in the direction of R&D as a factor contributing to growth and productivity. The literature on the subject can be grouped in two categories: (a) R&D-productivity growth studies, and (b) innovation process studies.

2.1 R&D - Productivity Growth Studies

2.1.1 R&D and Productivity Growth: National Economies

Most of the empirical macro-econometric studies on this subject have established that the historic rate of growth in western economies is generally greater than could be accounted for by growth in labour and capital inputs. The unexplained difference, or the "residual growth", is frequently identified with technical change. In most of these studies, a residual growth component of about one per cent a year has been identified.

One of the earlier works on this subject was a 1957 study by Robert Solow (2). This analysis showed that the output of the non-farm portion of the American economy increased at an average rate of about 1.5 per cent per year during the period 1909-1949. Solow found that gross output per manhour doubled over this period, and be attributed 87.5 per cent of the increase to technical change and the remaining 12.5 per cent to increased use of capital.

Denison (3-5) also carried out a number of major empirical studies in this area during the 1960s. In one of these analyses (3), Denison found that, between 1929 and 1957, increased education and the advance of knowledge contributed 42% of the U.S. growth rate in output per person employed. In contrast, increased capital output accounted for 15% of the growth rate during the same period, and a contribution of 9% was made by economies of scale associated with the growth of the national economy.

Denison extended this work (4) in an in-depth examination of the sources of growth of GNP in the United States and eight western European countries during the period 1950-62. Twenty-three separate determinants of growth were analysed and divided into two categories: increases in inputs of labour, capital and land; and increases in output per unit of input (i.e. productivity increases) due to such factors as "advances in knowledge". For the period under examination, Denison found that advances in knowledge added about 0.75 percentage points to the annual rate of growth of national income in the nine countries studied. This meant that, in the United States for example, advances in knowledge were the source of 23 per cent of the growth in total national income and 34 per cent of the growth in national income per capita.

The growth of knowledge in Denison's studies included all types of knowledge (such as "technological" and managerial" knowledge) which are relevant to efficient production. Denison estimated that about one-fifth of the contribution to growth by advancement of knowledge could be attributed to organized R&D.

Considerable attention has been focussed on the limitations of Denison's analysis, both by the author and by others (6). On the one hand, for example, "advances in knowledge" in Denison's treatment is a residual which includes errors in the contributions of other growth factors; thus, the importance of advances in knowledge may be overestimated. On the other hand, the growth of national income does not account for growth in activities whose output is measured by inputs (e.g. parts of the service sector), or for improvements in quality of output; thus, advances in knowledge may be underestimated. Ultimately, the conclusion to be drawn from this work, and from other similar studies, is that R&D and advances in knowledge do make a significant contribution to economic growth at the national level; however, the exact magnitude of that contribution remains uncertain.

2.1.2 R&D and Productivity Growth: Industries and Firms

Relationships between productivity growth and innovation have been far more effectively studied at the level of the industry sector or the firm. These studies tend to focus on a limited number of variables (e.g. equipment, workers' education, etc.), and as a result, the nature of the technologies employed becomes a factor in determining productivity. The problem here is that economists agree on most of the factors affecting productivity, but not on the weights to be assigned to each. They also disagree on the fundamental mechanisms of causation.

Prominent among these studies is the work of Terleckyj, who has tried to estimate both the direct and indirect effects of industrial R&D on productivity growth (7,8). In a study of twenty manufacturing and thirteen non-manufacturing industry groups in the United States, Terleckyj attempted to identify separately the returns from R&D conducted within industries (i.e. direct returns), and R&D "purchased" from other industries as technology embodied in capital and intermediate goods (i.e. indirect return). He found that an industry's rate of productivity increase is directly related to both the amount of its own R&D and the amount of R&D carried out by industries that supply it with inputs. (This latter aspect is clearly reasonable, since one industry's R&D often results in improved products or processes which are inputs for other industries.)

Terleckyj found that, for manufacturing industries in the period 1948-1966, direct returns to productivity from the firms' own R&D were of the order of 30 per cent per year; indirect returns were about 80 per cent annually. The rates of productivity returns, both direct and indirect, from government-financed R&D were estimated as nil. In response to this, however, Globerman (9) has pointed out that government-financed R&D is often aimed at product quality rather than cost reduction, and thus would not have a readily apparent impact on productivity. Further, Globerman suggests that government-financed R&D may also be directed at basic conditions underlying the industry's productivity, and that there may be a time lag before its impact is observed.

For non-manufacturing industries (e.g. wholesale trade, retail trade, mining, farming, etc.) Teleckyj found no indication of positive returns to productivity from R&D conducted in the industry. Indirect annual returns to productivity, however, were approximately 187 per cent.

In another study of industrial productivity, Griliches (10) estimated that annual rates of return on R&D investment in 833 large U.S. manufacturing companies were about 20 per cent. The two industries with the largest federal R&D financing (electrical equipment; aircraft and missiles) had the lowest rate of returns. This, however, did not show up in the regression analysis which formed the basis of the work, but was "stumbled on" in the interpretation of the results. The author suggests (11) that "in these two specific industries the externalities created by the large federally financed R&D investment and the constraints on the appropriability of the results that may have been associated with such investments have driven down the realized private rate of return from R&D significantly below its prevailing rate in other industries."

Griliches also found no evidence that larger firms (i.e. those with a thousand or more employees) have a higher propensity to invest in R&D, or are more effective in deriving benefits from it. This supports the conclusions drawn in studies by Mansfield (12), Cooper (13), and Scherer (14) on the petroleum, drug, steel and glass industries.

Another author who has made substantial contributions in this field is Edwin Mansfield. For example, in an examination of seventeen industrial innovations, Mansfield and co-workers (15-16) found that there could be wide differences in the 'private' and 'social' returns from investments in innovations. The median social rate of return (i.e. benefits obtained by those who did not invest directly in the R&D) was 56 per cent per year; the median private rate of return (i.e. benefits gained by the individual actually making the R&D investment) was about 25 per cent per year. This generally agrees with findings by Griliches (17) and Terleckyj (7), that the rate of private return is usually lower than the rate of social return.

In another study of twenty manufacturing industries between 1948 and 1966, Mansfield (18) examined the importance of basic research. Using multiple regression analysis, Mansfield concluded that there is a direct relationship between the amount of basic research carried out by an industry or firm and its rate of increase of total factor productivity, when its expenditures on applied R&D are held constant. Similar findings were obtained for the 1966-76 period; however, the "fit" was not as good, possibly because of an inadequate recognition of the more prominent role being played by factors such as regulation. Mansfield suggests that his findings may reflect a tendency for basic research results to be more fully exploited by the industries and firms responsible for them, or for applied R&D to be more effective when carried out in conjunction with basic research.

In this same study, Mansfield examined survey data on the R&D expenditures of 119 firms. He found that between 1967 and 1977, practically all industries had made cuts in the proportion of their R&D expenditures devoted to <u>basic</u> research, though the proportion devoted to relatively <u>long-term</u> projects (i.e. those lasting five or more years) did not decline. The share of R&D expenditures aimed at entirely new products and processes did decline somewhat during the period. Mansfield reports that survey respondents (particularly drug and chemical companies) identified the increase in government regulations as one of the major reasons for these changes. In addition, breakthroughs are more difficult to achieve than in the past because many fields have been thoroughly worked over within the context of existing knowledge. High rates of inflation were also cited as one of the reasons for cutbacks in basic research.

The studies cited so far, and numerous others (e.g. 19-24), have dealt with industries in the United States. Far less work has been done in the Canadian context. However, the Ministry of State for Science and Technology (MOSST) has carried out a comprehensive study (25) on R&D in Canadian manufacturing industries. The purpose of the MOSST work was to assess the performance of R&D intensive industries relative to those industries which do little or no R&D. Industry performance was analysed in terms of employment, output, productivity and price movements over the 1961-1974 period.

Table 1 taken from the MOSST study, (26) shows that research-intensive and medium-research intensive industries clearly outperformed low-research and no-research industries according to each of the four economic indicators. Research-intensive industries registered the highest rate of growth in productivity and had the lowest rate of price increase, whereas medium research-intensive industries had the highest rate of growth in output and employment.

Table 1

AVERAGE ANNUAL RATES OF GROWTH
1961 - 1974
PERCENT

	Employment	Real(1) Output	Productivity (2)	Prices (3)
Research-Intensive Industries	2.42	6.41	4.49	1.39
Medium-Research-Intensive Industries	2.75	6.60	3.95	1.64
Low-Research-Intensive Industries	1.61	5.19	3.47	3.13
No Research Industries	0.73	3.85	3.14	3.25
Total Manufacturing	1.87	5.79	3.82	2.37

(1) 1971 Dollars
(2) Real Output Per Person
(3) Value-added implicit price index
Source: Based on data from Statistics Canada.

From the preceding, it is apparent that on an industry-wide basis, there is a strong relationship between R&D and productivity growth. Despite differing methodologies, the more prominent authors in the field, like Mansfield, Terleckyj and Griliches, are reasonably consistent in estimating the direct rate of return to R&D in the manufacturing industry at 20 to 30 per cent. Indirect returns, while more difficult to estimate, are also substantial, ranging from 20 to 80 per cent.

2.1.3 Government-Funded R&D and Productivity Growth:

Although there is a clear relationship between industrially-funded R&D and productivity growth at the industry and firm levels, the linkage between government-funded R&D and productivity growth is less unequivocal.

Clearly, the reasons why the governments support and conduct R&D are not parallel to those of industry. Government mission-oriented R&D projects, for instance, are often aimed at solving "public" problems; (e.g. research in agriculture, environmental protection, health and safety standards). Other government-supported R&D is in areas where the government itself provides the major market for the resulting technological innovations (e.g. space, defence). Besides these reasons, however, the government also funds and performs R&D aimed more directly at developing industrial technological capacities or products (e.g. EMR mining process R&D; Telidon and other communications R&D), encouraging industry's own R&D performance (e.g. programs like DIPP, IRAP, EDP), and transfering technologies to industry that have been developed in government laboratories (e.g. programs like PILP and TIS).

At present, there is very little evidence available on the relationship between government-funded R&D and productivity returns, especially in Canada. Those studies which have been done relate primarily to American experience, and are discussed below according to two categories: government-funded, industry-performed R&D; government-funded, government performed R&D.

(a) Goverment-Funded, Industry-Performed R&D

This type of R&D is funded either partially or wholly by goverment, but is performed by industrial organizations.

One major study of the effect of this type of publicly-financed R&D on national productivity was a review by Chase Econometric Associates (28) of economic benefits to the United States from NASA's R&D activities. The study is a time-series analysis of aggregate U.S. productivity in relation to NASA R&D during the period 1960-74. Nearly all of the R&D was undertaken in high technology industries, and was largely directed toward space exploration.

The Chase study found extremely high returns for NASA R&D, of the order of 40 per cent per year. It was also concluded that a sustained increase in NASA R&D spending of $1 billion would result in productivity improvements and multiplier effects that would raise real GNP by $23 billion by 1984.

The Chase report has been criticized, however, for its methodology (29). In particular, it is argued that the study's attempt to correlate the total NASA R&D budget with changes in the gross productivity of the U.S. economy is at too aggregate a level to accurately indicate a true cause-and-effect relationship. Thus, it is suggested that the study would have been more convincing if it had identified specific products of NASA research and their subsequent impact on productivity in the industries involved.

As indicated earlier in this paper, some studies of productivity growth at the industry level have referred to the impact of government-funded R&D. Work by Terleckyj (7) and Griliches (10), for example, estimated that the rate of return on R&D investments in the manufacturing sector is lower in those industries which have a high level of federal R&D support. This may, in part, reflect the previously noted fact (9) that government-funded R&D is often aimed at factors which may not be reflected readily in industrial productivity figures, or may take some time to have an impact on productivity. In addition, these results may also be partly due to data collection problems, in that companies may report resources earned through government-funded contract research under general revenues, rather than as part of the company research budget.

However, various methodological or conceptual problems make it difficult to accurately estimate the impact of government-funded R&D on industrial productivity. One such problem occurs in the quantification of "spillovers" from government-funded research. Spillovers -- that is, benefits to firms other than the one actually receiving the funds, or benefits to society as a whole -- are not usually explicitly recognized at the level of the firm. However, spillover effects may be a substantial outcome of federally-funded R&D, especially as such R&D may, in aggregate, be oriented towards industry-wide productivity, or to the development of technologies which are beyond the capacities of a single firm (e.g. Telidon, nuclear reactors). Generally, the hope has been to "catch" spillover effects in assessing total factor productivity on a sector-wide basis.

Measurement difficulties also plague another possible approach to assessing the economic impact of government-funded industry-performed R&D -- that of reviewing the ownership of patents or intellectual properties that may arise out of the R&D. In part, this is because there are great variations in the propensities of firms, and of industries, to patent or otherwise formally protect these intellectual properties. In part, also, it is due to the varying rules for intellectual property rights derived from government-funded R&D. In Canada, for example, NRC's IRAP and DRIE's Defence Industry Productivity Program allow ownership of intellectual property to be assigned to the companies involved. However, in the contracting-out of government S&T requirements, the ownership of the intellectual property is generally retained by the Crown, although non-exclusive licenses have been awarded to companies which have been closely involved in the development of a particular technology. To the extent that ownership of intellectual properties provides a measure of the impact of R&D, or allows that impact to be enhanced, the intellectual property rights deriving government-funded R&D need further examination.

(b) Government-Performed R&D

In addition to supporting R&D in industry, government performs basic and applied R&D in its own laboratories. This R&D may sometimes be of interest to industry, and may result in product or process innovations that have significant impact at the firm or the industry level. Generally speaking, though, government performance of R&D is usually aimed at meeting collective needs or at addressing situations where the benefits will accrue more to the society at large than to any individual private investor.

To the extent that these arguments are true, the economic impact of much government-funded R&D will not be found through short term measurements of industrial productivity, but in assessments of productivity improvements in government. However, the usual means of determining public sector productivity growth - the measurement of changes in inputs, rather than outputs (30) - are not very satisfactory. Indeed, the previously cited work of Terleckyj (7,8), which found no effect on the productivity increase of an industry or firm resulting from government supported R&D, assumed an arbitrarily constant government productivity; in other words, there would be no measurable effect using this methodology, from the introduction of "public goods", no matter how innovative, from government-financed R&D (31).

The knowledge developed through government-performed R&D is generally viewed as a "public good" available to all companies on a non-preferential basis. Certain of these S&T activities are of a more applied orientation, where productivity can be measured in terms of contributions made to technological and socio-economic development. However, much of the research done in government is more basic or fundamental than that done in industry, and its independent effect on productivity is almost impossible to assess. Such research has a potentially wide range of applicability, and the time lag for its effects in terms of diffusion of knowledge is likely to be longer and more variable than for applied research, and hence more difficult to estimate. As Griliches points out (32), this should not be interpreted as implying that basic research is unimportant; it may only reflect the inability of the data to reveal longer-term effects.

2.2 Innovation Process Studies

One of the major criticisms of the productivity growth literature is that it has been mainly concerned with describing the consequences of technological innovation in a very general, aggregate fashion. Not enough attention has been paid in these studies to the factors which influence the rate and direction of innovation, and there has been little explanation of the specific innovative outputs of industries and firms and of the forces explaining differences among firms, industries and nations.

An understanding of the influences which motivate innovation, and channel its direction, is necessary if government actions are to be successful in increasing innovative activity in specific areas. In this context, the following sections review, under several different headings, a number of studies which have been carried out on the innovation process.

2.2.1 Sources of Innovation

Among a number of studies of the sources of innovation is the review by Langrish et al (33) of 84 innovations which had received the Queen's Award in the U.K. Concluding that linear models of the innovation process are unrealistic, the study shows that the sources of innovation are multiple. Moreover, the interaction among the various components of the innovation chain is a two-way flow of ideas and resources, rather than a one directional flow from science to technology. The authors emphasize that innovation must involve a synthesis of some kind of need with some kind of technical possibility. The single most important factor delaying successful innovation, occurring in a third of the cases examined, was the insufficient development of some other technology; thus, complementary technologies are very important variables in accounting for the timing of innovations.

Langrish and his co-authors found that the barriers to the development of innovation differed for "large" and "small" technological changes. Thus, 'lack of market' and 'lack of complementary technology' were equally important in the case of the large technological changes, while lack of complementary technology was the predominant barrier to the development of the small technological changes, with lack of market being a secondary barrier only. Large technological changes included such innovations as the hovercraft and the first commercial dyes reacting with cellulosic fibres; small technological changes were developments, such as improved systems for solvent extraction and structural steelwork, which did not involve radical advances in knowledge.

In another study, Gibbons and Johnston (34) examined the origins of thirty innovations from industries of varying research intensity. Specifically excluded, however, were fields of high technology where government-university-industry interaction are known to be important (e.g. aerospace, telecommunications), and fields where scientific interest was newly emerging (e.g. organometallic chemistry). The authors found that the interactions between science and technology were much more varied, complex and indirect than had been previously assumed.

Table 2 (taken from a review article by Pavitt and Walker (35)) compares the findings of the two studies mentioned above with a third study (36) regarding the origins of knowledge inputs to industrial innovation. Even in those industries where research laboratories are essential to industrial innovation, 'in-house' R&D activities are not the only sources of knowledge inputs. Other in-house sources include the personal experience and knowledge of scientists and engineers, scientific papers and text books, and operating materials and handbooks. The three studies also agreed, despite different methodologies, that 46 per cent or more of the knowledge from outside sources that was crucial to innovation came from universities and government-funded laboratories.

Table 2

SOURCES OF KNOWLEDGE INPUTS TO INDUSTRIAL INNOVATION FROM OUTSIDE THE FIRM: THE RESULTS OF THREE STUDIES (PERCENTAGE)

	Langrish et al.	Rothwell and Townsend	Gibbons and Johnston
Industry	47	33	53
Government-funded laboratories	39	50	18
Universities	14	11	28
Other	0	6	0
Total	100	100	100

Sources:
J. Langrish et al., Wealth from Knowledge (Macmillan, London, 1972);
R. Rothwell and J. Townsend, The Communication Problems of Small Firms, R&D management, Vol. 3, No. 3 (June 1973);
M. Gibbons and R. Johnston, The roles of Science in Technological Innovation, Research Policy 3 (1974) 220.

While these studies, and a number of others (37-41), depict the experience in other countries (mostly the U.K. and the U.S.), it is probable that the results are also applicable to Canada. In sum, it is clear that the innovation-process is very complex. Earlier linear models of innovation, (i.e. that research leads sequentially to discovery, development and application) are too simplistic, and are inadequate to show the feedback between knowledge inputs and the motivation for innovation. The knowledge inputs that contribute to innovation vary widely in nature, covering the spectrum from basic science theories and principles to the detailed design and specification of materials and components. Finally, the knowledge inputs can come from various institutional sources, with governments and universities thereby contributing substantially to the innovation process as it actually occurs in industry.

2.2.2 The Role of R&D in the Innovation Process:

From the literature cited above, it is clear that the role of R&D in the innovation process is intricate and involved. Thus, for instance, it is obvious that all basic research does not and should not be expected to lead to applied research, development, and innovation. Indeed, the process can be quite the reverse, with invention and technological innovation sometimes leading to basic research to determine the theoretical underpinnings of empirical findings.

The distinction between research and development is also important in this context. Development, which both preceeds and follows innovation, clarifies the possibilities and options -- the various paths that innovation might take. Technology development programs undertaken in government or industry provide a necessary part of the basis for such decisions (42).

The relationship between research and innovation is usually more tenuous. The results of basic research go into the general bank of knowledge and stimulate the never-ending cycles of discovery, analysis and synthesis. The contribution of basic research to innovation in the economy often depends on a flash of insight by some individuals or groups - the research scientists themselves, engineers, inventors, or market-oriented people in industry who see how the new knowledge can be put together with the old to get a new product or process that will sell (43).

Several authors have examined the relative cost of the different stages of technological innovations. One such study emphasizing the Canadian situation was carried out by Stead (44). Using a Statistics Canada survey of 83 completed projects in 57 firms, Stead found that there are subtle variations in the structure of innovation processes in different industries and countries. For example, R&D costs are, comparatively, a large proportion of the total sales of the electronics industries, but are much less significant for the chemical and wood-based industries. Further, R&D is a relatively more expensive activity in larger projects. New product/process innovations also require more R&D than those concerned with improvements of earlier products or processes.

Stead also shows that small and medium-sized developed countries such as Canada spend more on R&D, relative to the other phases of the innovation process, than is the case in larger countries. On average, R&D accounts for approximately 60 per cent of the total costs of innovation in Canada; by comparison, such costs have been estimated in the United States at 15 to 30 per cent, (45) and 46 per cent (46). Stead suggests that the different cost patterns between Canada and the U.S. may be explained by differences in industry structure and market size. The U.S. firms tend to be larger and are concerned with larger markets, with the result that "commercialization" (tooling, facilities construction, manufacturing and marketing start-up) tend to be larger components of the innovation process than they are in Canada.

European studies (47) also show similar inter-country differences, indicating that the variance in innovation development and its diffusion depends on relative cost differences, capital availability, and technical and regulatory factors.

2.2.3 Diffusion and Adoption of Technological Innovations

As indicated above, the geographical and institutional sources of information inputs to innovation are many and varied. The means of transferring such information from the source to the location of the innovation, and the movement of innovation to potential users are critical to the impact which the innovation will have on productivity. The resulting diffusion patterns for product and process innovation have been studied by a number of authors, including Nabseth and Ray (47), Rogers and Shoemaker (48), and Mansfield (52).

In general, these studies indicate that the diffusion of industrial innovation to potential users is a slow and expensive process, and that the development from an idea to a product can take ten years or more. The rate of diffusion of an innovation depends on its profitability, the uncertainty and risk involved, and the speed with which this uncertainty and risk are reduced. Management attitudes are crucial in all of these areas.

Gold (50) recently examined the factors affecting the adoption of technological innovations by firms and industries. He suggests that a company's likelihood of adopting innovations depends heavily on its perceptions of its position in the market place. For instance, a company may consider accepting new and risky technologies if its market share is threatened by a competitor's technological advances, or if the company, for any of a variety of reasons, is suffering an erosion in its competitive position. A company's behaviour towards new technologies may also be motivated by persuasive evidence that an internally developed innovation has really promising market possibilities, or by recent market success with a particular innovation.

Gold believes that industry is making inadequate and decreasing allocations for long term, risky R&D programs aimed at major technological advances in processes and products. The reasons for this, he feels, are desires for short-term profitability, and management's perception that research programs will not contribute adequately to that profitability.

In recent year, Gold suggests, management has tended to underestimate the benefits derived from major long term research programs, and has concentrated primarily on the incremental returns from major product or process innovations. This approach ignores the flow of minor improvements in processes, facilities and products that can result from fuller understanding of the factors affecting performance, and that can restrict the advantages enjoyed by competitors who happen to reach common technological improvement targets sooner.

2.2.4 Regulation and Innovation

Industries have long been subjected to a variety of regulations, such as anti-trust laws, tax and labour laws, environmental regulations, health and safety regulations, and so on. Industry spokesmen and certain economists often see this "over regulation" as being responsible for restraining economic growth. In this context, the OECD has noted (51), that while there is disagreement on the magnitude of such effects, "there is no question that a growing share of new physical investment is going into equipment imposed by regulations, which will not necessarily contribute to enhanced worker productivity in traditional dimensions."

On the other hand, it should be recognized (51), that shifts in resource allocation to cope with regulations reflect changes in social values, and are clearly the intent of regulation in the first place. Moreover, reflecting the theme of the present paper, it is clear that regulation can inspire and encourage R&D, innovation, and enhanced productivity in certain sectors of the economy.

Royston (52), for example, has examined the effect of pollution abatement legislation as a stimulant for generating increased economic activity in Japan, Sweden and the United States. During the recession in 1974, Japan used pollution control to boost construction and engineering, and hence re-stimulate the economy. Twenty per cent of Japanese economic growth since then has been attributed to the new environmental legislation. In the process, Japan has become a world leader in supplying advanced pollution control equipment, such as pyrolysis plants and flue gas desulfurizers.

Sweden is stated to have used similar measures in the face of an economic recession in 1970. The government introduced strict pollution controls and offered industries cash grants of up to 75 per cent of the purchase price of pollution control equipment installed before 1975. The result has been a major improvement in the environment, as well as stimulation of the construction, equipment and technical industries. Like Japan, Sweden has also developed companies that are recognized as leading suppliers of advanced pollution control equipment and know-how in the world.

Royston also reports (52) a 1978 estimate of the economic impact of environmental policies in the United States. This indicates that by the end of 1980, U.S. environmental regulations had added 0.1 per cent to the consumer price index, reduced unemployment by 0.4 per cent and increased the Gross National Product by $9.3 billion.

Well-designed, unambiguous standards or science-based regulations can be a powerful stimulus to innovation, diverting R&D funding to new areas of exploration. Much of this research may appear "unproductive" from the point of view of those firms which might have had other plans for deploying their resources. However, the resulting changes in a company's research program may give the company, through the new knowledge acquired, an advantage over its competitors' products or processes. In addition, companies not directly affected by the regulations may perceive technology development opportunities in assisting directly affected firms to cope with stricter standards.

Empirical investigations to assess the impact of new regulations on research and development, particularly basic research, are lacking. However, there are reasons to suspect that the development of standards and regulations has contributed significantly to the advancement of basic research, and vice versa. This is supported by the increasingly frequent use, by both government and industry, of specialized government-owned testing equipment and facilities.

Ultimately, though, the issue is not whether a particular regulation affects the rate and direction of technological change. As Eads points out (53), the fundamental concern is the tradeoffs a society is willing to make between the positive social and economic aspects of technological changes, and the losses associated with new product and process hazards that result from quickly applied technological change.

The regulation of technological change is, in certain areas, the result of concerns arising from risk assessment. "History teaches that the introduction of new technology almost invariably brings with it unforeseen consequences which not only disturb the established social order but are often very damaging to man and his environment"(54).

Such "unforeseen consequences" are arising with distressing frequency (e.g. urea formaldehyde foam insulation and the Mississauga train derailment). Various factors may contribute to any given incident, but the overall implication is that there is a need for more effective screening systems that offer a better possibility of avoiding unwarranted risks to the population. In the food and drug areas, generally adequate screening systems exist to test the effects of new products, because of the extreme impact which unsafe products could have on the health and well-being of consumers. However, screening systems of comparable effectiveness and comprehensiveness do not exist for the introduction of most other technologies. Moreover, there does not seem to be adequate recognition that the screening of a given technology often depends on the existing state of scientific knowledge, and that there may be a need for periodic re-screening as new scientific facts or techniques emerge.

Clearly, governments have a major role in this risk assessment process. Ultimately, it is the government's responsibility to develop adequate mechanisms to monitor and regulate the introduction of new techlogies, and to promote the R&D that will permit these mechanisms to function. This may, at times, impede the rate of commercialization of innovations; it may also even slow down the performance of certain types of research, as may have happened in the case of recombinant DNA. The question, finally, is one of balance, and of ensuring that the development of technologies recognizes not only economic consequences, but social and environmental impacts as well.

2.2.5 Government Mechanisms for Promotion of Industrial Innovation:

Reflecting the complexity of the innovation process, there are a number of mechanisms whereby governments seek to encourage industrial innovative performance. These mechanisms, which include both incentive and regulatory approaches, address the different stages or problems in the innovation process. They have been categorized by Knight and Baca (55) in four major groupings: capital, productive resources, market and information. Among capital incentives are: direct loans, provision of risk capital, cost-sharing, loan guarantees, interest subsidies, grants for R&D and demonstration, joint government-industry corporations. Under productive resources, governments encourage industrial innovation through tax credits, tax deferrals, employment subsidies, employee training; in addition, government may assist in providing patents, technology research facilities and personnel. Market incentives include such mechanisms as direct procurement, price-supports, anti-trust regulations, trade policies and tariffs. Finally, information incentives refer to education support, information exchange and assistance, technology information banks, and intellectual property protection.

From a public policy perspective, this range of mechanisms offers governments a substantial degree of choice in encouraging industrial innovation. The difficulty arises in tailoring these choices to the realities of the innovation and market processes in the industries or sectors being addressed. Quite clearly, the usefulness of any of these mechanisms, individually or in combination, will vary substantially from industry to industry, depending on the technology intensiveness of the industry and the market conditions which prevail (55).

2.2.6 Government-Supported R&D and the Innovation Process

One approach which government can use to support or encourage industrial innovation is the funding or performance of pertinent R&D

by the government itself. From a theoretical perspective, the rationale for government support of R&D has been discussed in the welfare economics literature since the early 1960s. Where an open market does not exist, due to either the organization of the market or the characteristics of the goods being produced, it is argued that there is an a priori case for collective intervention to deal with the situation.

Nobel Laureate economist Kenneth Arrow, in 1962, explicity addressed the allocation of resources to invention, or as he termed it, "production of knowledge" (56). Arrow concluded that the socially optimal level of resources for inventions cannot be realized by the investments of private firms in a competitive market. A free enterprise economy would tend to underinvest in research because it is risky and uncertain, because its returns can only be appropriated to a limited extent, and because its use cannot be restricted to one consumer (that is, the use of information by a consumer does not diminish the quantity available for use by any other consumer). This underinvestment will be greater for basic research than for applied research or development, because of the longer time lag between the production of basic scientific research and its successful incorporation in productive economic activity. For an optimal allocation to invention, Arrow argues "it would be necessary for the government or some other agency not governed by profit-and-loss criteria to finance research and invention" (57).

In the event, governments do finance "research and invention", funding and performing basic and applied research in many areas. There is evidence that the resulting contributions to innovation have been substantial. An earlier section of this paper has already identified empirical studies (33-41) which suggest that basic scientific knowledge and expertise, much of which is derived as a result of government support, are important in influencing what engineers and inventors try to do, and their strategies and successes in doing it. More concretely, there are numerous examples of high-risk technological innovations which have resulted from government-supported basic research. A recent National Science Foundation report (58), for instance, has examined twenty-six case histories of innovations that have resulted from U.S. government-funded basic research over a period of thirty years. Though the report might be critized for looking at success stories only, the payoffs from the cases which were studied (e.g. disease resistant corn and potatoes, medical diagnostic equipment, techniques for growing semiconductor crystals, optical fibers) have been handsome.

Government-funded basic research can also be important in providing the knowledge base necessary for developing proper standards and regulations. This, in turn, may have a significant impact on the very nature of an industrial sector. Critics of nuclear energy, for example, point to the low level of government support for basic research on reactor safety, management of the fuel cycle, and waste disposal. This, it is argued, has retarded the growth of the nuclear energy option, in that emerging new industrial firms have not been inclined to devote their own resources to solving problems affecting the entire industry. Horwitz, concludes that:

> "...this type of R&D has a tendency to fall between two stools. It is too diffuse and uncertain in its effects to be undertaken by private firms, but being motivated by a desire to advance technology, as opposed to science, it is alien to many scientists".(31)

A number of empirical studies have also investigated the benefits which have been derived from applied R&D programs carried out or assisted by governments. Project HINDSIGHT (59), for instance, examined the payoff from weapons systems R&D carried out under the auspices of the U.S. Department of Defence. Cost-benefit analyses were carried out comparing the costs of performing a given military function using newly developed weapons systems, with the costs of utilizing predecessor systems, at an equivalent level of effectiveness. Financial savings were attributed directly to the R&D expenditures incurred in systems development, and were found to be substantial. The study concluded that the "approximately $10 billion of DOD funds expended in the support of science and technology over the period 1946-62...has been paid back many times."

A more recent NASA study (60) attempted to assess the impact of NASA's R&D, using a basic approach similar to HINDSIGHT. Total economic benefits to the nation resulting from four technologies developed through NASA R&D were compared with the benefits that would have resulted had NASA not contributed. The study concluded that the NASA-supported R&D led to an earlier realization of the technological changes under consideration than would otherwise have been the case.

Another series of impact studies dealt with the economic, technological, scientific, managerial and social effects of NASA's scientific and technological effort (61). These analyses concluded that the $25 billion spent on civilian space R&D during the 1959-69 period returned $52 billion through 1970, and will produce a total payoff of $181 billion through 1987. It was also claimed that the space shuttle program resulted in direct employment of 95,300 man-years in California, and a national employment increase of 266,000 man-years.

These same studies (61) concluded that government R&D programs have provided important new technologies for particular industrial sectors (e.g. semiconductors; computers; weather satellite systems), and have advanced the state of the art in the sciences (e.g. astronomy). Following a review of more than a hundred developments in a variety of technical fields, the authors suggested that most of the technical advances occurred earlier than would have been expected had NASA not funded the R&D involved. It was further argued that the management innovations developed by NASA to successfully handle its large R&D programs have led to significant advances in the design of advanced management systems now being used in the private sector.

Other studies have dealt with the transfer, application, diffusion, and successful commercial exploitation of technology developed from government applied R&D. The question which some of this work raises is how far the government should assist in the commercialization of particular innovations (62). The general impression obtained in a number of case histories from different countries is that, in areas where the government itself is not the customer, government-funded R&D projects have usually had limited results in producing commercially successful innovations (31).

NASA experience suggests, however, that there may be substantial indirect effects of federally-supported applied R&D, for example, in the creation of jobs for highly qualified manpower, and in the spinoff of commercial products modelled on innovations created originally as public goods. The problem, though, remains one of allocating federal funds in selected areas in such a way that their impact is not diluted through diversion to the development of products of little or no commercial significance. The empirical evidence does not offer any clear-cut answers to this problem.

One recent study which does claim to have developed a rationale for federal involvement in commercially-oriented R&D examines the U.S. automotive industry (63). The authors, Abernathy and Chakravarthy, note significant links between government's new energy-saving and environmental legislation, and the state of the American automobile industry in the 1970s. They argue that, in order to rejuvenate the U.S. auto industry, the federal government will have to spend more money on R&D because "it is equivalent to changing the conditions that support technological change within the industry from those that support accelerated incremental innovation to those that nurture major or radical innovation". The report advocates a massive federal investment in automotive R&D on the premise that there has been a significant breakdown in the U.S. market economy vis-a-vis the automotive sector, and that government intervention is necessary to correct the situation.

General principles to guide the allocation of government funds to R&D and to other activities intended to enhance long range economic growth have been addressed by the National Science Foundation (64). These general principles, according to recent analyses by Bean and Roessner (66), have been quite broadly accepted, and provide the basis for guidelines for public investment decisions in technology commercialization activities. Accordingly, such public investment should only take place when:

(i) the benefits to society of a public investment exceed the costs imposed on society by that investment;

(ii) the net benefits or net returns from the investment are at least as great as the net benefits from alternative investments the government could make;

(iii) there are inadequate financial incentives for industry to undertake the proposed investment if government does not;

(iv) there is an absence of institutional changes that could be made to stimulate the needed investment;

2.2.7 The Innovation Process in Canada:

The examination of the innovation process in Canada has been confined primarily to studies carried out by the Science Council and the Economic Council. For the most part, these two organizations, have considered innovation at a very high level of aggregation in relation to the country's broad sectoral problems. The dominant concern has been for the development of Canadian innovative capabilities to reduce our economy's dependence on exports of natural resources, and on the importation of technology through direct foreign investment.

Recently, however, the Economic Council has attempted to analyze innovation and technological change processes in Canada at the micro level (65). This study, based on a survey of manufacturing firms, examined 82 process and 201 product innovations in five industries: telecommunications, electrical equipment, plastics and synthetic resins, non-ferrous smelting and refining, and petroleum exploration and production. Attention was focussed on the basic characteristics of the innovations, sources of funding, factors affecting the decision to innovate, and innovation performance in Canadian-controlled versus foreign-controlled firms.

The Economic Council study found that innovations are costly, with process innovations being more than twice as expensive to develop as product innovations. On average, firms spent two and one-half years developing their process innovations, and one and three-quarter years developing product innovations. Generally, companies tended to opt for the development of innovations which had short pay-back periods, usually less than three years. This was possible in the majority of cases because no basic and applied research activities were involved. The predominant expenditure for product innovations was in development costs, while manufacturing start-up costs were the biggest expense in process innovations.

Most (66 per cent) of the innovations examined by the Economic Council were based upon technologies developed through in-house R&D. A further seven per cent of the innovations originated through a combination of in-house R&D and external inputs, and the remaining 27 per cent were based primarily on technologies acquired from sources external to the innovating firms. Intracorporate technology transfer within the multinational enterprise was the dominant external source of innovation, especially for complex and costly process technologies. Survey respondents indicated that other external sources of technologies, such as the federal government and universities, were not utilized to any great extent.

Firms in the Economic Council survey were also asked to indicate the most difficult problem they encountered in developing and commercializing their innovations. For ten per cent of the 260 innovations, no significant difficulties were experienced. Technical problems predominated among the other innovations, occurring at the design, development and deployment stages with about equal frequency.

Table 3 below indicates the most frequently occurring "problems".

Table 3
PROBLEMS ASSOCIATED WITH MAJOR INNOVATIONS

Type of Problem	No. of Innovations for which Problem cited	% of All Innovations
Technical	98	38
Marketing	55	21
Financial	46	18
Obtaining Necessary Components	26	10
Labour Supply	18	7
Government-Related	16	6

Source: Reference 65

The Economic Council study highlights the dearth of domestic sources of innovative ideas on which Canadian firms (particularly small and medium-sized firms) can rely. Most of the companies surveyed apparently do not have the capacity to carry out longer-term research because of the uncertainty in the commercial potential of such R&D, and because of the costs involved. Yet, while governmental assistance through special industrial research support programs (e.g. IRAP, DIP, PAIT) was seen as useful, the companies surveyed did not attach much importance to federal laboratories as sources of knowledge, expertise and R&D facilities. These are somewhat contradictory observations, and it would seem obvious, in the face of limited resources, that Canadian firms will increasingly have to turn to government and university laboratories as additional sources of innovative ideas, especially in rapidly emerging high technology sectors like space, electronics, biotechnology, oceans and energy.

The Economic Council finding that the multinational enterprise is a primary source of innovative technologies is quite consistent with conventional wisdom. A 1978 MOSST report (66) provided additional analysis in this regard by calculating the magnitude of "invisible" in-flows of technology through unrecorded access of Canadian subsidiaries to the R&D base of their parent companies. This study found that the inclusion of this R&D raised Canada's Gross Expenditures on R&D (GERD) to 1.37 per cent of GNP in 1975, as compared 1.00 per cent based on domestic R&D alone.

The Canadian experience clearly shows that large-scale access to innovation does not necessarily depend on the domestic performance of R&D. However, the substantial benefits obtained through the import of technologies are not without costs. Multinationals, for instance, often restrict the use of their technologies through limiting their subsidiaries' access to world export markets (e.g. 67). Thus, Canadian industries may have limited opportunities to become internationally competitive. Moreover, a heavy reliance on imported technology makes the economy vulnerable to foreign decision-making. Opportunities for highly-trained Canadians may also be restricted (66), and the solution of particularly Canadian problems (e.g. exploitation of Arctic energy resources) may be delayed because the technology usually available abroad may not fit the country's needs (67).

3. R&D, TECHNOLOGICAL INNOVATION AND INFLATION

Inflation is defined as the rate of change in the overall price level. This change may be caused by two inter-related sets of factors: (i) cost-push, and (ii) demand-pull. Cost-push inflation results mainly from a rise in the price of inputs (i.e. labour, capital, resources). Demand-pull inflation occurs when there is an increase in prices due to excessive demand and limited production capacities.

Whether inflation is of the cost-push or demand-pull variety, or is a mixture of both, it is influenced by R&D (68). Studies cited earlier in this paper (e.g. 2-5, 7, 8, 15, 18) have provided evidence that expenditures on R&D affect the rate of productivity increase at the firm, industry and national economy levels. In turn, an increased rate of productivity will lower unit costs and will thus have a positive impact upon the inflation rate.

The microelectronics industry provides an obvious example (69). Today's microprocessors have significantly reduced computer costs; the cost per chip function has been dropping at an average rate of 28% annually. The result has been a dramatic drop in the price of computers for any number of industrial and personal applications, with resulting productivity improvements and, indeed, the creation of entirely new industries.

The inflation-R&D relationship has another aspect however - a high rate of inflation can adversely influence the rate of investment in R&D. Quite often, the response of a firm to high levels of inflation will be adoption of expenditure restraint programs, with cutbacks in longer term activities such as basic or more speculative R&D. Similarly, governments' anti-inflationary fiscal policies usually include reduction in "discretionary" activities which, again, often means less money for research programs. At this point, the situation risks becoming something of a circular argument as foregone R&D may result in slower increases in productivity growth, producing less relief from inflation, and so on (68).

Inflation can also have a further inadvertent effect on R&D expenditures. Official R&D statistics at the national level are usually corrected for inflation by being expressed in relation to the GNP. However, there is evidence (68, 70) that price indices which more accurately reflect the cost of inputs to R&D would, in fact, "deflate" official R&D statistics more that the GNP deflation. In other words, broad policy decisions based on R&D statistics linked to GNP may be underestimating the actual impact of inflation, and may thus be suggesting lower real R&D spending targets than might be desired.

4. R&D, TECHNOLOGICAL INNOVATION AND EMPLOYMENT

4.1 Macroeconomic, Sectorial and Personal Perspectives

There are differing views on the impact which innovation has on employment. On the one hand, technological innovation, because of its increasing emphasis on labour-saving devices and processes, is seen to be replacing people with technologies, thereby increasing the present rate of unemployment. Others, however, see this process as a short-term aberration. From this perspective, the introduction of new technologies is thought to lead to increased economic growth, and this growth will create employment and compensate for any large scale displacement of labour.

Generally, though, it must be admitted that, whether a new technology is domestic or foreign in origin, its existence will always threaten to make some part of the work force redundant. The results can be viewed from three perspectives - macroeconomic, sectorial and personal (71).

From a macroeconomic stance, as long as national economic purchasing power for aggregate demand remains constant, any increase in output per worker resulting from a new technological advance will reduce the number of workers required in the economy. In this narrow sense, technological innovation may be viewed as contributing to higher unemployment. However, deployment of the new technology also creates new investment opportunities, and even new industries, thereby leading to increased employment in the sector affected. Overall, purchasing power may be increased, the standard of living raised, and income redistribution programs created to compensate those who are temporarily forced into unemployment. Ultimately, the recent OECD report, 'Technical Change and Economic Policy', concludes that (68):

> "Historical performance, as well as theoretical analysis, suggest that ... it may be easier to maintain full employment when technical advance is rapid than when it is slow, provided the direction of technical advance is not adverse."

From the <u>sectorial</u> viewpoint, the main sectors of employment show several consistent and fairly strong trends in the highly industrialized countries over the past twenty years (73). Employment in agriculture has continued its long decline, although agricultural production has steadily increased (agriculture having become one of the most capital intensive industries in the developed countries). As well, the trend of employment in manufacturing stagnated or declined in the 1970s. The only sector in OECD economies which has expanded in terms of employment in the mid-seventies is the service sector.

In this context, those manufacturing industries that have increased productivity fastest in the past two decades in the U.S. and the U.K. have raised their employment significantly, despite an overall decrease in employment in the manufacturing sector as a whole The trend in Canada has been slightly different, in that there has been employment growth in non technology-intensive manufacturing industries during the period 1965-1975. Nevertheless, employment has grown much more rapidly in the technology intensive elements of the manufacturing sector which, as indicated earlier (25), have also shown superior growth in output and productivity, as well as lower rates of price increases.

From the personal perspective, unemployment caused by technological change can be serious, even disastrous. New jobs that are created as a result of technological innovation are often very different from the ones that are eliminated, and the transfer of people from redundant jobs to new jobs may be difficult or even impossible. As Donner point out (71), "from the personal perspective, the theoretical income yield to society as labour shifts from one industry to another, or from one occupation to another, may not flow down to the worker who is directly and adversely affected by the innovation". However, he concludes that the bulk of today's high unemployment in Canada and the United States has not been caused by technological change, but by weak economic activity and the lack of real purchasing power in North America.

4.2 A Current Example: Microelectronics and Employment

Many new technologies with cross-sectoral impact (e.g. applications of biotechnology to agriculture, medicine and manufacturing (74)) have strong implications for employment. However, the technology which will probably have the greatest impact in the near future is microelectronics.

Microelectronics, especially since the development of the microprocessor, has suddenly provided a quantum expansion in possibilities for automation, and has extended electronic data processing to many applications in communications, office equipment, consumer goods and services, transportation, recreation, medicine, and so on. Moreover, the diffusion of microlectronics-based innovations is happening at a much faster rate than any new technology which has gone before.

The issue of structural unemployment caused by the "microelectronic technological revolution" was recently discussed in a Science Council of Canada workshop (75). The workshop concluded that, in the short term, the problem does not seem to be one of overall unemployment, but rather one of labour displacement. On this basis, attention was focussed on the kinds of jobs that would be created or displaced, where these jobs would be located geographically, which sectors would be involved, and who is going to be affected.

Two-thirds of all employment in Canada is in the service sector, the very sector where microelectronics technologies will have their greatest disemployment and organizational impact. As the Science Council report points out (76):

"The service sector has absorbed almost ninety-two per cent of the rate of increase in the labour force in this country since 1949. In essence, the goods-producing sector of the economy, which included mining and manufacturing and agriculture, absorbed only eight per cent of the rate of the increase in the labour force.

Between 1946 and 1978, the labour force in Canada more than doubled, from 4.6 million to 10.5 million. Now, of that almost five million increase in employment, the entire goods-producing sector absorbed only 400,000. The question is, can the service sector absorb the natural rate of increase of population if it is also to be automated?"

Similar concerns have been raised about the possible unemployment effects of microprocessors in the manufacturing sector. The use of microprocessors allows various types of machines to be endowed with a memory function. The resulting application of numerically controlled machines and robots to computer-aided design and computer-aided manufacture is beginning to have a major impact in such areas as automated warehousing, packaging, inspection and testing, inventory control, and material handling. At present, the most extensive use of robots is expected to be in the manufacture of automobiles.

From a productivity point of view, robots and other numerically controlled machines can perform repetitive tasks over the full twenty-four hour day if necessary. The machines do not go on strike and take no holidays or sick leave. As for costs, robots may be able to operate at near or below the minimum wage rate.

The resulting bleak prospects for manufacturing sector employment do have a brighter side however. The rapid expansion in microelectronics applications is already creating a major increase in demand for highly skilled people in systems and computer design and in sophisticated software development. This may even result in shortages, which, as part of a broader scarcity of highly skilled labour expected to occur in the 1980's, must be overcome if our economy is to benefit fully from microelectronics innovation, or even if it is maintain its present level in the face of much tougher international competition.

Ultimately, the question is whether the creation of new jobs will match the destruction of other jobs. The Science Council workshop concluded (77), rather pessimistically, that there will probably be widespread structural unemployment as a result of the microelectronics revolution, and that certain groups (e.g. older workers and women) may suffer permanent unemployment problems. To minimize these problems, it is clear that the ability of the educational system to produce and retrain people for highly skilled employment has to be enhanced. In addition, ways have to be found to increase cooperation between management and trade unions so that the decision processes on technological change properly recognize both productivity and human concerns.

5. R&D, TECHNOLOGICAL INNOVATION AND INTERNATIONAL TRADE

5.1 Technology and Theories of International Trade

Since the early 1950's, numerous studies have been concerned with technological superiority as a means of ensuring a strong trading position in world markets. Most of this work suggests that a nation generating new products and processes has certain trade advantages over non-innovating nations, at least as long as the innovations remain significantly unimitated. A distinction is also made between "technological gap" trade (where the sources of certain goods are limited because the technology is closely held) and "low wage" trade, which result in the gradual transfer of technological improvements to countries where they can be applied more cheaply than in their country of origin.

A major contribution in this area has been Raymond Vernon's theory of the product cycle (78). This provides a hypothesis on the genesis of innovations, reasons for the initial location of production in the country of innovation, and reasons for the gradual transfer of production to other countries which may become exporters of the product.

Vernon points out that the successful commercial production of a new product requires close contact with potential customers and, more importantly, with the suppliers of the necessary machinery and components. Thus, the new product is usually produced in the national economy for which it was designed. From here, it is exported to other markets where a demand exists, these exports constituting "technological gap" trade. However, as demand develops in these other markets, and as competitors begin selling their own versions of the product, there is a tendency for production to be transferred to lower cost locations. This may be in the foreign countries where the market demand is occurring, or in other low wage countries from which the product is then exported to the market countries (perhaps even including the country in which the innovation originated). As a result of this general tendency for production to be transferred towards low-labour-cost locations, production costs come to reflect less the availability of entrepreneurs, technical expertise and skilled labour, and more the availability of low-cost materials, standardized processes and lower-wage labour.

The product life cycle model is not the only explanation which has been offered for the role of technology and innovation in international trade. The "neofactors theory of trade" (79, 80), for instance, treats technology as a capitalized human skill, that is, as a factor of production which may provide a firm with a trade advantage. In other words, the comparative advantage accrues to a firm because of the firm's own resources, rather than from the product itself. R&D "skills" are included in this approach under human skills, in a manner somewhat analagous to the treatment of "advances in knowledge" in the previously cited studies of R&D and productivity growth.

McGuinness and Little (80) suggest that the trade of typical new industrial products might best be explained by some combination of product-related R&D factors, representing the life cycle viewpoint, and certain characteristics of the firm, as derived from the neofactors theory. Accordingly, their analysis of Canadian industrial exports proposes a model in which the influence of product-related R&D

on a new-product's foreign sales performance are "moderated" by broad qualities of the firm (e.g. size, ownership, technological attitudes).

Another explanation for the role of technology and innovation in international trade, especially among industrialized countries, has been offered by Linders (81, 82). This "demand similarity" view suggests that slight differences in consumer preferences within and between countries will create demands for slightly differentiated products between the countries involved (e.g. automobile trade among various producing countries). This would suggest that international trade in manufactured goods would be most intense between nations with similar tastes and per capita incomes, and that trade in technology intensive goods would take place among all countries with advanced technological capabilities. While there is a degree of empirical evidence which favours this theory over the product life cycle viewpoint, other analyses of world manufacturing trade appear to be supportive of both models (82).

5.2 Industry R&D Performance and Trade Success

Regardless of the model used to explain international trade, there appears to be a strong linkage between an industry's R&D and innovative performance, and trade success. Numerous studies (e.g. 79, 80, 82-88) have observed that industries with high R&D intensity export a greater proportion of their output than industries with low R&D intensity, and that an industry's share of the world export market is often strongly related to the propensity of that industry to innovate.

Various qualifications can be made, however, as to the exact meaning of the above studies, and to the degree of causality to be associated with the role of R&D in international trade. Thus, for example, it has been suggested (80) that what has been measured as R&D, at least in some studies, may in reality be a substitute for characteristics of the firm, or for certain managerial qualities.

Nevertheless, the weight of evidence heavily suggests that R&D and innovation contribute strongly to export performance. A dramatic illustration of this, on a national basis, is seen in the National Science Foundation's Science Indicators 1980. This report shows (89) that the positive U.S. trade balance in R&D intensive manufactured products has increased from $5.6 billion to $39.3 billion in the period 1960-1979, while the trade balance in R&D non-intensive manufactured products has changed from -$0.2 billion (i.e. imports exceeded exports) to -$34.8 billion in the same time frame.

Governments are becoming increasingly conscious of the above phenomena as they attempt to combat inflation, recession and energy shortages. Western nations, in particular, are turning to technology policies (e.g. 90,91) aimed at altering and encouraging the directions of domestic technological change in order to seek international trade advantages.

In this context, the OECD points out (92) that certain structural changes are occurring in the global pattern of technological development:

a) The technological capabilities of a number of industrialized nations have advanced very rapidly during the past decade or so. There has been a geographical shift in the location of innovation activities, with a relative increase of R&D in Japan, and in most, but not all, European countries (e.g. West Germany, Sweden and Switzerland), as well as a relative decline in the United States.

b) The industrial sectors of a limited number of the so-called developing nations have grown very rapidly in recent years. Some of these countries, because of their low-wage economies, are beginning to emerge as important exporters of certain types of manufactured goods.

c) Within OECD countries, there have been significant shifts in patterns of government, academic and industry-financed R&D. Within the government sector, higher priority is being given to mission-oriented research, with increased emphasis on energy R&D and on projects related to the quality of life.

There has been a considerable reduction in the rate of growth of academic research,. and industrial R&D fell in the late 1960's and early 1970's. Canada is one of the OECD countries where industry R&D spending as a proportion of manufacturing value added has fallen since the mid-1960s.

5.3 Technology and Trade - The Canadian Perspective:

Questions of international trade, such as tariffs and foreign investment, have long been a focus of Canadian political and economic concern. In this context, the Canadian economy is generally conceded to be based heavily on resource exports. However, there are growing doubts about the ability of Canada, over the long term, to "pay for" expanding imports of services and manufactured goods with resource exports. These worries are further magnified by our growing trade deficit in technology-intensive manufactured products, and by an apparent loss of international competitiveness among many Canadian manufacturing firms (due in part to high costs and technological backwardness).

There are two schools of thought, each with a long history, on how there problems should be addressed. One view considers that the Canadian economic weaknesses referred to above can be corrected by liberalizing trade between Canada and other countries, especially the United States. This, it is argued, will expose Canadian firms to increased competition, with enhanced productivity and innovative performance being the result. This "continentalist" approach (i.e.

favouring establishment of a de facto North American market) has been advocated, at least until recently, by groups like the C.D. Howe Research Institute (93, 94), the Economic Council of Canada (95), and the Senate Standing Committee on Foreign Affairs (96).

The opposing viewpoint stresses that free or more liberalized trade will exacerbate Canada's economic difficulties unless and until various structural deficiencies are remedied in the Canadian economy, particularly in the manufacturing sector. These arguments for "technological sovereignty" stress the need for domestic policy instruments aimed at developing the innovative and technological capacity of Canadian manufacturing industry. Proponents of this view have included the Science Council (e.g. 97), the Canadian Federation of Independent Business (98) and the Canadian Institute for Economic Policy (99).

Recently, there has been at degree of convergence between these two schools of thought. In particular, there appears to be a more consistent recognition that a measure of government intervention is required in order to help compensate Canadian firms for their more limited resources. This can be done through policies that consciously foster the development of innovative products and processes, and that seek to establish Canadian manufacturing firms in international markets.

The need for, and potential impact of, such policies can be seen in the statistics on Canada's trade position. Exports represent about 25 per cent of the value of this country's goods and services, well above the 18 per cent average for other major trading nations. Despite this, however, Canada's trade deficit in end products has climbed steadily from $3.0 billion in 1970 to $12.3 billion in 1978. The overall merchandise trade surplus of $2.3 billion in 1978 was a result of a massive surplus of $14.5 billion in raw materials and primary products (100).

The Export Promotion Review Committee, in a recent analysis of efforts to strengthen Canada's trade position (96), identified the lack of an indigenous technology base as one of the major reasons for Canada's poor trade position in manufactured goods. Canada's dependence on outsiders for technology is evidenced by a persistent net outflow of technology royalties. Most royalty flows are between parent and subsidiary, but a number of Canadian-owned firms have also found it much more attractive to compete at home against multinational subsidiaries by licensing technology from abroad, rather than doing their own design and product development work. Thus, most products manufactured in Canada are designed elsewhere, with the sourcing of components and parts often occuring in the country where the design originated.

The Export Development Review Committee suggested a number of areas where policy attention might be focussed. Energy development mega-projects, for example, are seen as the eventual source of major export opportunities, provided Canadian firms are given an adequate chance to enhance their own capabilities through participation in the necessary technology development. The Committee also felt that particular encouragement should be given to developing an indigenous technology base in sectors where there have been growing trade deficits because of technology imports (though specific sectors were not identified). Finally, the Committee urged that emphasis be given to supporting smaller firms, in light of evidence that such firms tend to be more committed to export markets than large companies, and have a more innovative posture.

No discussion of trade and the innovative capacities of Canadian industry would be complete without focussing more fully on the role of the multinational entreprise (MNE). Clearly, MNEs have been a major source of the capital required to develop Canadian industry to its present state, and, as such, have contributed significantly to the economic well-being which Canadians enjoy. A major element in this contribution has been the provision to subsidiaries of technology developed abroad, which enhances Canadian productive capacity and expands the base of Canada's S&T infrastructure.

As is well known, however, Canada's rather heavy reliance on the MNE has also been the subject of criticism. Much of this criticism has focussed on the alleged negative long term effects of the MNE on domestic R&D and innovative performance.

MOSST (101) has recently examined the effects of foreign-controlled firms on Canadian R&D, and has concluded that the relationship is more complex than has generally been perceived. Foreign-controlled firms, in recent years, have not only performed less R&D than Canadian firms, but have generally done different R&D as well. The primary purpose of these R&D efforts has generally been to adapt foreign technology to domestic Canadian needs, rather than the promotion of exports.

Similar observations have recently been made by Rugman (102). Again, the claim is made that less R&D is done in the Canadian subsidiaries of multinational firms than in either the parent multinationals, or in an independent Canadian firms similar in size to the subsidiaries. Rugman's analysis is integrated into a theory of "internalization", which says that a multinational enterprise will tend to concentrate its R&D in the parent firm in order to protect its "knowledge advantage". The author suggests that, if this is true, R&D support mechanisms which do not clearly favour Canadian firms will have little impact on increasing industrial R&D in Canada.

These findings, and their implications in terms of exports, receive additional emphasis in a recent empirical study of Canadian export performance by Hanel and Palda (88). The authors' statistical analysis of data obtained in the previously cited Economic Council survey (65) found a causal relationship between firms' R&D expenditures (but not other innovation-connected costs) and export performance. More precisely, R&D expenditures, whether at the level of the firm, the main activity category (as expressed by the Standard Industrial Classification) or the firm's major innovation, were seen to result in exports as far as a firm or its divisions are concerned. The study also shows that, in general, firms under Canadian control tend to export more of their sales than counterparts under foreign control. Finally, there was contradictory evidence on the influence which government funding on an innovation has on the "export intensity" of the innovation.

6. RECAPITULATION

Two basic streams of thought - the conjunctural and the structural can be discerned in observations on the role of R&D and technological innovation in economic growth. The conjunctural approach, views the economy as being in a state of equilibrium, or in the process of regaining that equilibrium, and sees innovation as part of this equilibrium process, embodied for the most part as a characteristic of the usual factors of economic production. The structuralist approach, on the other hand, says that there have, in fact, been major changes in the structure of the economy and the processes by which it functions; technological innovation, is one of many contributors to this structural change, and also plays fundamental role in the growth and development of the economy, which is in a perpetually unbalanced or dynamic state.

Most of the literature reviewed in this paper can be considered to be supportive of the structural viewpoint, even though some of the studies cited were carried out in a theoretical framework consistent with the conjuncturalist approach (103). Broadly speaking, studies by economic, public policy and business administration researchers on the linkage between R&D, innovation and economic growth can be summed up (104, 105) as suggesting that there is a need for continuing innovative activity to exploit new market opportunities in response to longer-term structural changes. In such an approach entrepreneurial activity in a developed country is no longer focussed on responding to domestic demand by investing in borrowed and adapted foreign technology, nor is it oriented to competing primarily on the basis of price. Instead, new product opportunities are sought in all industrially advanced markets, and in market segments where, as a result of innovative activity, quality has taken precedence over price. In addition, emphasis is placed on exporting equipment, technology, and skills to the newly industrialising countries. Essential features of this innovative ability are capabilities in R&D and design, and the ability to relate these to developments in world markets. While the dominant activity remains investment in productive capacity (capital facilities, plant and equipment), investment in R&D and in other activities necessary for product innovation become relatively more important.

In summary, the literature reviewed in this paper shows that innovative activity is particularly important for the longer-term rate of growth of an economy--especially in responding to international market pressures and opportunities arising from changing tastes, technology, relative prices and competition. The literature also indicates that the effects of technical change play an important role in determining the state of such macroeconomic indicators as productivity growth, exports, employment and inflation.

The material reviewed in this paper provides evidence of a correlation between R&D and productivity growth in industry. Indications are that there is a high rate of return on investments made in research and development, mainly at the level of the industrial sector or the firm. Despite methodological and conceptual difficulties that call exact quantitative fundings into question, private rates of return on R&D in the U.S. have been consistently estimated at 30 to 40 per cent per year, while social rates of return have been found to be 60 to 80 per cent per year, depending on the particular industry sector. Most of the work that has been done in this area refers to American experience and there is a need for similar investigations in the Canadian context.

The present paper, consistent with a recent review by Griliches (106), indicates that there are several unresolved problems in measuring the contribution of R&D to economic growth. One of these has been in relating basic research to productivity factors. The very nature of basic research difficult makes it difficult, if not impossible, to estimate its impact in quantitative terms. Generally, there is a considerable time lag in the dispersion of knowledge arising from basic research, and uncertainty about the areas where and when such knowledge might be applied. To some degree, in fact, all industries are beneficiaries of basic research, and it is almost impossible to assess its independent impact on productivity.

Problems also arise in attempts to compare the productivity impacts of industrial R&D which is privately-funded and that which is government-funded. The quantitative studies referred to in this paper tend to estimate rather low returns from federally-funded R&D in the U.S., and appear to undervalue the contributions of government-funded R&D. Part of this problem is methodological in that the usual accounting practices used by industry do not separate government-supplied R&D funds from other company revenues. Further, no appropriate accounting procedures have yet been developed to acknowledge the extent of intellectual property a company may have acquired (or benefitted from) while working on a government contract.

The undervaluing of government-financed R&D is probably further enhanced by the difficulty in measuring "spillovers". These are the indirect effects which may arise through transfers among companies (or industries) of knowledge or productivity gains derived by one company (or industry) through a given R&D effort. Again, as might be expected, spillovers are more difficult to estimate if the research is of a more fundamental nature. However, in some cases of R&D which has been closer to the "applied" or "development" end of the spectrum it has been possible to show, to some extent, the effects of such R&D on economic indicators like employment, exports, and regional economic development. U.S. studies on the effect of NASA R&D

expenditures, for instance, indicate extremely high returns , both direct and spillover. Parallel attempts to examine the rates of return on government-funded, industry-performed R&D in Canada might be useful.

With regard to R&D actually performed by governments, it is important to recognize that, for the most part, non-industrial objectives are being sought. This R&D is related to the regulatory and service missions of government departments, and thus has longer range social and economic objectives other than immediate commercialization. This public-good nature of R&D carried out within government laboratories makes it difficult to assess the resulting impact on productivity growth, except where the mission of a particular department or a program has identified industrial development of a specific sector as a program objective. Still, efforts to make such assessments should be undertaken, and mechanisms should be sought, where this is reasonable, to enhance the impact of such government research on industrial R&D and innovative capacities.

With regard to government R&D (with a non-industrial orientation), high social rates of return in investments made in medical and agricultural research have been noted in the United States.

The innovation process literature strongly emphasizes that R&D is only one of many sources of information required to bring an innovation to commercial fruition. Information is also needed, for instance, on the costs of various phases of innovation, on prevailing and anticipated market conditions, and on the availability of risk capital. In addition, of course, appropriate management skills are required to amass, integrate and utilize the necessary knowledge/information components in physically bringing the innovation to reality.

The studies reviewed in this paper show that diffusion of scientific and technical knowledge between government, industry and the universities is generally a time-consuming and expensive process which demands a coordinated, continuous flow of information, and a commitment by the personnel involved. This implies the need for a clearer understanding of the roles of these three sectors if more purposeful attempts are to be made to generate increased innovative activity in the country.

The literature indicates that government can play a crucial role in the innovation development process. In this regard, governments can and do generate effective demand for new technologies. This has, in fact, been characteristic of some of the "high technology" sectors like the defence, space and aircraft industries. The literature also recognizes that governments play a major part in building up an S&T infrastructure which is capable of effectively responding to the demands posed by technological changes taking place within and outside a country. It is shown, as well, that the private sector has an economic rationale for under-investing in research and development, particularly in risk-oriented longer-term basic research, and that it is therefore important for government to participate in this area.

Governments also actively influence innovative through the establishment of various types of regulations. It is clear that well-designed science-based regulations can be a stimulus to innovation, diverting the R&D resources to new areas of exploration: This, though, is not the fundamental intent of most regulation, and it must be recognized that those being regulated often perceive that their own innovative activities are being diverted to objectives which, while being socially and econimically desirable in a broad sense, are not commercially productive in the short-term. In any event, given the extremely rapid pace of scientific advance and the escalating destructive potential of new technologies, the literature indicates the need for governments to develop appropriate mechanisms to monitor the introduction of new technologies into society, and to develop regulations for the longer term social and environmental good.

The innovation process literature highlights the limited perceptions and understanding of the total innovation process by many in both the private and public sectors. The industry perception of the innovation process has been focussed on market pull/market demand; industry generally believes that market uncertainty is the greatest difficulty that innovations have to face. Such a perception tends to give inadequate recognition to the diverse set of supply side mechanisms (e.g. scientific and technical information flows, existence of supporting technologies, etc.) which may be equally fundamental to the timing of an innovation. There is also little understanding of the fact that university and government research organizations can and do contribute to commercial innovations in ways other than simply providing the private firm with exploitable scientific discoveries, and that market-pull innovations still require the application of scientific and technical knowledge.

The government and university sectors' perception of the innovation-process also seems somewhat myopic. The conviction still exists in some quarters that innovations essentially result from knowledge push/technology pull, and insufficient account is taken of factors such as market trends in consumer preferences, relative prices and competition (in national and international terms), and commercialization costs. Further, inadequate consideration is given in Canada to the fact that there are limits to the areas in which a country can excel in R&D, and that we should be focussing our R&D efforts on certain priority areas. It may not always be possible to compete with other countries in some areas of research; in these cases, it may be necessary to borrow know-how from outside, and to improve and adapt the technology borrowed to develop new processes and products.

The innovation process literature also reveals that in the past there has been a general tendency to view the industrial sector as an organized structure that acts and reacts as a single entity. The studies reviewed suggest that there are real differences in innovation in different industry sectors, which can be explained by variances in industry structure, technologies, market size and the availability of risk capital.

Careful examination is needed of the innovation-inflation relationship. Only modest attention has been given in the literature to the possibility that in the long run, new or improved technologies could keep production costs and prices down.

With regard to the innovation-employment relationship, the literature shows that innovation can greatly affect productivity at both the industry and firm level, and this, in turn, can have an effect on employment. It has been suggested that process-related innovations are employment reducing, and product-related innovations are employment creating, a question which needs further examination. It has also been posited that radical technological innovations, whose impact will be felt across a wide variety of industries, can result in a considerable degree of job displacement. In this context, however, it has been argued that unfavourable employment effects from major innovations are short-term in nature. With the introduction of new technologies, more efficient products will be available at lower prices, more of the products will be purchased, and more labour will be needed to produce them; hence, the growth induced will compensate for any large scale displacement. Serious difficulties may arise, however, for those individuals who are displaced, and greater cooperation is required among all sectors of the economy to minimize these hardships.

The argument for the necessity of maintaining "technological superiority" for a high-wage economy is most convincingly made by the analysts who have studied the patterns of international trade. A country with a high wage economy can achieve a high level of economic prosperity by maintaining a lead in international trade through innovating new products and processes. Such a trade advantage over non-innovating nations could only be maintained through a continuing search for new scientific and technological opportunities. The urgency for doing this is enhanced by the fact that many OECD countries are taking more deliberate approaches to technology development, with the implication that world market competition in high technology sectors will become uncreasingly severe.

Canada's situation differs significantly from that of other western industrialized nations due to our high level of dependence on exports of primary products, and on foreign investment as a source of technology. The result is that, where foreign investment is greatest, functional and technological dependence is most pronounced. A careful examination is required of areas where a conscious policy of import substitution in selected S&T areas would be desirable, and from this examination, strategies could be evolved to bridge the technological gap in these areas.

7. CONCLUSIONS

7.1 Elucidation of the Innovation Process in Canada

The literature reviewed in this paper suggests that as a prerequisite to employing R&D effectively for economic growth, a clearer understanding is needed of the interdependence and complementarity of a number of factors. These include availability of risk capital, status and ownership of supporting technologies, S&T information flows, market possibilities (at home and abroad), and overall economic conditions. Also required is a better understanding of the respective roles (what they are and what they should be) of government, industry and the universities in the innovation process, and we suggest that this is particularly true for Canada.

The relationship between R&D/innovation and various economic indicators needs a good deal of further attention. Much remains to be learned not only about the impact of R&D and innovation on productivity growth, but also on employment, inflation, and trade. There are many unresolved questions which need further investigation. For example, is it correct, as has been suggested, that product-related innovations are employment creating, while process-related innovations are employment reducing? Do the quickly rising prices of an inflationary period necessarily discourage investment in R&D? On the other hand, do R&D and innovation really bring lower product and production costs, thereby having a stabilizing effect on prices? Finally, on the topic of trade, will a conscious policy of import substitution in selected S&T areas be beneficial?

Resolution of these and other related questions must also recognize the Canadian context. Most of the existing work that examines the innovation process and its effect on macroeconomic indicators, however, relates to conditions in the U.S., and to some extent, the U.K. and other European countries. While many lessons can be drawn from this work, it is important to realize that these lessons may not be applicable to the economic conditions peculiar to Canada, particularly the relative importance of our resource base and the extent of foreign ownership of our industry. Thus, the way in which R&D and innovation interact with employment, productivity, growth, inflation, trade and so on, needs to be studied more intensively from the Canadian perspective.

7.2 The Analysis of Structural Change

There is a need in Canada to create or maintain a "technological superiority" in certain selected areas if we wish to maintain a reasonable pattern of growth and achieve a more favourable balance-of-payments situation. This derives partly from the fact that we are a high wage economy, and partly from the explicit and powerful emphasis which other western industrialized countries (with whom we already have negative balances of high technology trade) are focussing on technology-based economic growth. Only by developing our resource sector effectively, and by exploiting certain leading-edge technological opportunities, can we hope to retain a sufficient array of comparative advantages in the international marketplace to keep our economy healthy.

This cannot be done, however, without a fuller understanding of the ways in which our industrial structure is changing. We need to know the proper context within which to choose and make known those technologies on which we may wish to see particular emphasis placed. To put it another way, because structural change can give rise to new options and opportunities and remove old ones, innovation and R&D decisions for the medium and longer term need to be made in the context of the future structure of the economy, not the past or present structure.

During the last decade there have indeed been major structural shifts in the Canadian economy (e.g., major increases in the price of energy inputs), and there is good reason to believe that structural change will continue to be significant. Considered in an international trading context, these changes will tend to favour certain innovational thrusts over others, and it is important to determine what the more promising thrusts are likely to be.

To obtain a clearer picture of the future structure of the Canadian economy and of the technological possibilities and priorities that this suggests, it is first necessary to gain a reasonable idea of the future international patterns of trade and production, taking into account the impact of new technologies, shifting resource demands, availability of a skilled labour force, and so on. Then, with this as context, attention could be turned to the technological opportunities which could provide comparative advantages for this country.

7.3 Identifying and Quantifying the Benefits of Government R&D

Greater attention needs to be given to developing an understanding of the economic importance, both present and potential, of government R&D activities. This is particularly crucial in the Canadian context, given the relatively weak R&D and innovative performance of the industrial sector, and the comparative strength in government R&D programs.

The linkages between government R&D activity and economic growth have not proven easy to quantify. Nevertheless, interesting efforts have been made to establish the economic benefits that have been derived from certain U.S.government-funded R&D activities. Few such efforts, however, have yet been made for government-funded R&D in Canada.

Part of the difficulty in assessing such benefits is that governments fund and perform R&D for a wide variety of reasons. R&D might be aimed, for instance, at the government's unique responsibilities for the establishment and enforcement of various types of regulations, for the setting of standards, and for the management of natural resources. Other R&D is meant to assist the government to provide certain services (e.g. weather forecasting) for the "common good", or to act as a substitute for industry in certain fields (e.g. agricultural research) where a viable private sector R&D capacity is unlikely to exist. Defence-related R&D is another unique government responsibility. Some government R&D is also explicitly aimed at the support of industry; this may be through performance of longer-term research oriented to particular technologies, through the solution of particular scientific and technological problems affecting individual industries or sectors, and through the establishment of an adequate S&T infrastructure in the country (including the provision of highly qualified manpower).

Clearly, the types of economic benefits that can be expected from these different government R&D activities will vary. This has fundamental implications for the methodologies which are used in attempts to measure the resulting benefits, and, perhaps more importantly, for public policy initiatives intended to enhance or maximize these benefits. More study is therefore needed on the contributions which government R&D can be reasonably expected to make to economic growth in general, and to the enhancement of private sector R&D and innovative capacities in particular.

7.4 The Impact of Science and Technology on Society

Technical change has many repercussions for society. Nuclear energy, micro-electronics, and biotechnology, for example, all hold significant promise in improving our standard of living. At the same time, they pose certain dangers, problems and difficulties. Governments have the responsibility of seeing that these problems are overcome (i.e. of increasing our capacity for technology absorption), or of ensuring that society is adequately protected from them (i.e. by controlling the rate of diffusion of technologies with unacceptable risks attached). In this context, longer-term purposeful technology planning should be adopted as a means of coping with and benefitting from structural changes in the economy. To put it another way, care should be taken to ensure that proper mechanisms and procedures are in place to assess the risks to society of yet-to-be-diffused technologies, and to provide appropriate countermeasures.

7.5 Summary of Conclusions

The conclusions reached in this paper suggest the direction for the next generation of science policies in Canada. Given that the first generation of government S&T policies has successfully culminated in the setting of the 1.5 percent GERD/GNP target, policy focus should now be directed at four major objectives:

-- the closer integration of science and technology in the processes underlying the formulation of our macroeconomic policies -- through a better understanding of the innovation process;

-- the development and maintenance of comparative advantage in the resource sector, and in certain leading-edge technologies

-- taking account of changing trade patterns and industrial structure;

-- the identification of ways and means of increasing the economic impact of government-funded R&D -- through a better understanding of the benefits of this effort and how they can be most effectively derived;

-- an increase in the government's ability to alert society to, and protect it from, the negative impacts of technological change.

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